BASF Plastics

Styropor®

Technical Information

Welcome to “Styropor Technical Information”

Dear Styropor customer,

We would like to offer you the following hints on using “Styropor Technical Information”.

This CD-ROM version of Styropor Technical Information” is available in three languages (German, English and Spanish), and is complete in this version.

If you have any question about “Styropor Technical Information”, please contact the following address:

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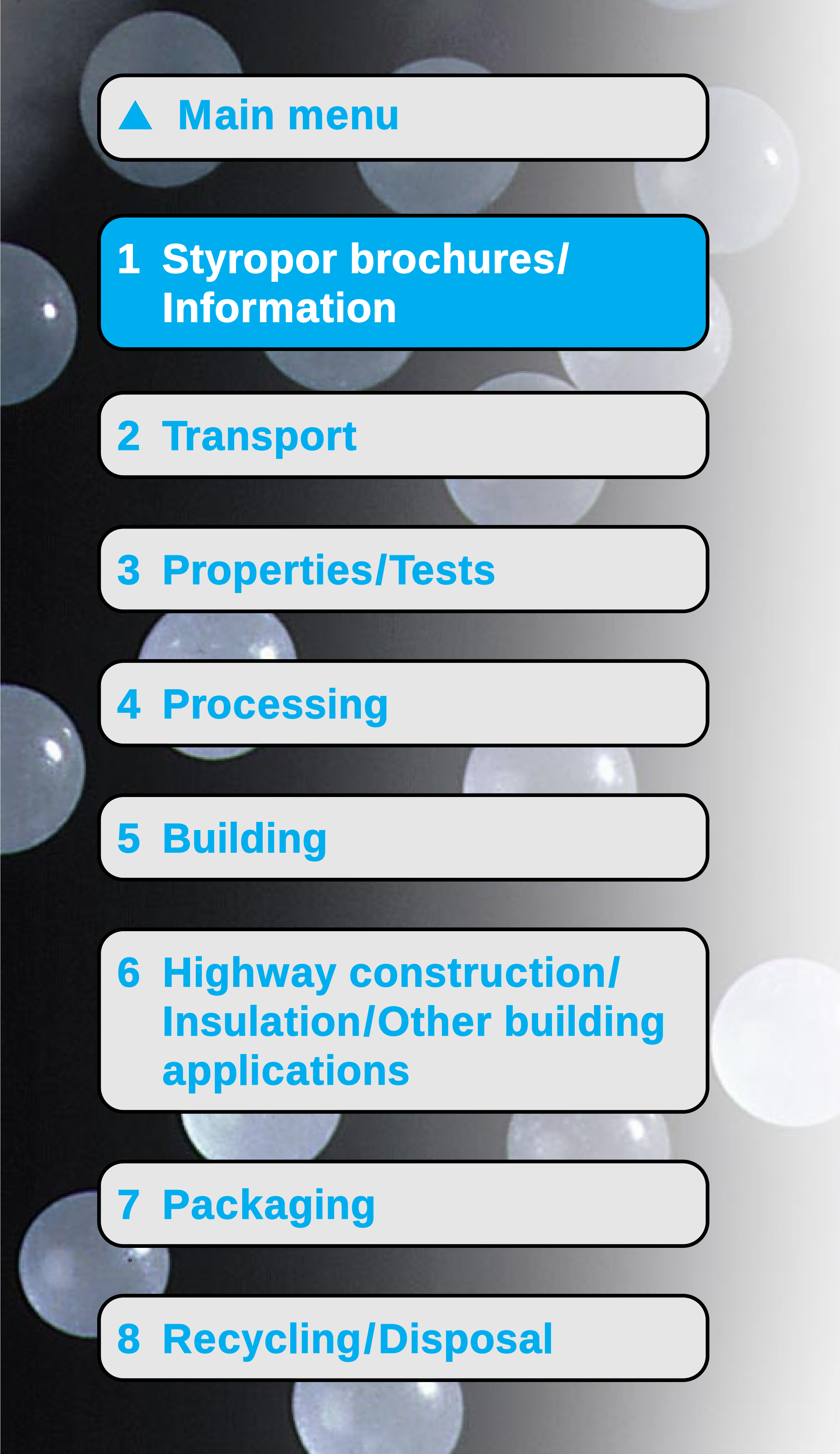
Foams

BASF



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Styropor® Technical Information

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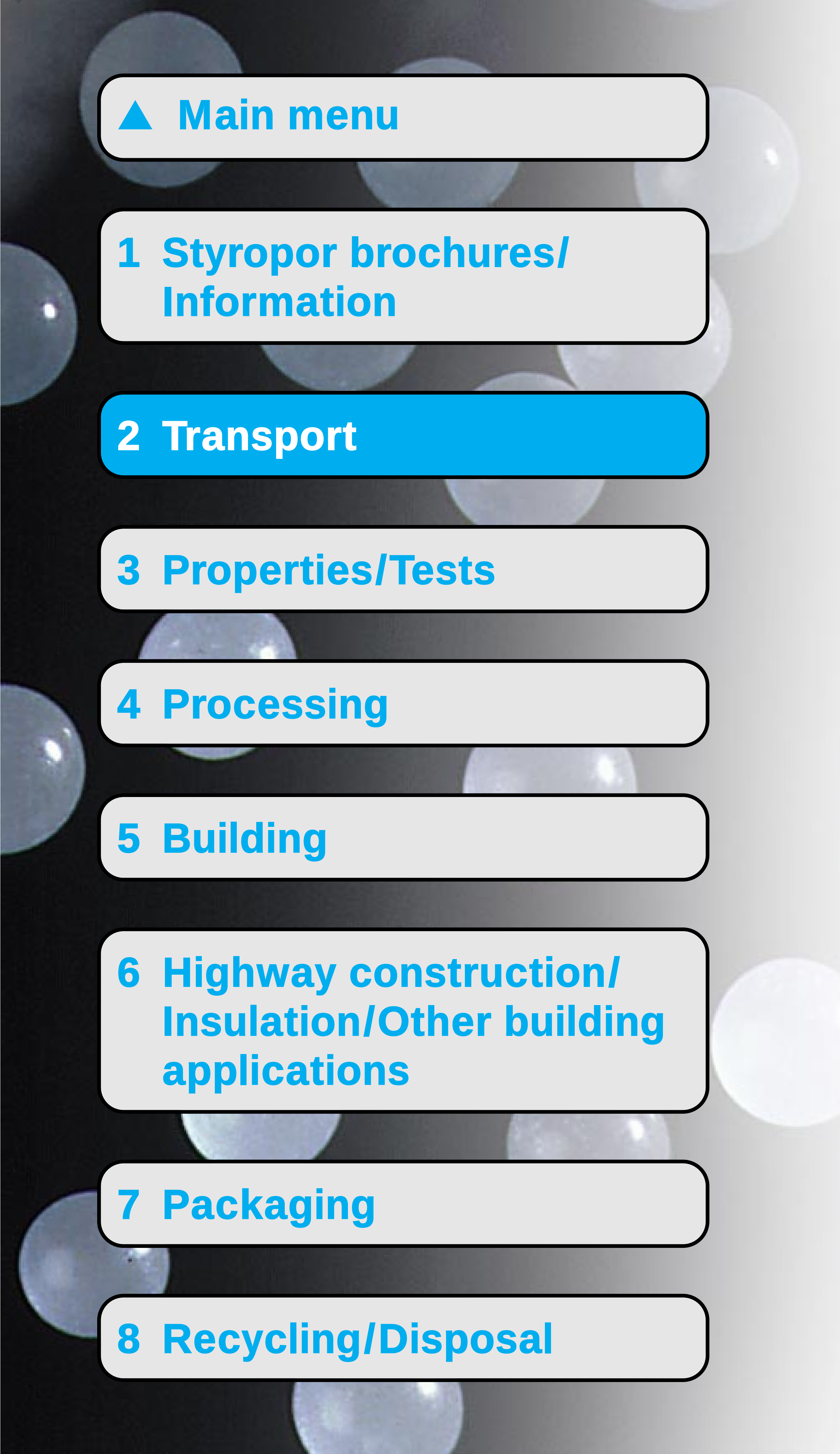

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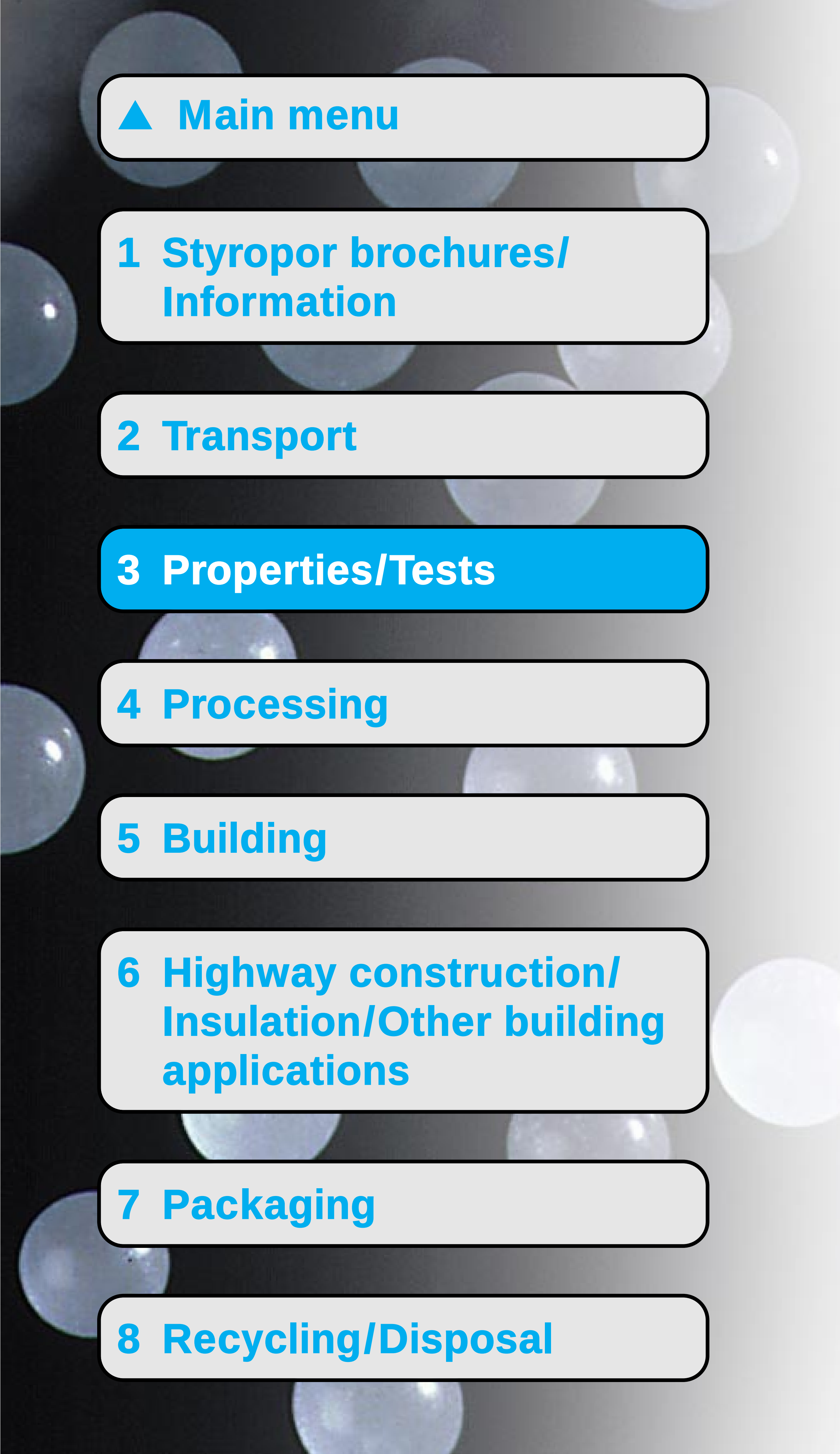

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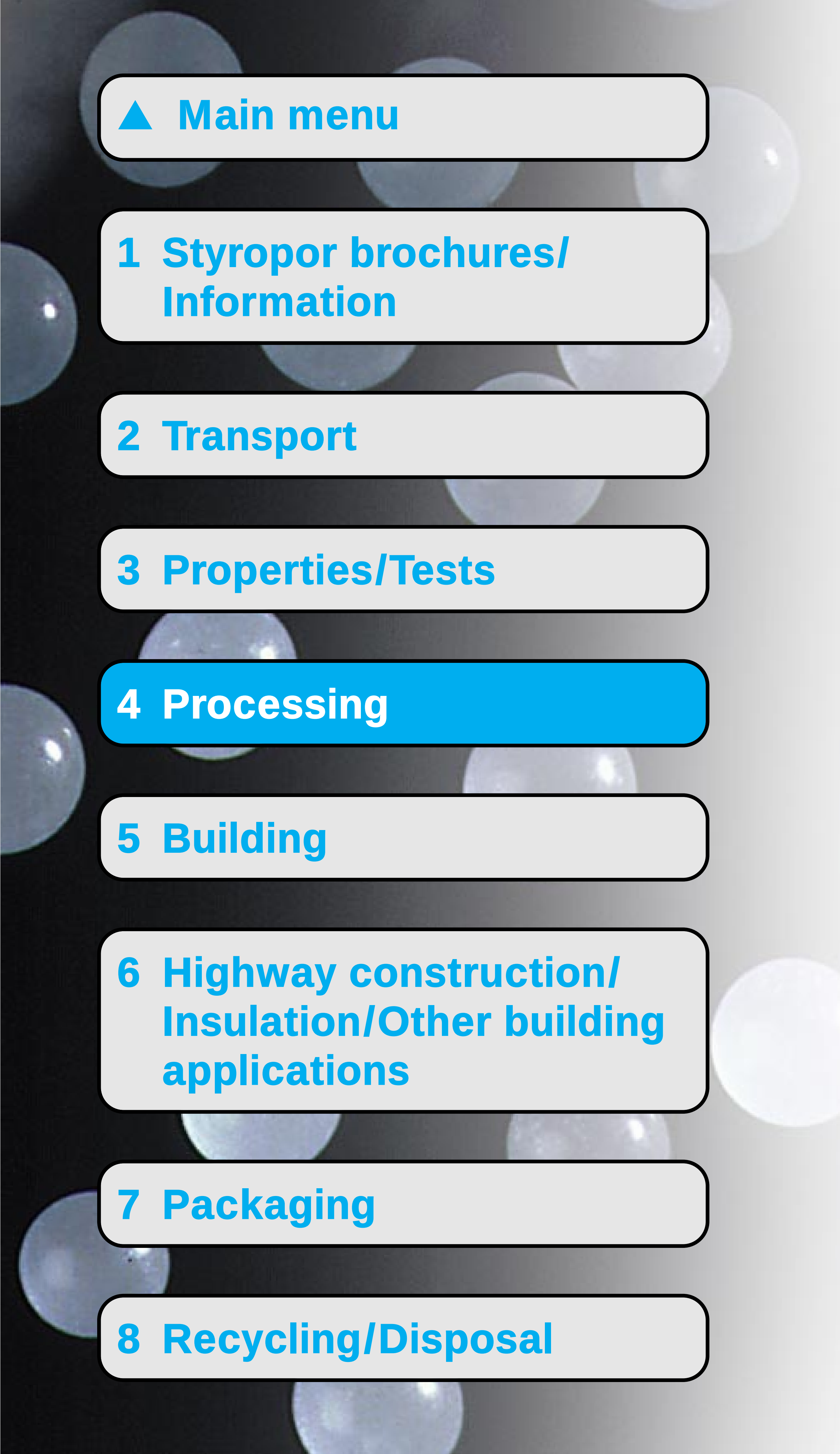

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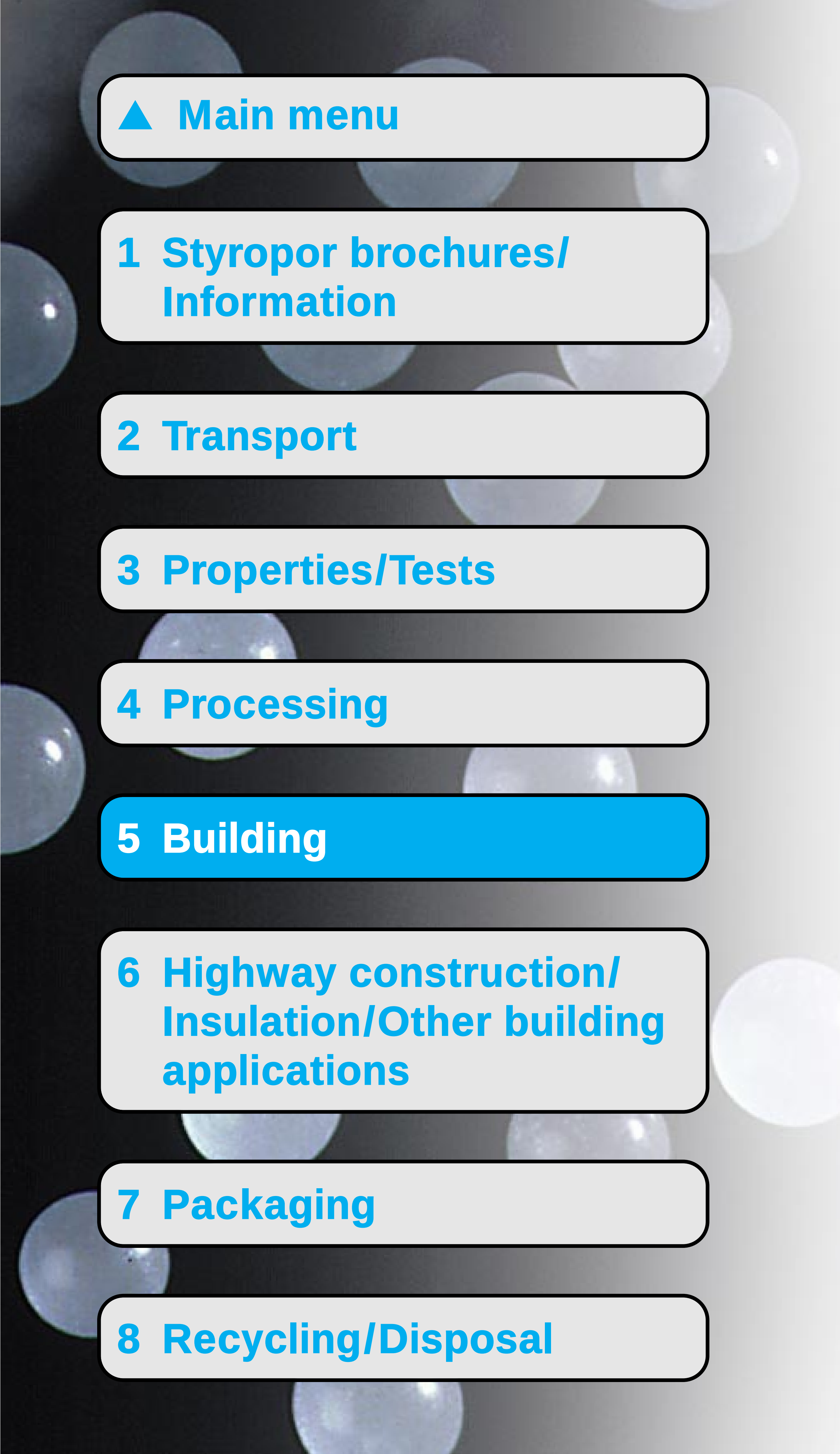

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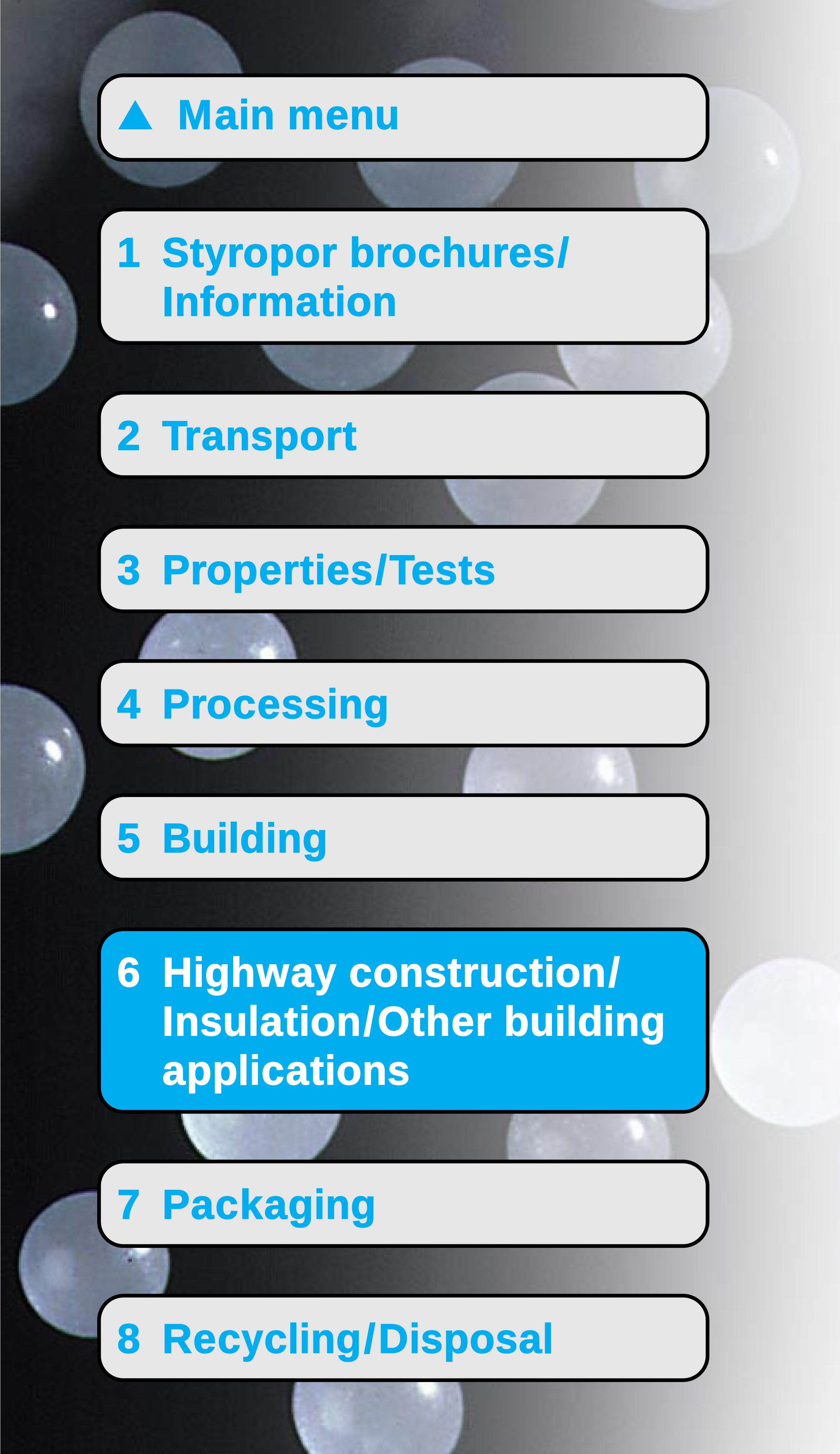

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Highway construction/Insulation/Other building applications

	Code of Practice Using Expanded Polystyrene for the Construction of Road Embankments
800	Rigid Styropor foam as a lightweight construction BASF material for highway foundations: GEOFOAM®
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Styropor® Technical Information

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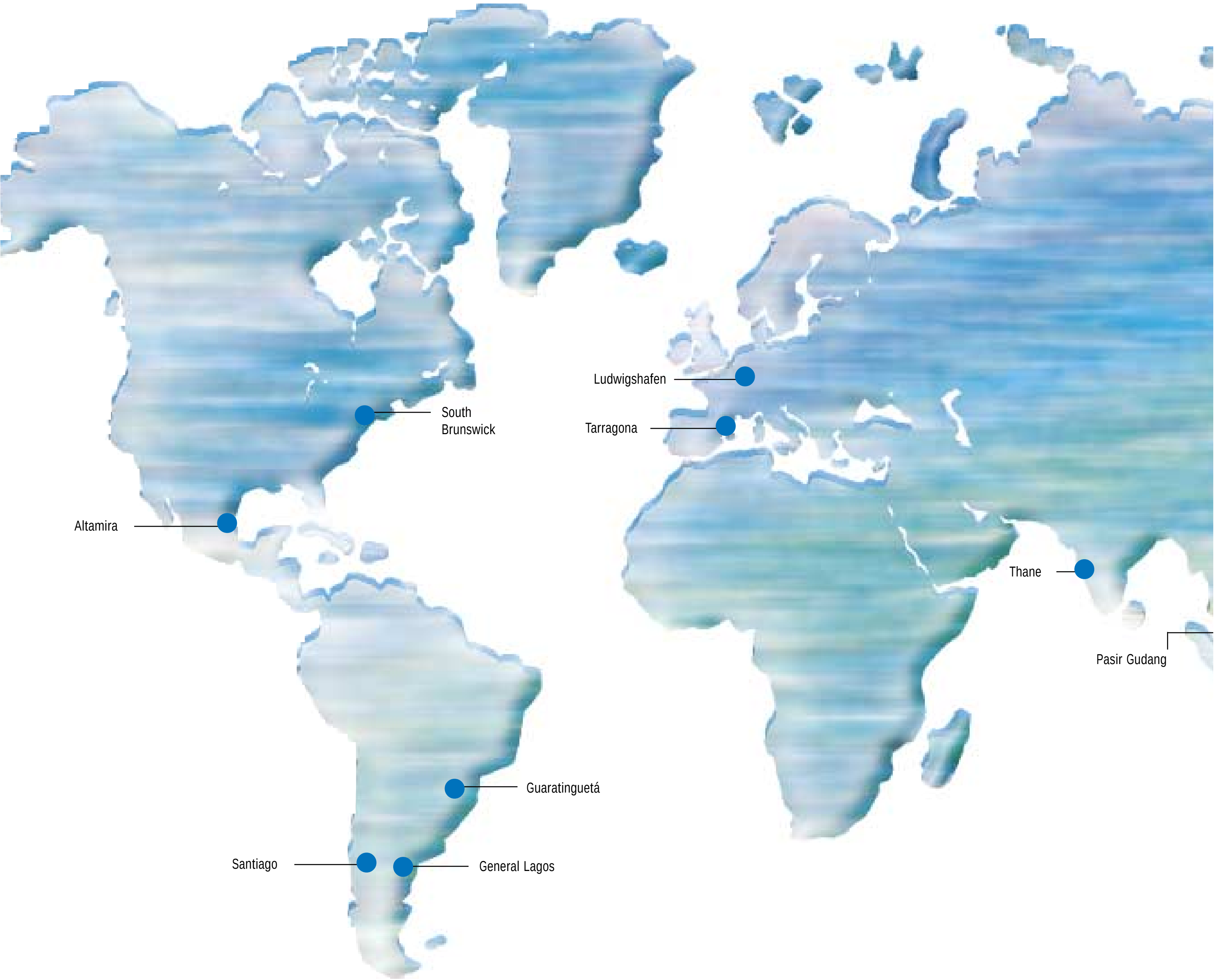
Recycling/Disposal

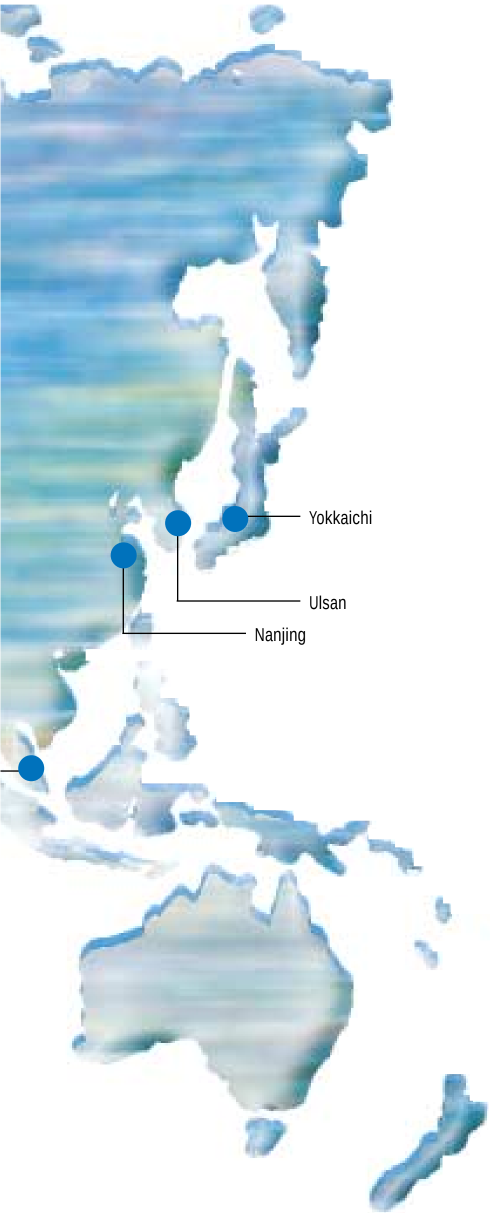
Styropor comes from ...



Plastics represent one of BASF's most important fields. In the pioneering years, BASF started the first large-scale production of polystyrene in 1930 and of polyamide in 1940. In 1950, expandable polystyrene – Styropor® – was invented at BASF. Today BASF is one of the world's biggest and most successful plastics manufacturers.

In its almost 50-year history Styropor has become almost a synonym for energy-saving building and secure, economic packaging. It has been improved continually, new variants have been devised, processes and machinery have been refined and updated, and novel applications have arisen. And the R&D people at BASF are still active, still keen to ensure that the product meets the requirements of today's market ... and tomorrow's.

Styropor Range, Properties, Processing, Applications



Styropor – the Proven

BASF, with 12 Styropor production sites and sales organizations in all countries, keeps in close touch with markets and customers everywhere – always supported by a Technical Service which gives state-of-the-art advice.

“Styropor” encompasses more than fifty types and grades of expandable polystyrene from an annual production capacity exceeding 500,000 tons whose economic basis is assured by an integrated supply of raw materials.

The success of Styropor does not just come from effort and money put into research and development or even the latest manufacturing processes – though much is due to both. Without the high quality standards every member of our staff has always applied, it would have been impossible. Our products come from locations that have been certified in accordance with DIN ISO 9001/2.

Thanks to further development and continual improvement, the Styropor range now includes six distinct groups of products, each made up of a number of members dedicated to meeting particular requirements.

All members of the Styropor range have one advantage in common: their price-to-performance ratios are highly favourable. This is seen in every field they are used in.

For instance, the building trade, required to erect dwellings with high energy ratings, chooses insulation made from Styropor, because it increases living comfort and provides a way of realizing an ideal economically. In providing thermal insulation, Styropor not only counters waste of energy: it also makes a direct contribution to reducing carbon dioxide emission.

The makers and users of packaging also base their ultimate choice of materials on performance and price. In this case, performance, while including versatility and adaptability, is equated in the last resort with reliability. Styropor packaging materials can be relied on to help protect goods from the jolts, bumps, and falls to which they are inevitably subjected while in transit, reducing damage and preserving their value.

For 50 years Styropor has been a material of proven worth, tried in many fields. For very special applications, its offshoots – special products – are available.

Styropor is a highly recoverable material, one of the first plastics for which practicable closed recycling and scrap utilization systems are available.

The Styropor Range

Standard products

Styropor® P	building, moulded packaging, miscellaneous articles	• low-energy processing • low densities • short moulding cycles • high thermal resistivity • highly uniform density
Styropor® F	building, moulded packaging, miscellaneous articles, when flame-retardant material is needed	• best possible classification for combustible materials according to tests given in all national standards • high thermal resistivity • short moulding cycles • low densities • highly uniform density

Special products

Styropor® P 006	drainage board with adhesive-bonded or welded beads	• low adhesive consumption • narrow bead-size distribution • extra-large bead size for high permeability • good resistance to compression, even at low densities
Styropor® P+F Particulate Grades	microvoid-former in brick clay and refractory materials; lightweight aggregate in concrete, rendering, and plaster	• *low density* beads • advantageous behaviour on expansion • gsurface structure promoting good adhesion • extra-small bead size
Styropor® P+F	high-density mouldings with little aftershrinkage; flame-retardant or not, as required	• *high density,* uniform preexpanded beads • raw beads with reduced blowing agent • short moulding cycles even after reduced intermediate aging • mouldings require only brief aging

Styropor Properties

Chemical and physical structure

Styropor is an expandable polystyrene containing a blowing agent. It is formed by polymerization of monostyrene, with the addition of pentane.

Cellular polystyrene formed from Styropor consists of an assembly of myriads of tiny, air-filled cells.

Physical properties

Most of the physical properties of cellular polystyrene depend on the density of the material – see Table 1.

Corresponding values for cellular materials made from Styrotherm are given in Table 2.

Resistance to chemicals

Expanded Styropor is essentially as resistant as polystyrene to attack by chemicals. It is therefore unaffected by water, alkalis, and most acids. However, substances that soften, dissolve or destroy massive polystyrene will affect expanded Styropor similarly but much faster. This is because the walls of each individual cell are exceedingly thin. It follows that the rate of attack increases as the density of the cellular polystyrene decreases.

In practice, expanded Styropor is most likely to be affected by organic solvents or plasticizers. Adhesives and paints must be chosen with care, and direct contact with plasticized PVC should be avoided.

Whenever a substance of unknown composition is considered for use in contact with expanded Styropor, tests should be carried out before a final decision is reached.

Burning behaviour

All cellular polystyrene is combustible, like practically all organic building or packaging materials. In practice however its burning behaviour depends on the conditions under which it is used as well as the inherent properties of the material. The latter differ according as the cellular material is made from Styropor P or Styropor F.
Other materials bonded to cellular polystyrene affect its burning behaviour considerably.

All grades of Styropor F are flame retarded, which make the expanded material much more difficult to ignite and considerably reduce rates of spread of flame. Fire tests differ greatly from country to country, but cellular polystyrene made from Styropor F always attains the best possible classification in its category.

Combustion of Styropor F under the conditions prescribed in DIN 53436 yields no traces of brominated dibenzodioxins, either in the gaseous phase or in the solid residue, only negligible proportions of brominated dibenzofurans, not one of them a toxic substance within the meaning of the [German]
Prohibited Chemicals Order 1994.

The gases and fumes formed by combustion or pyrolysis when cellular material made from Styropor is involved in fires are not as toxic as those from the same mass of wood.

Packaging materials made from Styropor behave similarly to many other materials in fire. If, to reduce storage risks, packaging materials made from appropriate grades of Styropor F are chosen, insurance companies are prepared to reduce fire-insurance premiums.

Physiological effects

Styropor has been manufactured and processed for decades, and during this time the cellular material made from it has been used for widely different purposes. No deleterious effects on health have ever been reported.

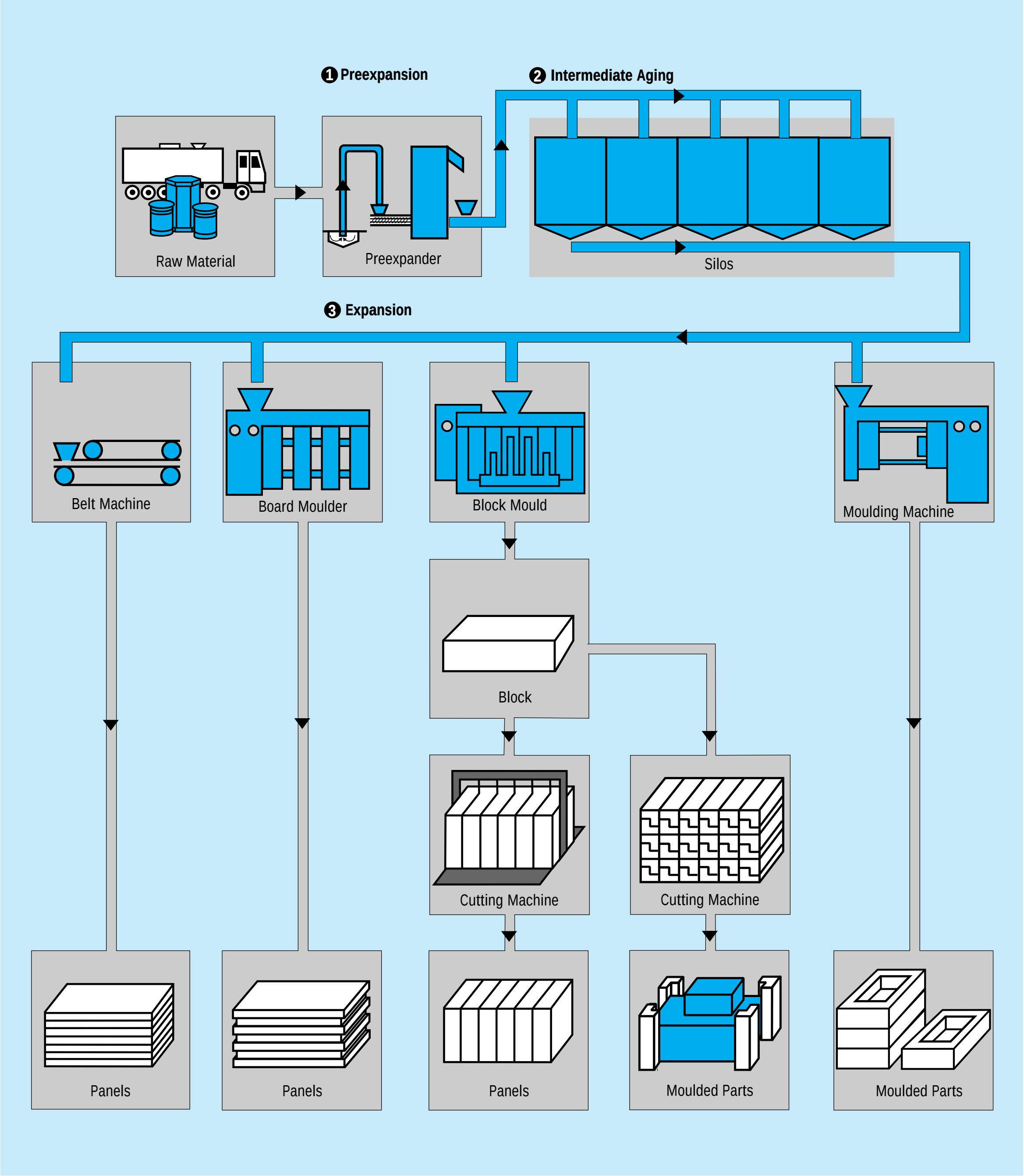
Foodstuffs legislation

The monomer used for the manufacture of Styropor is listed in the [German] Utensils Order of April 10, 1992 and complies with legislation implementing Directive 90/128/EEC of February 23, 1990.

Other substances used in the manufacture of Styropor are listed in recommendation of the [German] Federal Office of Health relating to styrene polymers and colorants. These recommendations are followed in every respect.

Enclosed you will find the tables “Properties of Styropor foams for packaging purposes” and “Construction applications”.

Styropor Processing



Styropor Processing

① Preexpansion
② Intermediate Aging
③ Expansion

Processing

Conversion of Styropor into moulded cellular material is marked by low energy consumption and short moulding cycles. Because of the highly consistent quality of all Styropor products, it is also notable for freedom from unexpected or intermittent difficulties.

Most Styropor is converted into moulded blocks, board, contoured mouldings, or articles made by machining, but selected grades can be used as cellular beads as aggregates in concrete, plaster, or mortar or as microvoid-formers in brick clay.

Styropor in Construction

The leading application of expanded Styropor in building is thermal insulation, but it performs other functions too. It forms the cores of elements and components such as wallboard panels; it is used as lightweight fill in civil engineering; it provides impact sound insulation in floating floors; it serves as aggregate in lightweight concrete, plasters, and renderings. Styropor is chosen because its use is economic.

Because of the wide scope of its applications, Styropor is available in many types and grades; each of these is intended to suit particular methods of conversion or provide expanded material with just those properties that best fit it for its intended function. Architects and engineers know this; consequently, they exploit the useful properties of expanded Styropor in many ways. Here are some examples.

Roofs

Flat roofs can be insulated economically with cut or moulded Styropor board, simply laid on the deck, fixed mechanically, or bonded with hot or cold bitumen. In the case of rollable insulation sheets, the lamination with roofing felt already counts as the first roof sealing layer.

Styropor board worked to allow fitting between the rafters (Styrotect® S) provides the high thermal resistance required for habitable spaces under pitched roofs. Alternatively, Styropor board or composite board can be fixed over the rafters.

Insulating a pitched roof by attaching Styropor® boards to the rafters.

Rollable Styropor® insulation sheet.


Outer wall insulation.


Laying impact-sound boards.


Preparation of road foundations.

Walls

A number of very different products made from Styropor are used for insulating walls. Styropor board applied outside may be protected by a coat of fabric-reinforced render; moulded Styropor formwork may be used to build the wall; mortar with expanded Styropor aggregate may be used as insulating render. In cavity walls, Styropor board is used as insulation between the leaves, and existing wall cavities may be filled with expanded Styropor beads.

Voids filled with preformed expanded Styropor increase the thermal resistance of blocks; microvoids formed by Styropor beads increase that of Poroton® fired-clay units.

Composites made from expanded Styropor and gypsum plasterboard make effective insulating linings.

Floors

Precompressed, impact-sound grade Styropor board forms an excellent resilient layer for floating floors, which greatly lessen the transmission of impact noise.
Styropor board may also be used to provide the thermal insulation required below the heating elements of underfloor heating systems.

Civil engineering

Expanded Styropor is not only a material of extremely low density and an excellent insulant; it is also very durable, being unaffected by water and microorganisms occurring in soils. For this reason, it has found many civil-engineering applications.

Styropor board is used for geothermal insulation beneath roads etc., where it prevents the break-up of soils through freezing. In block form, expanded Styropor can be used as lightweight fill in embankments and ramps where the bearing capacity of the soil is low. Around foundations, expanded Styropor of low density provides a cushion against ground forces.
Styropor drainage board is a special material consisting of large cellular beads welded or bonded together so as to leave large interstices through which water can pass easily.

Poroton® = registered trademark of Verband der Poroton-Hersteller e.V. (Association of Poroton Manufacturers)

Styropor in Packaging

Moulded Styropor is ideal for packaging. Its inside contours can exactly match those of the articles it protects, giving support where it is needed, or avoid areas that can stand no pressure. Sections can be cut away to save material or improve cushioning. So long as functionality is preserved, wall thicknesses and outside contours can be chosen at will. There is even wide scope for modifying the properties of the material through appropriate choice of processing conditions.

This adaptability and the almost limitless design possibilities have led to the use of expanded Styropor for packaging in many forms and by many industries. The goods pictured here – computers and fish, cast-iron fire hydrants and cakes – seem to form a bizarre assortment, but they have one thing in common: they need to be transported with care.

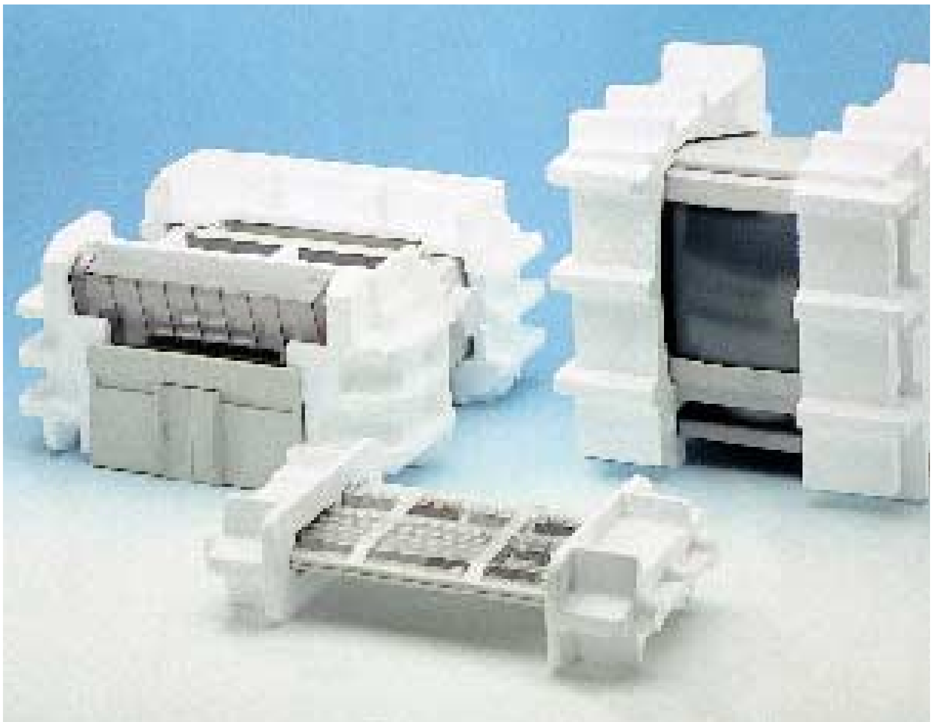
Packaging must satisfy certain essential requirements. It must

- withstand the pressures in stacks
- absorb energy imparted by jolts
- delay temperature changes.

Expanded Styropor does have high thermal resistivity ensuring very slow heat flow; it does absorb mechanical energy – better than almost any other cushioning material; and even open-topped boxes made from it are strong enough to allow high stacking. Expanded Styropor is a very well-qualified packaging material.

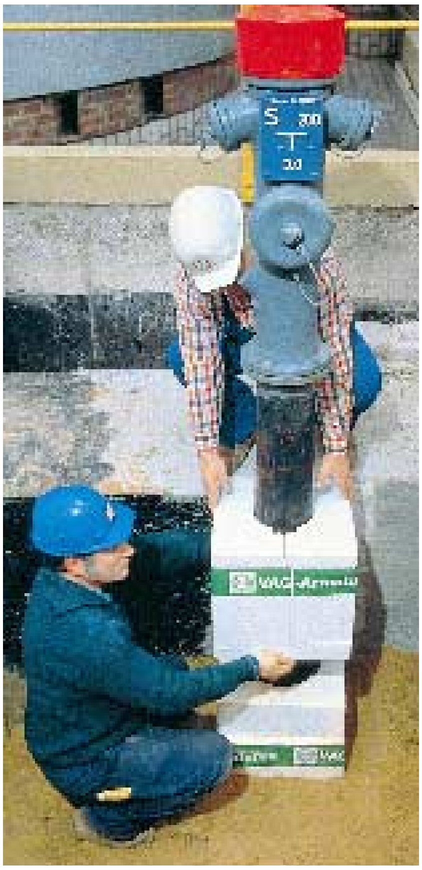
The variety of goods large and small that all branches of industry have chosen to protect with expanded Styropor is its best recommendation. Washing machines and refrigerators; sensitive electronic equipment for research, communications, and entertainment; packs of medicines and cosmetics; food and drink: these are just a few of the things that have been protected reliably by Styropor mouldings or inserts for decades.

Fishboxes, heat-insulating and hygienic, cleared for direct contact with foodstuffs.



Jolt-protection – packaging for electronic equipment.

Stacking pressure:
8 fridges stacked on top
of each other.



Packaging fire hydrants.
Second use:
installation in the ground
as protection against frost.

Cake packaging.

Styropor Special Products

Besides standard products of the Styropor P and Styropor F series, BASF offers special products for particular applications.

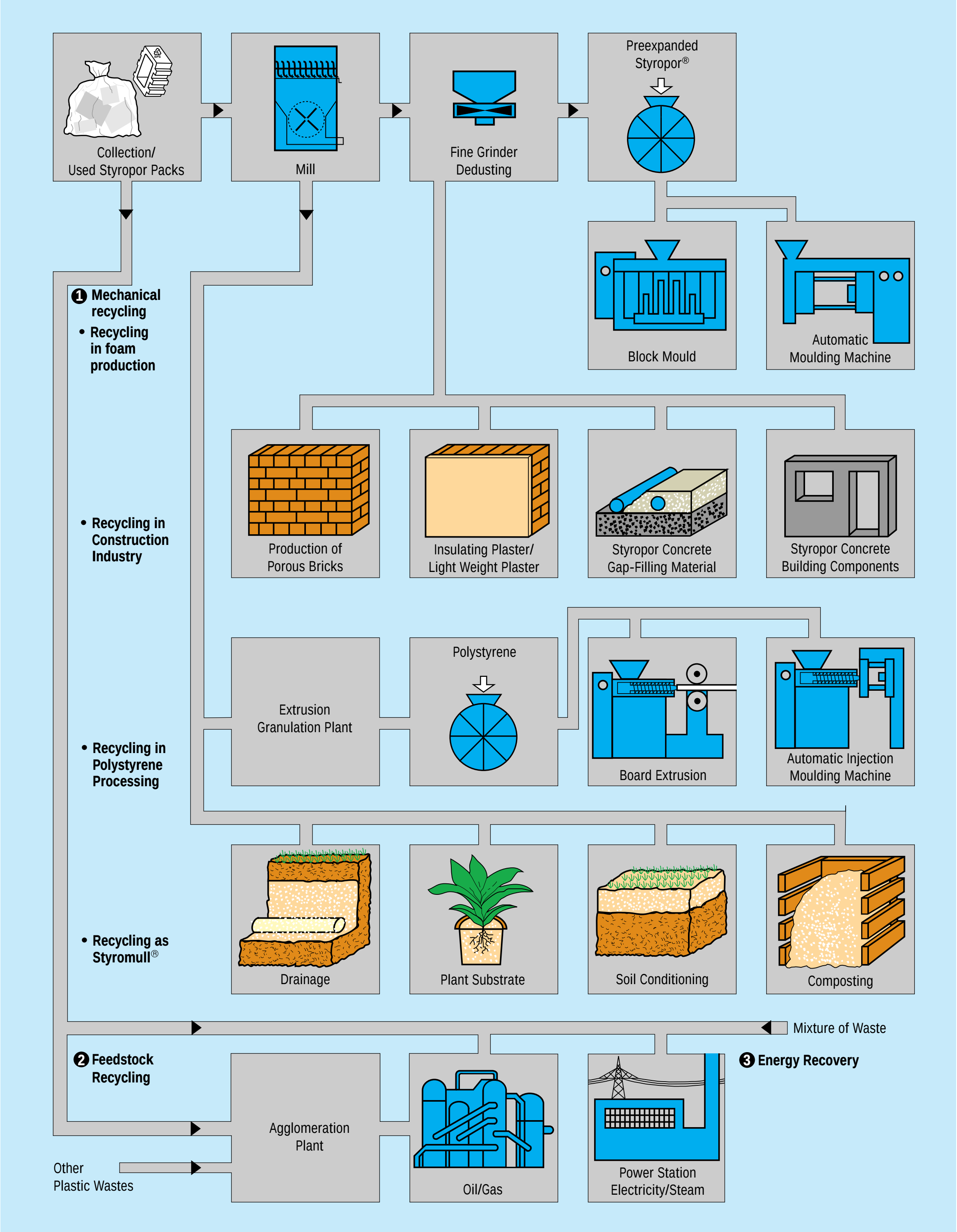
Styropor P 006

Drainage board (with expanded beads joined by adhesives or welding) is best made from the coarse beads of Styropor P 006.

Styropor® P 006 – laying drainage board.

Styropor® – a cycle helmet is comfortable to wear and gives protection.

Styropor Recycling



Recycling of expanded
Styropor foams

① Mechanical Recycling
② Feedstock Recycling
③ Energy Recovery

Expanded Styropor or its congeners can be recycled in a number of ways. It can go into new EPS, be used as lightweight aggregate, serve as a source of raw materials, or provide energy. If disposed of by landfill, it facilitates aeration without contributing to pollution of water or the atmosphere.

Styropor Recycling

Incorporation in fresh EPS

Clean scrap can be mixed with virgin expanded beads, having first been ground to the same size, and incorporated in new block or mouldings.

Soil improver and light aggregate

Scrap expanded Styropor ground to a particle size of 4–25 mm is a commercial product (Styromull®) valued as a soil improver, composting aid, and permeable material for filter drains.

Ground smaller (1–4 mm), scrap expanded Styropor can also be used as lightweight aggregate for concrete and insulating mortars.

Scrap expanded Styropor ground similarly is added to brick clay as a microvoid-former.

Polystyrene recovery

Expanded Styropor consists of air enclosed by a thermoplastic, polystyrene, which can be recovered from clean scrap for use in extrusion compounds etc. by simultaneous compression and heating in special equipment (single-roll plasticators, screw extruders).

The recovered polystyrene can be used too in expandable polystyrene.

Feedstock recycling

All above mentioned methods of mechanical recycling are only valid for pure EPS scrap. Feedstock recycling does not depend on scrap free from gross soiling and consisting of one plastic only. One recovery method uses scrap in steel production (as a source of crude carbon). Others yield valuable hydrocarbons.

Energy recovery

Waste expanded polystyrene can serve as a fuel. Broken down into lumps, it can be mixed with refuse and burnt in furnaces; no smoke is formed if the air supply is adequate and the usual temperatures (1000 °C or more) are attained. EPS has a high calorific value and is a good substitute for the oil normally used as secondary firing (1 kg of EPS replaces 1.2–1.4 l of fuel oil).

Landfill

Waste expanded polystyrene causes no problems whatever when disposed of by landfill (controlled tipping). It is however best to break it up first. Then, mixed with household refuse, it promotes aeration and faster breakdown of organic matter.

Further information

For more detailed information, consult BASF’s extensive technical literature on Styropor and related products. Our current Technical Information bulletins and brochures deal with subjects such as processing and uses of Styropor in building and packaging, fire safety, pigmented Styropor (Styrocolor), and Styrotherm.

The advice of BASF’s Applications Development staff is also available whenever you need it.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

Table: **Physical data for foams made from Styropor® for construction**

Properties 1)	**Test standard**	**Unit**	**Test result**		
Quality assured types	GSH quality conditions		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18164, Part 1		W	WD	WS + WD
Minimum bulk density	EN ISO 845	kg/m^3	15	20	30
Building material class	DIN 4102		B1, Poorly flammable	B1, Poorly flammable	B1, Poorly flammable
Thermal conductivity					
Measured value at +10 °C	DIN 52612	mW/(m · K)	36 – 38	33 – 35	31 – 34
Calculated value according to	DIN 4108	mW/(m · K)	40	40	35
Compressive stress at 10 % compressive strain	EN 826	kPa	65 – 100	110 – 140	200 – 250
Resistance to sustained compressive loads at < 2 % strain after 50 years	ISO 785	kPa	20 – 30	35 – 50	70 – 90
Flexural strength	EN 12089	kPa	150 – 230	250 – 310	430 – 490
Shear strength	DIN 53427	kPa	80 – 130	120 – 170	210 – 260
Tensile strength	DIN 53430	kPa	160 – 260	230 – 330	380 – 480
Modulus of elasticity (compressive test)	EN 826	MPa	1.0 – 4.0	3.5 – 4.5	7.5 – 11.0
Heat deformation temperature					
short-term	based on DIN 53424	°C	100	100	100
long-term at 50 kPa		°C	75	80	80
long-term at 20 kPa		°C	75	80	80
Coefficient of linear expansion		1/K	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$
Specific heat capacity	DIN 53765	J/(kg · K)	1210	1210	1210
Water absorption when submerged (by volume)					
after 7 days	DIN 53 434	Vol. %	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapor diffusion rate	DIN 52 615				
Water vapor diffusion resistance factor	Calculated according to DIN 4108, Part 4	1	20/50	30/70	40/100

1) corresponding to Test Norm

$1\ N/mm^2 = 1000\ KN/m^2 = 1\ MPa = 1000\ kPa$

BASF Aktiengesellschaft
Geschäftseinheit Styropor
67056 Ludwigshafen
Germany

Table: **Physical properties of Styropor® foams for packaging**

Properties 1)	Test standard	Unit	Test result		
Density	EN ISO 845	kg/m^3	20	25	30
Thermal conductivity at +10 °C	DIN 52612	mW/(m · K)	33 – 35	32 – 34	31 – 34
Compressive stress at 10 % compression	EN 826	kPa	110 – 140	150 – 200	200 – 250
Permitted compressive stress for packaging calculations	DIN 52612	kPa	39	31 – 34	71
Flexural strength	EN 12089	kPa	260 – 360	360 – 460	460 – 560
Shear strength	EN 826	kPa	230 – 330	300 – 400	380 – 480
Tensile strength	DIN 53427	kPa	120 – 180	160 – 200	210 – 260
Modulus of elasticity in compression	EN 826	Mpa	3.5 – 4.5	5.0 – 8.5	7.5 – 11.0
specific custioning factor, C*	DIN 55471, Teil 2 2)	1	2.5	2.5	2.5
specific impact resistance capacity e*	DIN 55471, Teil 2 2)	kJ/m^3	150	200	250
Coefficient of linear expansion		1/K	5 – 7 · 10^{-5}	5 – 7 · 10^{-5}	5 – 7 · 10^{-5}
Specific heat capacity	DIN 53765	J/(kg · K)	1210	1210	1210
Water absorption when immersed in water					
after 7 days	DIN 53 434	Vol. %	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapour diffusion flow density	DIN 52 615	1	55	75	85

1) corresponding to Test Norm

2) corresponding DIN 55471, Part 2

1 N/mm^2 = 1000 KN/m^2 = 1 MPa = 1000 kPa

BASF Aktiengesellschaft
Geschäftseinheit Styropor
67056 Ludwigshafen
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KSR 9500 e 07.98

Better together –

Together better

BASF Foam-Technology

http://www.basf.de

Note:
You will find more information on
Styropor in the Technical Information
leaflets available on CD-ROM.
KSR/MK – D 219
Tel.: +49-621-60-9 90 38
Fax: +49-621-60-7 22 26

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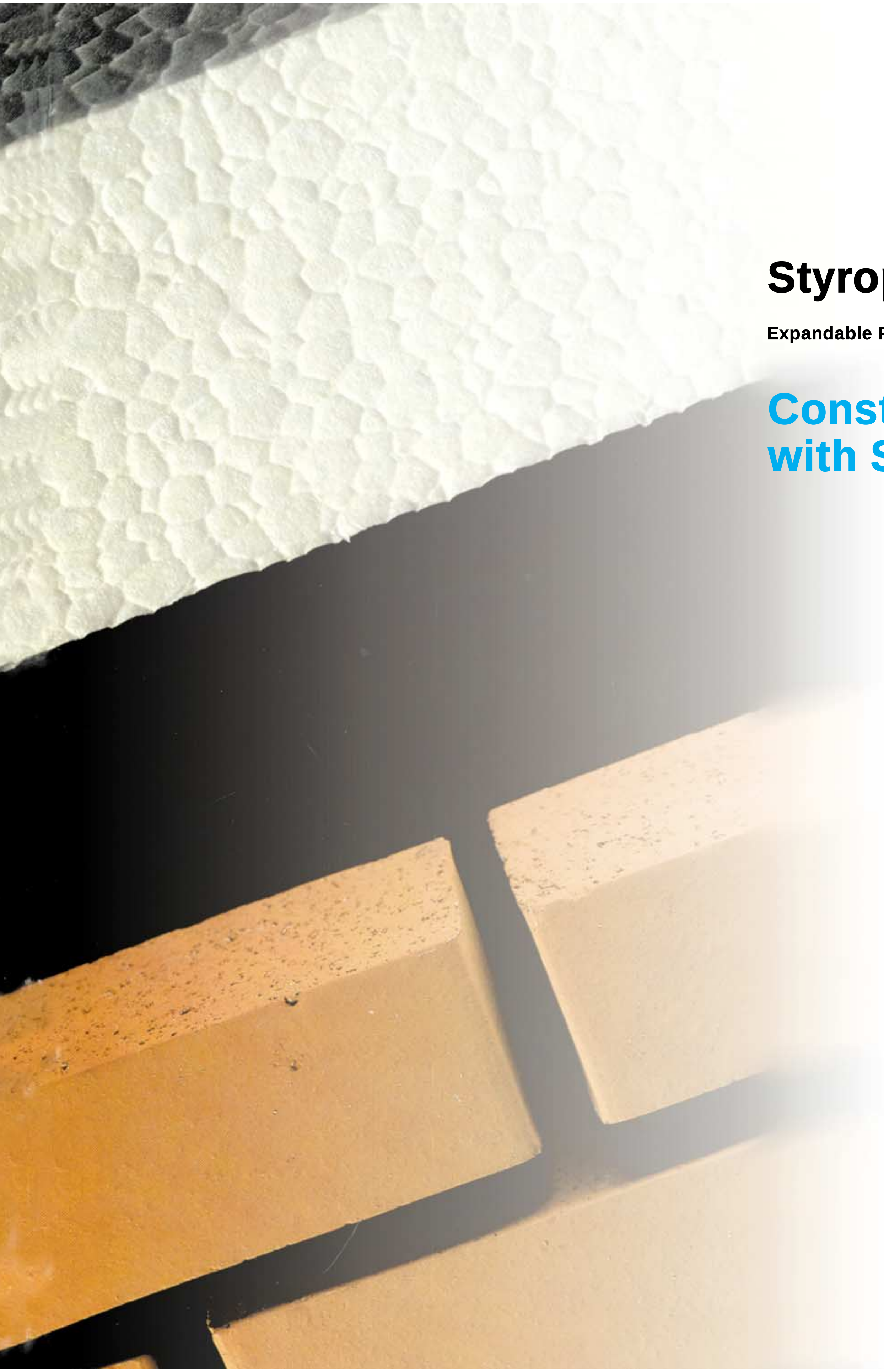


Styropor®

Expandable Polystyrene (EPS)

Construction with Styropor

Styrenic Polymers

BASF


Im Petrus

Construction with Styropor

Fig. 1:
The pitched roof as a striking architectural element: the roof becomes the area bounding indoors and outdoors. Here roof insulating systems of Styropor offer permanent thermal protection – both in summer and in winter.

® = registered trademark of BASF Aktiengesellschaft

Thermal insulation in the construction industry

With this brochure we are presenting to you a material which, by virtue of its properties, has acquired and secured a firm position for itself as an insulating material in the construction sector during the course of over 40 years: Styropor foam, a polystyrene rigid foam for up-to-date, energy-saving and economical construction.

Styropor is the expandable polystyrene from BASF. It is supplied to foamed plastic producers in the form of bead-like granules.

BASF has a total of 12 plants around the world where it produces Styropor, the raw material for a diversity of application areas, insulating and building materials for the construction industry being uppermost.

Foamed plastics from Styropor

The production of Styropor foamed plastics takes place in three stages: preexpansion, intermediate aging and moulding. First of all, the granules are preexpanded and thus foamed by heating. The blowing agent contained in the raw material inflates the particles up to about fifty times their original volume to form closed-cell foam particles. This is followed by an intermediate aging time, during which air diffuses into the material and blowing agent partially diffuses out of the material.

Finally, the preexpanded particles are filled into moulds and undergo final foaming, the foam particles expanding once again and fusing together. A rigid foamed plastic with a high air content is produced, which is trapped in a large number of small cells and brings about excellent long-lasting thermal insulation!

The special production process makes it possible to vary the apparent density of the Styropor foamed plastics within a wide range. As the properties of the foam depend substantially on the apparent density, foamed plastics can be produced with a variety of qualities suited to particular applications ranging from insulating boards to lightweight structural units.

Construction today and in the future is and will be characterized substantially by requirements for energy saving, noise and environmental protection.

Virtually all industrialized countries today have statutory minimum requirements for the constructional thermal insulation of heated and air-conditioned buildings.

By now, even in countries with moderate to tropical climates, a comparatively high level of constructional thermal insulation is prescribed, as is the case in countries with relatively low winter temperatures. This is due to the fact that in these countries summer thermal insulation – namely the energy lost in the air-conditioning of buildings – is a relatively significant factor in energy calculations, as is winter thermal insulation in other countries. This is so because the energy loss in the air-conditioning of a building on hot summer days is greater than that in the heating of buildings with cold outside temperatures in winter.

Being forced to use additional insulating layers today means for architects and building contractors on the one hand a considerable intervention into the amount of freedom they have in planning and structural design. On the other hand, this intervention has a beneficial effect on the development of new, innovative system solutions. Here, Styropor as a material for the insulation of complete compound units has for a number of years and in many countries held a significant place in practical construction on account of its excellent material properties.

Construction with Styropor

By using Styropor rigid foam, architects and construction engineers today are also at the same time making use of the opportunity presented by system solutions and incorporate them in their plans appropriately for the functions concerned. The trend is clearly toward specific insulation systems, such as external wall and roof insulation systems, underfloor heating systems etc.

Such systems give the owner of a building under construction not only considerable cost/benefit advantages but also reduce the risk of technical errors in the planning and execution of work.

The examples on the following pages show how Styropor is used as a system on a structure. They are current practical examples from internationally known construction applications.

They provide interesting insights into the unique versatility of foamed plastics from Styropor as system materials. Of course, this “practical exhibition” cannot cover all possible construction applications because there are so many. Even today, 4 decades after its invention, Styropor has lost nothing of its attractiveness and is more a part of today’s construction industry than ever.

Roof constructions with Styropor

From the viewpoint of construction physics, the roof, no matter of what design, is the most highly stressed part of a building. Heat and cold, dryness and wetness, storms and snow act from the outside, internal relative humidity acts from inside, either alternately or both at the same time. Roof designs and materials have to be adapted to these conditions if the roof is to fulfill its protective function. Plastics play a significant part in this connection, as insulating layers, waterproofing membranes, vapor barriers, underlays, gutters, downpipes and many other functional elements.

Whether a flat roof or a pitched roof, whether someone’s home or an office building, on factories, workshops or warehouses, whether a roof garden or an underground garage: Styropor foamed plastics are always involved because they have outstanding insulation and offer economical answers as insulating systems.

Flat roofs

Flat roof insulation is an important field of application for Styropor foamed plastics. Depending on the roof design, the insulating material is laid loosely, fixed by hot or cold adhesive or mechanically fastened to the underlying surface.

The insulation of a nonventilated flat roof is performed simply and economically by means of insulating units of Styropor which have been precoated with roofing felt. The lamination with roofing felt protects the insulating layers when the hot bitumen is applied to fix the roof seal (Fig. 2).
In the case of rollable insulating sheets, the lamination already counts as the first roof sealing layer.

Unlaminated rigid foam boards are used on what are known as tarpaulin roofs (Fig. 3). In this case, the insulating boards and the plastic tarpaulin sealing are loosely laid and provided with a ballast (eg gravel) or are fixed with special dowels.

Fig. 2:
Rollable insulating sheet

Fig. 3:
Tarpaulin roof

Pitched roofs

In many countries, use of the roof space for living purposes is already a consideration during the planning of a building. Even on existing buildings, roof space is increasingly being developed as additional living areas for guest rooms, play rooms or hobby rooms. Adequate thermal insulation of the roof surface – as the area bounding indoors from outdoors – must be provided. Making the insulating layer adequately thick is also worthwhile with regard to the effect of sunlight in the summer.

Suitable for use as insulation in pitched roofs are Styropor rigid foams in the form of filler insulating boards between the rafters, laid on the rafters (Figs. 4 – 6) or in the form of thermally insulating structural composite units. Such insulation systems make economical construction work possible and offer lasting thermal protection. One example of this offers advantages in particular in the case of a subsequently installed roof insulation: foam moulded boards with underlying vapour barrier are laid on the existing roof battens. The tiles are then re-laid on the profiled insulating units (Fig. 7).

Fig. 4:
Construction and insulation with Styropor rigid foam

Fig. 5:
A Laying system:

1 = Tile roofing
2 = Roof battens
3 = Underlying battens (for ventilation)
4 = Nailing through the Styropor insulation
5 = Styropor laying system
6 = Rafters
7 = Formwork
8 = External wall with, for example, core insulation

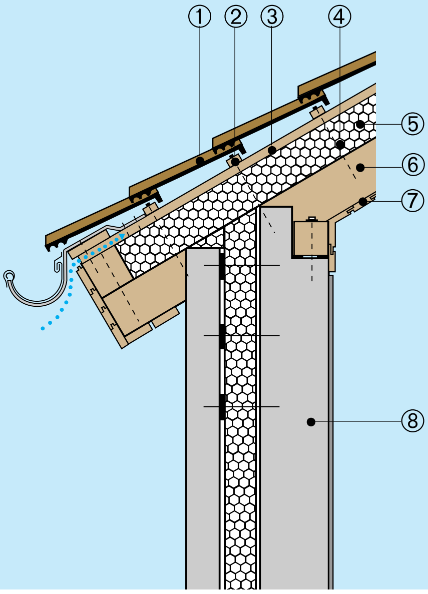


Fig. 6:
Nailing the bearing battens

Fig. 7:
Foam moulded insulating boards

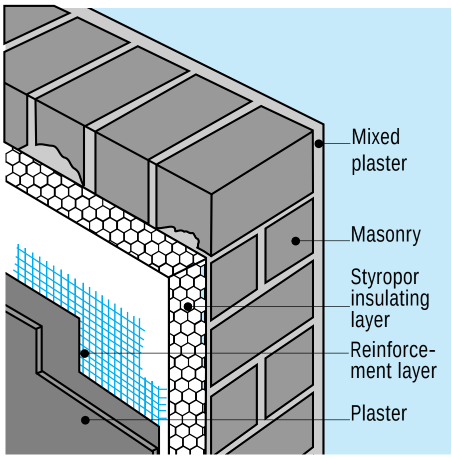
Wall constructions with Styropor

A wall is both a load-bearing and a protective building unit. It protects the surrounded space against the effects of temperature and weather and against noise. Nowadays, the thermal insulation function is assumed by modern insulating materials, such as Styropor foamed plastics.

In what is the optimum type of external insulation from a construction physics viewpoint, the Styropor insulating layer is applied on the outside of the load-bearing masonry and weather-protected either by a reinforced special plaster or by a ventilated facing layer. Another effective type of external insulation is an insulating plaster with foamed Styropor particles as lightweight aggregate, applied as a continuous layer. But composite Styropor/plasterboard units are also used to achieve thermal insulation to today's requirements by insulating external walls from the inside, for example by subsequent interior insulation on existing buildings.

A method widely used in Europe is that of external insulation with Styropor boards and fabric-reinforced plaster coating. In this method, the insulating boards are fixed to the masonry by bonding mortar and subsequently covered with a fabric-reinforced dispersion plaster (Figs. 8 and 9). The reinforcement of the plaster layer with alkaliresistant glass fibre sheets is necessary to absorb the material and temperature – dependent stresses in the plaster layer occurring on the insulated facade as the result of temperature fluctuations.

Figs. 8 and 9:
External wall insulation with the composite thermal insuiation system



The production of lightweight large-panel wall units with a plastercoated external insulation is particularly widespread in the USA. The supporting board is mounted on a sectional steel frame and provided with the insulation and fabric-reinforced plaster coating (Fig. 10). The easy-toassemble compound units give the impression of a solid external wall.

Another system of thermal insulation which is likewise widespread – is the use of mouldings from Styropor for the external walls of buildings. The mouldings are placed dry and then filled with concrete.

Walls and floors are produced “in one” when Styropor formwork elements are used for the production of reinforced concrete ribbed floors. The formwork elements are easy to lay and produce an even, thermally insulated ceiling which can subsequently be plastered or lined (Fig. 11).

Fig. 10 (above):
Installation

Fig. 11 (below):
Floor formwork elements

Fig. 12:
Wall construction system

There is an extremely wide variety of variations of wall moulding systems: large wall units, produced on continuous moulding machines and, for example, mouldings of Styropor with stainless steel connecting elements (Fig. 12) or wall formwork elements already provided with a pre-coating for plaster bonding.

In the case of a cavity wall, the insulating layer is provided between load-bearing wall and weather-resistant facing masonry. The closed-cell boards, rebated all around, make it possible to dispense with the otherwise customary air gap between insulation and facing masonry. The cavity between the two wall skins can be fully utilized for insulation (Fig. 13).

For the insulation of an already existing cavity wall, there is likewise an economical method: foamed particles are blown into the cavity between the two masonry skins. For this purpose, holes are drilled into the skin and closed again after the filling operation. Foamed beads are delivered in special silo vehicles.

A method of construction which is as simple as it is economical is the use of special masonry blocks in which the Styropor insulation has already been introduced into the cross-section of the block. This may be performed by the insulating boards being pushed manually into corresponding block cavities or already moulded-in during block production.

Another method is to fill the block cavities with preexpanded beads and then foam them with steam.

This economical production method makes possible an integrated insulation and thus a substantially improved thermal insulation capacity of the hollow blocks.

To reduce heat loss through the mortared joints, a light masonry mortar is generally used.

Fig. 13:
Core insulation

Insulating plaster

A further possibility of improving the thermal insulation of external walls is to coat them with a thermally insulating lightweight plaster. In this case, small, foamed Styropor particles are added to the plastering mortar mix, substantially reducing the apparent density of the plaster and thus increasing its thermal insulation.

The dry mix is delivered to the construction site in sacks or containers and is prepared ready-for-use just by adding water.

Such lightweight Styropor plasters can be mechanically processed and sprayed on up to a thickness of 6 cm in a single operation (Fig. 14).

3 to 5 days after applying the layer of insulating plaster, a mineral plaster is added for surface protection.

Depending on the plaster thickness, profiling and surface coating, unconventional facade designs are also possible (Fig. 15).

Fig. 15
Insulating plaster facade
Building: Les Grottes,
Geneva

Fig. 14
Insulating plaster

Lightweight concrete

Foamed Styropor beads are not only suitable for lightweight plasters, but also for the production of lightweight concrete and porous bricks. The possible applications of Styropor concrete as a thermally insulating, lightweight construction material have already been investigated by BASF years ago and formulations for various apparent density ranges with different concrete properties developed.

From the point of view of structural thermal insulation and economical processing, Styropor concrete is of particular interest in the low, very light apparent density range: for example as a special prefabricated system in which the tubular cavities in the lightweight Styropor concrete wall units are later filled with normal concrete, which undertakes loadbearing and reinforcing functions. Recesses or openings can be cut out simply by using a saw (Fig. 16).

Or for the production of domed houses, using a blown-up shell on which the Styropor concrete is mechanically sprayed.

Fig. 16:
Styropor concrete
wall units

Prefabricated Systems

The use of Styropor foamed plastic boards as thermal insulation in large-format facade units of normal concrete (sandwich construction) has long since proven successful (Fig. 17).

The high mechanical load-bearing capacity and dimensional stability of Styropor rigid foam also make possible a trouble-free production of largepanel lightweight units which can be covered with various materials depending on the intended application (Fig. 18, see page 12).

- Such as sheeting with wood or chipboards as load-bearing wall or roof unit in prefabricated home construction: an economical dry insulation technique which is used particularly in North America, where it has been recognized that houses made from prefabricated Styropor units make possible far more cost-effective construction and energy-saving living than conventional building methods.

Fig. 17:
Prefabricated concrete
unit

- Such as sandwich units covered with fibrated concrete slabs, as infill, thermal-insulating facade units.
- Such as large-format wall and roof units with metal coating as systems for industrial constructions and cold stores. Such structural systems are preferred in particular in countries where there is a high demand for cold rooms or cold storage houses, such as South America and Australia. In this application, as in the insulation of refrigerant lines, the good thermal insulation and dimensional stability of Styropor foamed plastics prove effective even at low temperatures.

The lightweight, prefabricated composite units can be transported costeffectively over large distances. They are therefore also used as a structural system in the construction of houses and housing estates, in particular in locations where living quarters have to be created under difficult climatic and constructional conditions. Whether in the cold of the Antarctic or in the heat of dry desert regions: Styropor composite units make economical construction possible and offer pleasant living conditions (Figs. 19 and 20).

Fig. 18:
Detail of Styropor composite unit

Fig. 19:
This region in West Australia suffers from cyclones and summer temperatures of 45 °C (113 °F). All the buildings of this settlement were constructed using the Styropor sandwich technique. The 50 mm to 75 mm thick sheet steelcoated panels were brought 1600 km for this project.

Fig. 20:
Australian research center in the Antarctic. The building consists of 100 mm to 150 mm thick Styropor sandwich units which have to withstand temperatures down to 40 °C (–40 °F) and wind speeds of up to 280 km/h (174 miles/h).

Floor constructions with Styropor

Impact sound insulation

In some countries, structural sound insulation is even today only of secondary importance; nevertheless, in the meantime noise pollution has become so great everywhere, especially in large built-up areas, that adequate sound insulation is becoming ever more important. As well as limiting sound transmission through external compound units, impact sound insulation is of great importance. To achieve effective impact sound insulation, the sound which is made by walking on a floor must be prevented from being transmitted to other compounds units. For instance, a thick carpet may be laid on a concrete floor. However, this is only a temporary solution, as the carpet wears out or may be taken up. Another possibility is to increase the weight of the floor and thus reduce the sound transmission. However, this is only possible to a limited extent for financial and technical reasons. All of these considerations finally led to the development of what is known as the "floating floor system", a flooring structure common in particular in Germany and a number of other European countries (Fig. 21).

A floating floor is a flooring (for example cement screed) which is laid on a flexible insulating layer and can freely oscillate, thus acting as a spring-mass system. This substantially prevents the penetration of structure-borne sound into the floor structure.

Special Styropor foamed plastic boards, which are elasticized by special subsequent treatment, have proven their value for impact sound insulation. Such boards have a low dynamic rigidity (comparable with an air cushion) and are nevertheless sufficiently compression-resistant to bear the load of the floor permanently.

Fig. 21:
Structure of floating floor

Floor heating

Impact sound insulation is often combined with underfloor heating. To avoid downward heat loss, an insulating layer of Styropor rigid foam is laid between the underfloor heating and the impact sound insulation. Boards with moulded-in grooves or elevations on the upper side are used for this to permit easy laying of flexible polyethylene hot water pipes (Fig. 22).

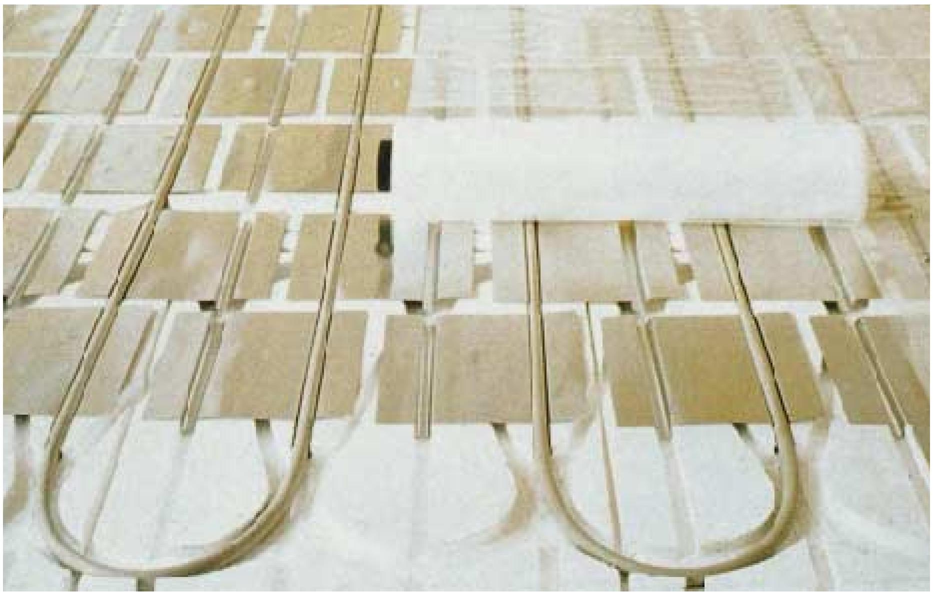


Fig. 22:
Floor heating

Fig. 23:
Laying moulded Styropor elements for the thermal insulation of the normal floor construction in Japan

Styropor as a multifunctional element in construction

As well as applications in the area of thermal and impact sound insulation, Styropor foamed plastics perform a wide variety of other functions in construction.

Drainage boards

Drainage boards of Styropor consist of foamed Styropor beads which are interconnected in such a way that the voids produce a large continuous pore volume. As a vertical filter layer in front of cellar walls or retaining walls, drainage boards prevent seepage water accumulating in the ground until it exerts hydrostatic pressure. They form a path of seepage from the overlying ground to the drain tile at the foundation of the wall (Fig. 24).

Drainage boards of Styropor have also proven particularly suitable for the drainage of roof gardens. The advantages here are the additional thermal insulation and the low weight in comparison with a drainage layer of gravel.

Permanent formwork

To reduce the weight per unit area of large-span concrete floors, in particular in the case of ribbed floors and coffered ceilings, Styropor formwork elements are used. Depending on requirements, such formwork elements are cut from the block or produced as a foam moulded unit (Fig. 25).

Large-format wall and floor formwork with foamed plastic boards are produced by pushing the board sections into a correspondingly designed structure of galvanized steel wires. After assembly of the formwork elements, concrete is cast in the cavity. The thermally insulating Styropor formwork is subsequently plastered or lined, the outer steel mats offering a good anchorage (Fig. 26).

For making concrete facades, Styropor textured formwork is used. To create an artistic design on a concrete wall, the image relief may be cut in the foam, for example with a hot wire, and the foam then used as concrete formwork.

Fig. 24:
Drainage

Fig. 26:
Wall formwork system

Abb. 25:
Floor formwork

Foundation engineering

Especially in northern countries with severe winters and deep ground frosts, Styropor rigid foam has proven very successful as an insulating material for protection against frost damage to foundations and buried pipelines (Fig. 27).

The special properties of the closed-cell foamed plastic, such as stability and durability, the immunity to moisture and ground bacteria and also the good thermal insulation have resulted in rigid foam boards being used as a frost protecting layer in road and railroad construction. The practical experience of this since 1968 – in particular in Scandinavian countries – provided the basis for a new method of construction, which has been developed since 1972 in Norway and in the meantime is also put into use in other countries: the use of Styropor blocks as a loaddistributing substructure for road and bridge approach ramps in areas with poor loading-bearing soil conditions. In such regions, major settlement of the pavement structure have occurred over the years, necessitating expensive renovation work. Solving the problem was possible with Styropor rigid foam blocks which, assuming an apparent density of at least 20 kg/m^3 (1.25 pcf), have the strength properties necessary for this application. The high bending and shear strength of the lightweight block foam made a good pressure distribution possible on the muddy ground. The low weight of such a substructure permanently prevents sinking of the road structure.

The rigid foam blocks are secured against slipping by claw plates and stacked up to a height of 10 m. Then a 10 cm (3.94 in.) thick layer of concrete with steel mesh reinforcement is applied before laying the bituminous pavement.

After positive experience with this construction method in Scandinavian countries, it is also being practiced in many other countries: for example in the Polder regions of the Netherlands (Fig. 28) and in North America.

Fig. 28
Styropor as a load-distributing substructure

Fig. 27:
Foundation formwork

Characteristics of Styropor foamed plastic

Temperature behaviour

There is virtually no lower temperature limit for the application of Styropor rigid foam in the construction industry. Wherever a thermally induced volume contraction requires such a limit (for example in cold store construction), this is to be taken into account in design. If the rigid foam is subjected to elevated temperatures, the maximum permissible temperature depends on the duration of temperature exposure and the mechanical loading of the foam (see Table 1 on Page 17).

In the case of brief exposure (fixing with hot bitumen), Styropor rigid foam may also be subjected to higher temperatures. Under prolonged temperature exposure above 100 °C (212 °F), the foam structure begins to soften and to sinter.

Fire behaviour

Like many other construction materials, Styropor foamed plastics are combustible. When assessing their fire behaviour, it must be taken into account that this depends to a substantial extent not only on material-related effects but also on application conditions. Of considerable importance in particular is the combination with other construction materials and the often necessary or desired arrangement of protective and covering layers.

With regard to the material-related effects, a distinction has to be made between foamed plastics from Styropor P and -F grades. The latter include a flame-retardant additive which distinctly reduces ignitability and flame progagation. They achieve the best possible classification for combustible construction materials specified by various national regulations.

While foamed plastics of Styropor P grades are to be classified as highly flammable, construction material class B3, when tested in accordance with DIN 4102, Part 1 (May 1981) and therefore inadmissible as construction materials, foamed plastics of Styropor F grades meet the requirements specified in this standard for flame resistant construction materials, construction material class B 1. As proof of this, the test mark PA-III 2.1001 has been issued. The test certificate also reveals that these foamed plastics are to be classified as non-dripping when they burn.

Therefore, in most cases the use of foamed plastics of Styropor F grades for constructional applications may be permitted, though in each case the respective national building regulations are to be observed.

As biological investigations have shown, if Styropor rigid foam is involved in a fire, the toxicity of the gasses from burning and carbonization is lower than that of the same amounts of wood.

Biological behaviour

Foamed plastics from Styropor have no nourishing value to animals. They do not rot, are not water soluble and do not give off any water-soluble substances which could contaminate ground water. If relevant local regulations are observed, they may be dumped together with household refuse.

Foamed plastics from Styropor have been in production and use for several decades. No harmful effects on health have been discovered in this time. The health-safety of the application of rigid foam boards of Styropor is also evidenced by the fact that Styropor is used as food packaging.

Enclosed you will find the tables “Properties of Styropor foams for Construction applications”.

Table 1: **Resistance of Styropor rigid foam to chemicals**

Active agents	Styropor® P	Styropor® F	Styropor® FH
Salt solutions (seawater)	+	+	+
Soaps and wetting agent solutions	+	+	+
Bleaching lyes, such as hypochlorite, chlorine water, hydrogen peroxide solutions	+	+	+
Dilute acids	+	+	+
35 % hydrochloric acid, up to 50 % nitric acid	+	+	+
Anhydrous acids, for example fuming sulfuric acid, glacial acetic acid, 100 % formic acid	–	–	–
Sodium hydroxide, potassium hydroxide, ammonia solution	+	+	+
Organic solvents, such as acetone, ethyl acetate, benzene, xylene, paint thinner	–	–	–
Saturated aliphatic hydrocarbons, surgical spirit, test benzene	– (+ –)	– (+ –)	– (+ –)
Paraffin oil, vaseline	+ – (+)	+ – (+)	+ – (+)
Diesel oil	– (+)	– (+)	– (+)
Motor fuel (normal and super gasoline)	–	–	–
Alcohols, for example methanol, ethanol	+ –	+ –	+ –
Silicone oil	+	+	+

+	Resistant: the foam plastic is not destroyed even after prolonged exposure.	
+ –	Conditionally resistant: the foamed plastic may shrink or suffer attack to the surface after prolonged exposure.	
–	Unresistant: the foamed plastic shrinks at a greater or lesser rate or is dissolved.	

Table: **Physical data for foams made from Styropor® for construction**

Properties 1)	**Test standard**	**Unit**	**Test result**		
Quality assured types	GSH quality conditions		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18164, Part 1		W	WD	WS + WD
Minimum bulk density	EN ISO 845	kg/m^3	15	20	30
Building material class	DIN 4102		B1, Poorly flammable	B1, Poorly flammable	B1, Poorly flammable
Thermal conductivity					
Measured value at +10 °C	DIN 52612	mW/(m · K)	36 – 38	33 – 35	31 – 34
Calculated value according to	DIN 4108	mW/(m · K)	40	40	35
Compressive stress at 10 % compressive strain	EN 826	kPa	65 – 100	110 – 140	200 – 250
Resistance to sustained compressive loads at < 2 % strain after 50 years	ISO 785	kPa	20 – 30	35 – 50	70 – 90
Flexural strength	EN 12089	kPa	150 – 230	250 – 310	430 – 490
Shear strength	DIN 53427	kPa	80 – 130	120 – 170	210 – 260
Tensile strength	DIN 53430	kPa	160 – 260	230 – 330	380 – 480
Modulus of elasticity (compressive test)	EN 826	MPa	1.0 – 4.0	3.5 – 4.5	7.5 – 11.0
Heat deformation temperature					
short-term	based on DIN 53424	°C	100	100	100
long-term at 50 kPa		°C	75	80	80
long-term at 20 kPa		°C	75	80	80
Coefficient of linear expansion		1/K	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$
Specific heat capacity	DIN 53765	J/(kg · K)	1210	1210	1210
Water absorption when submerged (by volume)					
after 7 days	DIN 53 434	Vol. %	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapor diffusion rate	DIN 52 615				
Water vapor diffusion resistance factor	Calculated according to DIN 4108, Part 4	1	20/50	30/70	40/100

1) corresponding to Test Norm

$1\ N/mm^2 = 1000\ KN/m^2 = 1\ MPa = 1000\ kPa$

Further information

This brochure could only give a broad outline of the many fields of application of Styropor foamed plastics. Details on application techniques, structural engineering and construction physics are contained in the “Technical Information” publications by BASF.

Photo credits

Figure 11:
Rhodius – Chemie-Systeme GmbH,
5475 Burgbrohl, Germany

Figures 19 and 20:
BONDOR PTY LTD, Australia

Figure 22:
Felix Schuh & Co. GmbH, 4300 Essen, Germany

Figure 27:
ISORA OY, Finland

Figure 28:
ISO Bouw, The Netherlands

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Better together –

Together better

BASF Foam-Technology

http://www.basf.de

Note:
You will find more information on Styropor in the Technical Information leaflets available on CD-ROM.
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BASF

Styropor®

Expandable polystyrene (EPS)

Packaging with Styropor

Styrenic Polymers

BASF


TV
TV

Packaging with Styropor

Fig. 1:
Packaging line for
television sets

This is Styropor®

Styropor has made a name for itself – as a packaging material too. In combination with economical moulding processes, the special advantages offered by Styropor are used all over the world to protect packaged goods.

The versatility of Styropor was recognised early on. For engineers, packaging experts and designers, its possible applications are by no means exhausted. There are still many opportunities to be gained by using this high performance, low-cost foam. This brochure will tell you all about packaging with Styropor, while at the same time stimulating new ideas and further development possibilities.

Styropor is the expandable polystyrene made by BASF. The material is made in the form of beadlike granules 0.2 – 3.0 mm (0.007 – 0.12 in.) in diameter and supplied in this form to foam manufacturers.

Development

The first styrene synthesis was carried out by BASF in Ludwigshafen in 1929. Only a year later, in 1930, polystyrene was already being produced on an industrial scale, but it took another 20 years before it proved possible to make polystyrene foam. On the 14th August 1952 the German Patent Office published “Method of making porous masses from polymers” – and this marked the beginning of Styropor.

Styrene, which forms the molecular building block for Styropor, and pentane, which is used as blowing agent in the production of Styropor foam, are both obtained from petroleum and are therefore pure hydrocarbon compounds from which expandable polystyrene is obtained through suspension polymerisation.

The Styropor range

The various grades currently available are summarised below. Detailed descriptions of commercial and experimental products can be found in our technical data sheets.

Styropor® P
Used for making blocks, boards and moulded parts.

Styropor® F
A flame retardant material recommended for making flame resistant blocks and boards in accordance with DIN 4102, as well as moulded parts complying with the requirements of Group F1 according to DIN 53 438, part 3.

Styropor® FH
Recommended for flame resistant foams (DIN 4102) which are resistant to aliphatic hydrocarbons.

® = registered trademark of BASF Aktiengesellschaft

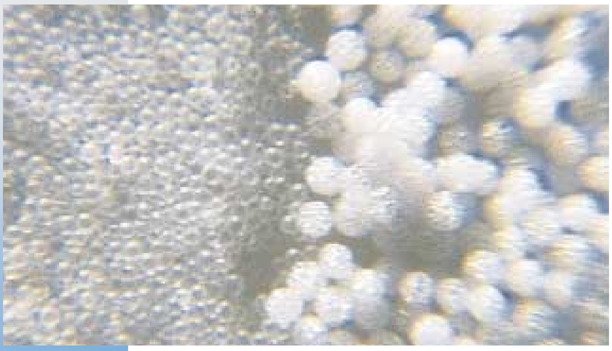


Fig. 2:
Increase in volume when Styropor is preexpanded

Fig. 3:
Size comparison between the raw material and preexpanded Styropor

From Styropor to the finished foam

Styropor is converted into blocks and moulded parts in three stages:

- preexpansion,
- intermediate aging and
- moulding.

Preexpansion

The raw material is heated to about 80 °C to 110 °C (176 °F to 230 °F) in special foaming units, using steam. During this process the apparent density of the material drops from about 630 kg / m^3 (39 pcf) to about 10 kg / m^3 (0.625 pcf), depending on the temperature and residence time. To make packages and other kinds of mouldings, Styropor is normally preexpanded to 18 – 30 kg / m^3 (1.12 – 1.87 pcf).

Prefoaming converts the compact Styropor beads into foam beads with small, closed cells.

Intermediate aging

As the freshly foamed particles cool down, blowing agent and steam tend to condense inside the cells, producing a vacuum which has to be equalised by air diffusing into the cells. This imparts greater mechanical stability to the beads, as well as extra foaming power, which is advantageous for further processing. This process takes place during intermediate aging in ventilated silos. At the same time, it gives the beads an opportunity to dry.

Moulding

The cavity of the foaming mould, which is usually in two parts, is now filled pneumatically with the prefoamed material. The mould walls are equipped with holes or slits to connect the mould cavity with the steam chamber. Foam moulding is accomplished by the use of steam to supply the necessary energy.

A surge of steam causes the beads to soften again and to expand. The expansion pressure compresses the beads and, at the same time, forces them against the mould walls so that they fuse together.

The resultant part is then cooled by spraying water onto the mould and by applying a vacuum. When it has cooled down sufficiently, the moulded part can be taken from the mould.

This technique can be used to make large blocks, boards and mouldings of almost any shape or size.

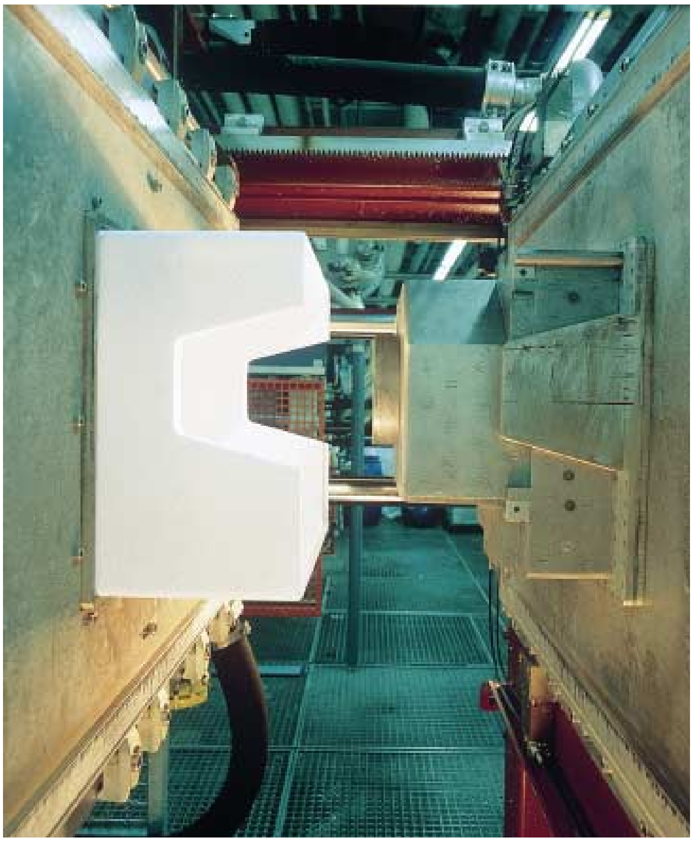


Fig. 4:
Continuous
prefoaming unit

Fig. 5:
Aging of prefoamed
beads

Processing

Styropor foams can be machined using the methods normally used for woodwork, e. g. sawing, milling and cutting. It is also possible to cut sheets and simple shapes from blocks, using heated and/or vibrating wires. This is a particularly economic way of working, and is used to make insulating panels and packages required in only small quantities. Models for a wide range of applications can be made in the same way, e. g. prototype packs, displays and teaching aids, art objects, decorations etc. (see Technical Information 310 “Modelling with expanded material”).

Model making

Models for many different types of packages and packaging applications can be made quickly and cheaply from Styropor foam. Since the material is so easy to fabricate, models and patterns can be altered bit by bit until a pack that is ready for testing is obtained.

Elastification

The elasticity of Styropor foams can be increased as follows:

- by pressing it inside the mould or increasing its volume during the foaming process
- by pressing or rolling the finished sheets

Fig. 6:
Cutting foam with a heated wire

Printing

Styropor foams can be printed by any of the established methods. Moulded parts with a raised design can easily be printed with inked rollers.

There is one golden rule which must always be observed, whatever the printing technique used: printing inks must never contain solvents which might attack the foam. The consistency and drying properties of printing inks will depend on what method of printing is used.

Painting

Mouldings made from Styropor can be painted without any problem. Painting can enhance mechanical strength and improve weathering resistance. It can also increase the material's water vapour diffusion resistance and indentation resistance. Paints can obviously also be used to achieve special decorative, coloured and gloss effects.

Here, too, it is important that paints used for application by dipping, rolling and spraying must under no circumstances attack the material. For this reason, only paints specifically formulated for use on polystyrene materials should be used.

Coating

Flexible as well as hard coatings for foams can be formulated with polyurethanes, depending on the particular formulation. These can be applied in one or several operations, depending on the required thickness .

Solvent-free epoxy resins can be applied directly to the foam, but polyester resins require previous application of a solvent-proof barrier coat. Glass fibre mats can be incorporated in the coating material to make it impact resistant.

Electrostatic flocking of the moulded parts opens up interesting design possibilities. Parts can also be covered with films, wood veneers etc.

Transfers, cold and hot bonding labels can likewise be applied to foam, using hand operated, semior fully automatic machines. The kind of adhesive used will be determined by the chemical nature of the foam

A coating technique specially recommended for large-scale production is the covering with films (Fig. 29), sheets or mouldings made from solid plastics, as well as with paper and cardboard. These can all be laminated immediately after the completion of foam moulding, in a downstream unit or, after the moulded part has been allowed to age for a while, in a special coating unit.

Characterisation

Packages made of Styropor are characterised in accordance with DIN 55 471, Part 1.

A typical designation looks something like this:

Foam DIN 55 471
– EPS 20 B – F.

This means:

DIN 55 471 – EPS =
type of material: EPS foam (expandable polystyrene), foam moulded.

20 =
density = 20 kg / m^3 (1.25 pcf) Tolerance: + 2.5 kg / m^3 (+ 0.16 pcf)

B =
degree of drying:
residual moisture content < 0.1 % by volume.

F =
fire behaviour (free of silicones):
requirements of Group F 1 according to DIN 53 438, Part 3 are fulfilled.

N.B.:
In view of the recyclability of Styropor packagings under the “single-grade, clean an dry” slogan, it is advisable to make sparing use of printing ink and coatings.

Enclosed you will find the tables “Properties of Styropor foams for packaging purposes”.

Physical properties

The physical properties of the material are influenced by its apparent density and how it has been processed .

Compressive stress according to DIN 53 421
The compressive strength of materials which experience elastic or plastic deformation when a force is applied, is essentially governed by the degree of compression. In the case of rigid foams, therefore, it is usual to indicate the compressive stress at 10 % compression, σ_{d10} (see Table 1) in order to obtain comparable figures.

The compressive stress of Styropor foams increases with increasing density (Fig. 7).

For test pieces with an outer skin the values of compressive stress will be slightly lower than for cut specimens having the same density. This is due to the fact that the density is unevenly distributed across the test piece thickness: near the edges it is higher than at the centre. The applicational advantage of a smooth, slightly compacted outer skin is therefore not made apparent when testing according to DIN 53 421.

Tensile strength according to DIN 53 430
The tensile strength of Styropor foams increases with increasing densitiy, as shown in Fig. 8. Elongation at break, determined in tensile tests, is among the properties that are also dependent on processing conditions, e. g. on fusion quality.

Flexural strength according to DIN 53 423
The flexural strength, too, increases with increasing apparent density, as shown in Fig. 9. The material's deflection at break (toughness) decreases with increasing density and degree of fusion.

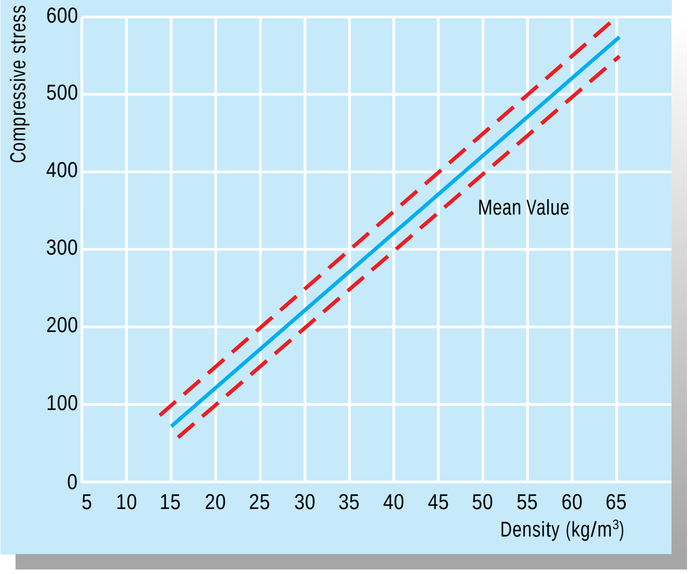


Fig. 7:
Effect of density on compressive stress at 10 % compression (DIN 53 421) (scatter range indicated)

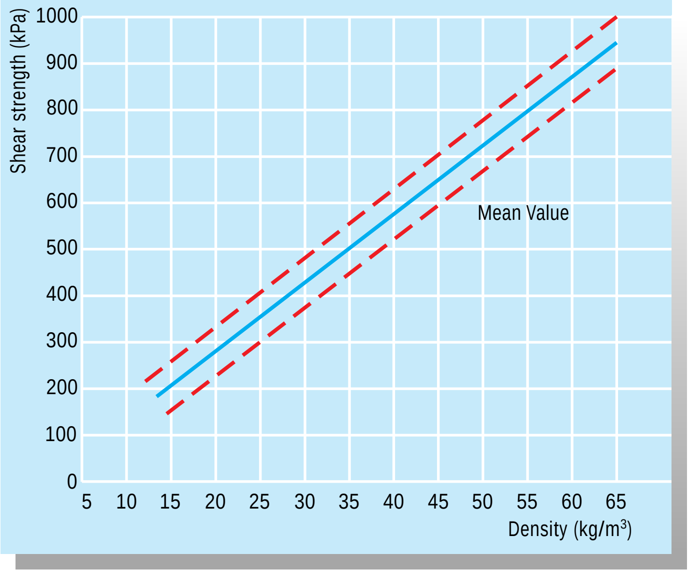


Fig. 8:
Effect of density on tensile strength (DIN 53 430)

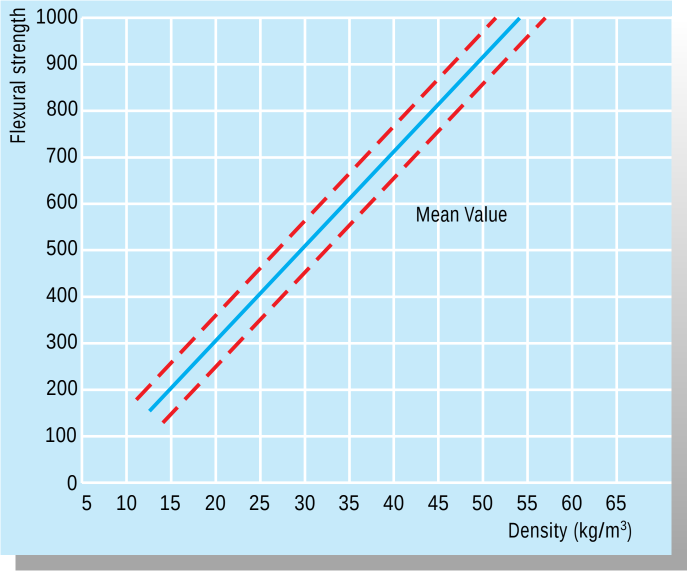


Fig. 9:
Effect of density on flexural strength (DIN 53 423)

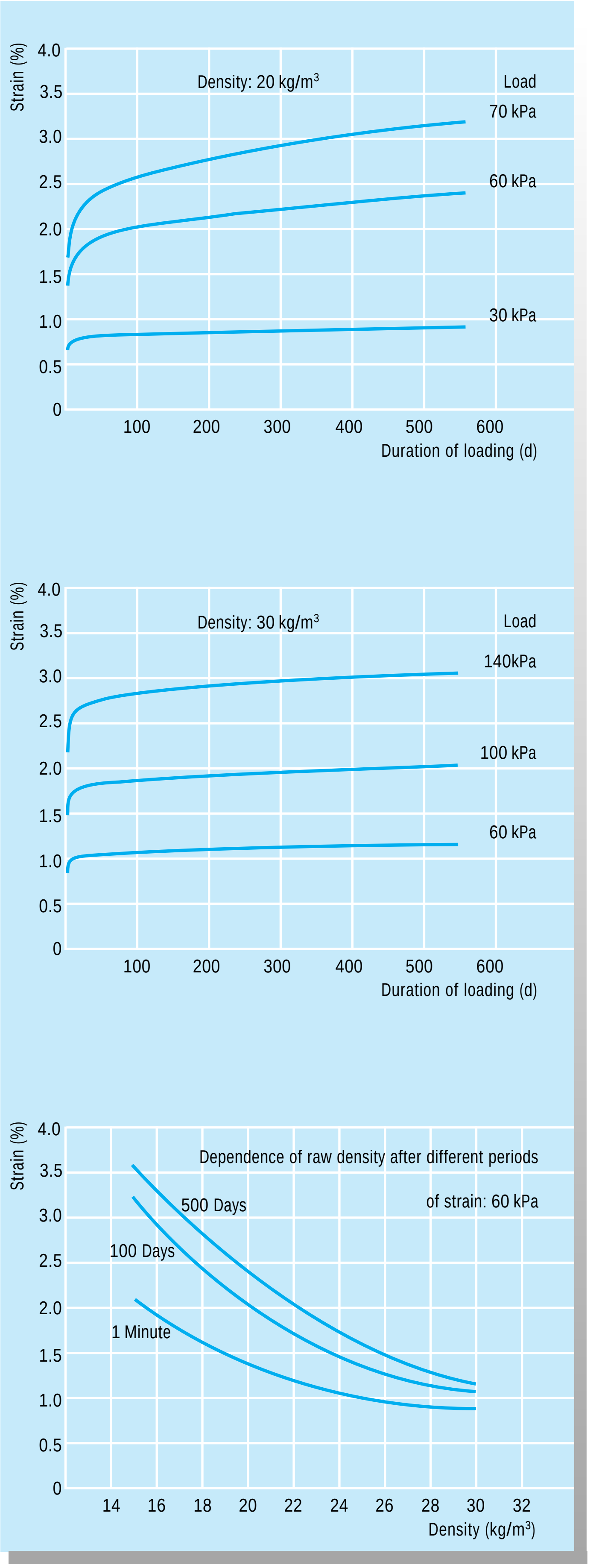


Fig. 10:
Relationship to density after various durations of loading

Long-term behavior under load

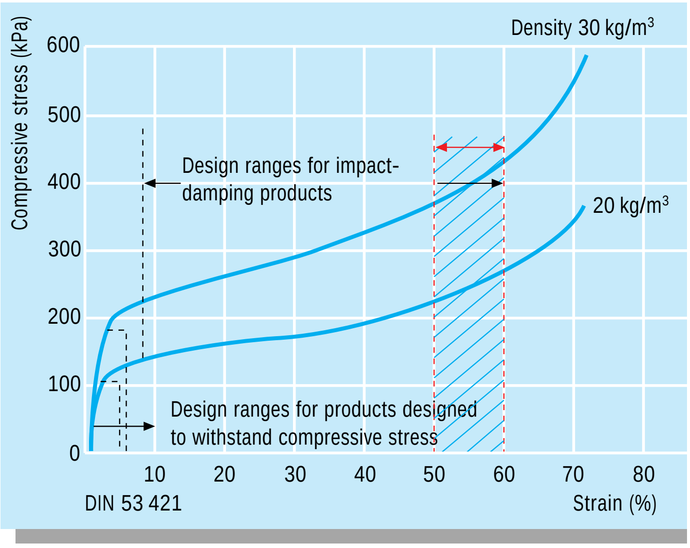
The material's deformation depends not only on size but also on the time for which pressure has been applied, Fig. 10.

Compressive stress is also affected by the age of a test piece. Freshly prepared foams will have only about 70 % of the final figure and just over 90 % after 24 hours. This final figure is, however, reached only after approximately 4 weeks.

The relatively big increase in strength during the first 24 hours is due mainly to the equalisation of the air pressure inside the foam cells, whilst the subsequent increase is caused by the gradual release of the rest of the blowing agent.

Fig. 10 and 11 shows compressive stress/deformation diagrams for the density range of 20 – 30 kg / m³ (1.25 – 1.87 pcf).

Fig. 11:
Compressive stress-strain relationship for expanded Styropor.



Thermal properties

The mechanical properties of the material depend on temperature. Fig.15 shows how the compressive stress at 10% compression changes in the temperature range of – 20 °C to + 60 °C (4 to 140 °F).

Styropor foams are noted for their particularly low thermal conductivity. This is dependent on the density and on the temperature of the foam (Table 3, p.30), as well as on its moisture content.

The specific heat capacity of Styropor foams is not influenced by their density. The material's heat distortion temperature increases with increasing density and decreasing applied load. The freshly made foam attains its final heat distortion properties only after aging. Foams not under stress will withstand temperatures of up to about 100 °C for short periods, independent of their density.

The coefficient of thermal expansion is unaffected by density and is around $5 – 7 \cdot 10^{-5}\,K^{-1}$.

The mechanical properties of Styropor foams are uneffected by their moisture content or by atmospheric humidity.

Water absorption and water vapour permeability

Styropor foams are not hygroscopic but will absorb moisture if brought into direct contact with water.

If there are different water vapour concentrations on two sides of a piece of foam, water vapour will tend to diffuse through the foam. This phenomenon is particularly evident if there is a temperature gradient. To characterise water vapour diffusion one makes use of the diffusion resistance factor µ, compared with a stationary layer of air having the same thickness (µ = 1). This factor depends on the foam's density.

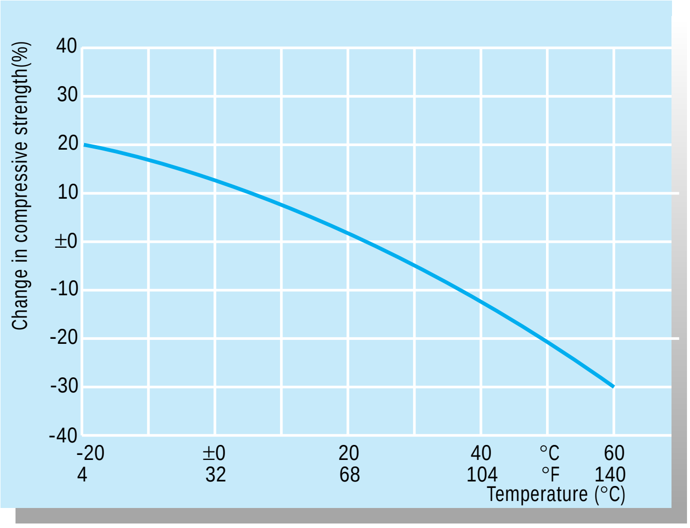


Fig. 12:
Effect of temperature on the compressive strength

Electrical properties

Styropor foam does not conduct electricity. The dielectric constant ε for foams with densities of between 20 and 40 kg / m³ (1.25 and 2.50 pcf) is 1.02 – 1.04 between 100 Hz and 400 MHz. The dissipation factor tan δ up to 1 MHz is less than 0.0005 and up to 400 MHz 0.00003. The specific dielectric strength reaches values of 2 kV / mm. The resistivity at 23 °C (73 °F) and 50 % relative humidity is about 1014 Ω (DIN 53 482).

Because of the high resistivity, the surface of foam mouldings can become electrostatically charged, especially if the relative humidity is low. The surface resistance of moulded parts can be reduced by treating them with antistatic agents.

Chemical resistance

(see Table 1, page 11)

Styropor P, F and FH behave exactly like polystyrene in the presence of chemical agents. Chemicals which attack polystyrene will destroy Styropor foam more quickly than the solid material, because of the thin-walled cells of which it is made. This means that low density foams will be attacked more intensely. Styropor is unaffected by water, most acids and alkali solutions.

Essential oils contained in the peel and juice of citrus fruit will attack Styropor, but the material is resistant to animal and vegetable fats as well as to anti-corrosive agents containing paraffins, as long as they do not contain aggressive solvents.

The material's sensitivity towards organic solvents should, above all, be noted in painting and adhesive bonding. The same applies to contact with plastics containing plasticisers, e. g. plasticiser migration in the case of PVC.

If Styropor has to be brought into contact with substances of unknown composition, the reaction of the material should first be checked. The best way of doing this is to age a piece of Styropor in close contact with the other material and observe what happens. The duration of the experiment can be reduced by raising the aging temperature.

Effect of UV light

Styropor foams, like other plastics materials, are affected by UV light if they are exposed to it for prolonged periods. As far as packaging is concerned however, this is of very minor importance, bearing in mind the transient nature of packaging.

Biological effect

Pentane escapes from Styropor during storage and fabrication. When the foam has to be cut with hot wires the fumes produced should be drawn off by an efficient ventilating system, since they will contain not only pentane but also small amounts of styrene monomer.

The MAC (maximum allowable concentration) for styrene (20 ppm) and for pentane (1000 ppm) should be observed .

Styropor foams do not rot, are insoluble in water and do not give off any water soluble substances which could pollute the ground water. Foam waste can be tipped on landfill sites along with ordinary household rubbish under observance of local byelaws.

Styropor foam has now been in production for several decades, during which no risk to health has been found .

Table 1: **Chemical resistance of Styropor foams**

Chemical or Solvent	Styropor P and F
Salt solution (seawater)	+
Soaps and wetting agent solutions	+
Bleaching agent solutions, e. eg. sodium hypochlorite, chlorine water and hydrogen peroxide	+
Dilute acids	+
Hydrochloric acid, 35%, nitric acid up to 50%	+
Anhydrous acids,e.g. fuming sulphuric acid, 100% formic acid	–
Caustic soda and caustic potash solutions, ammonia water	+
Organic solvents, such as acetone, ethyl acetate, benzene, xylene, paint thinners and trichloroethylene	–
Satured aliphatic hydrocarbons, surgical spirit, white spirit	–
Paraffin oil, vaseline	+ –
Diesel fuel	–
Engine fuels (normal- and super grade petrol)	–
Alcohols, e.g. methanol, ethanol	+ –
Silicone fluids	+

+ resistant: the foam is not attacked even after a long time
+ – limited resistance: the foam may shrink after prolonged exposure to the chemical, or its surface may be attacked
– not resistant: the foam shrivels up more or less quickly or is dissolved

Fire behaviour

Like many other packaging materials, Styropor foam is flammable. Its fire behaviour depends not only on the actual material but also on the conditions under which it is used. Here it is necessary to distinguish between Styropor P and F. The material’s fire behaviour is largely dependent upon other materials with which it is used and the protective coatings that are often necessary.

Styropor F materials are classified as “flameproofed”. This means that the foam’s flammability and flame spread along the surface have been much reduced. Styropor F foams therefore achieve the best possible classification for flammable substances according to various national specifications for building and other materials.

The fire behaviour of foam packages made from Styropor P follows much the same pattern as that of other flammable packaging materials. Styropor F foams are being used more and more to increase fire safety. This, incidentally, is taken into account by insurance companies in drawing up fire insurance agreements (see Technical Information 131, “Expanded Styropor F packaging").

Food regulations

The German Federal Public Health Office publishes the “Bundesgesundheitsblatt” (Federal Health Bulletin) which contains recommendations for the toxicological assessment of high polymers, their auxiliaries and additives and methods of testing. These recommendations specify, according to the current state of knowledge, under which conditions a consumer article made from high polymer materials will meet the requirements laid down in the 1974 regulations covering foodstuffs and consumer goods.

The composition of Styropor complies with the requirements of the recommendations for polystyrene, styrene copolymers and graft copolymers, issued by the German Federal Public Health Office.

Provided the material is processed correctly, there is no objection to its use in the production of consumer goods intended for food contact applications and for toys. The suitability of consumer articles for any given purpose must be checked by the manufacturer as well as the user.

The important proviso is this: packaging materials used for foodstuffs must in no way affect their taste or aroma. It is up to the firm doing the packaging to check that this requirement is met.

Practical experience has shown that there is no problem in this respect, if the Styropor packaging materials have been stored for some time. The exception is specially aroma-sensitive and fatbased products such as chocolate, margarine or cream cakes. Here it is best to use some sort of wrapping material like parchment paper, plastics film or aluminium foil.

The coloured grades Styrocolor G can also be used for packaging purposes, but it is necessary to check that the dyes will not migrate when in contact with food. A warning to this effect should be given by the packaging manufacturer.

Fig. 13:
Styropor foam boxes for transporting foods

Packaging Requirements

The purpose of packages is to protect their contents on their way from the manufacturer to the consumer. Packaging ranges from simple inserts to complex display packs, made in all shapes and sizes. They have an enormously wide range of uses in a large numer of industries and for many different types of products. Their main functions can be summarised as follows:

- protection during transport and storage
- production of standard and transportable units
- sales promotion with informative and publicity function.

Compared with traditional packaging materials such as wood, cardboard, paper, metal and glass, and the equally traditional crates, boxes, bags, wrappers, cans, tubes and bottles, plastics have proved to be the ideal packaging materials in many different fields. Plastics can cope with practically any kind of packaging problem. They are economical to use and show better adaptibility than many of the classic packaging materials.

Because of its excellent physical and chemical properties, Styropor foam offers the following advantages when used as a packaging material:

- low density, therefore lightweight packages
- high energy absorption when dropped or subjected to impact. Cushioning for protecting delicate items during transport and storage can therefore be relatively thin
- abrasion resistant yet relatively soft surfaces protect packaged goods against dirt and damage
- low thermal conductivity protects contents against sudden temperature changes
- since the foam is unaffected by water and water vapour, its mechanical properties remain intact
- chemically inert, so that it can be used for food packaging
- easy to mould into lmost any shape which helps the packaging designer.

Fig. 14:
Packaging inserts for sensitive goods

Ease of moulding

Foam components can be made in almost any shape for a wide range of packaging applications, using the simplest and most economic means. Here are some examples:

- protection against outside influences (outer containers and coverings)
- anti-impact cushioning to prevent high acceleration during impact, when dropped or shaken
- impact and stress distributors which evenly distribute mechanical forces across the whole load-bearing surface
- inserts and supports which prevent movement of the goods inside the pack (made of pieces of foam, moulded parts).

Rigidity, light weight, smooth, soft surfaces, good chemical compatibility with packaged contents – these are the properties which have made Styropor foam such a successful material in this field. The main condition is always that the package has been correctly designed and constructed for the intended application. It is particularly here that Styropor users have the advantage because of the ease with which the material can be shaped and moulded .

Many types of packaging

The main uses of Styropor packages are described below.

- Packaging inserts
  These are moulded parts or inserts used as shock absorbers, to distribute loads, to support the contents or to keep them separate. There are also sorting and assembly inserts and pallets for use in storage and inhouse transport containers.

- Box-type packs
  With customised inside space: individual portion packs, collective packs and packs which protect the contents against heat.

- Composite mouldings
  Where a particular packaging problem cannot be solved by using foam on its own, one can combine it with another material to form a composite, because Styropor foam can supplement or enhance the properties of traditional materials such as paper, cardboard, corrugated cardboard, wood and plastic. Such composite packs, made from Styropor foam and other materials have, for example, been successfully used for packaging heavy items, for gift and display packs.

- Crates and trays for foodstuffs
  These are used for fish, fruit and vegetables.

- Transport and display pallets

Fig. 15:
Trays for transporting fruit – compression resistant and re-usable

Fig. 16:
Thermal insulating packs for fresh fish

Packages and closures

Proven and simple – selfadhesive tapes which are easy to apply and stick down immediately.

If this is not enough, foam packages can, of course, be wrapped in film and then welded, bonded or shrunk. Shrink wrapping is used particularly for palletised goods, e. g. tubes, jars, bottles and similar products (Fig. 18).

Another type of closure takes the form of hinged foam parts. Here, the parts to be joined are made in one piece and, after foaming, the hinge is formed by strong compression along a line, as shown in Fig. 19. This compressed part becomes elastic and functions as a hinge for a limited period.

Fig. 17 (above):
Multiple-component packs protect the contents and are attractive in appearance

Fig. 18:
Shrink-wrapped pallet pack

Fig. 19:
Package with integrated hinges

Foam packages can also be equipped with interlocking closures. This is achieved by producing clawlike undercuts, which are difficult to tear apart (Fig. 20).

Packs can also be combined with carrying handles, e. g. with plastics straps which go around the pack, straps with jointed studs or with wooden carrying handles which can be slid into the pack (Fig. 23).

Fig. 20:
Packaging for hydrants
with interlocking
mechanism

Fig. 21:
Packaging fire hydrants.
Second use:
installation in the
ground as protection
against frost

Packaging and sales promotion

Styropor foam is also used for publicity and sales promotion packaging, since it can be moulded into almost any shape. Decorative effects are easily achieved by printing, coating and electrostatic flock spraying.

Small numbers of individual products do not necessarily mean high packaging costs. It is possible, for example, to design one uniform pack for differently shaped items. The number of items increases and packaging costs drop – and, nevertheless, one still gets a made-tomeasure pack. The only condition is that the inside is designed in such a way that all the products of a particular range can be accomodated.

Styropor sales packs can also be made so that they can be divided into smaller units which may be required by the retail trade. This is achieved by incorporating artificially weak lines, along which the pack can easily be broken off.

In many cases it is possible to solve a particular problem very economically also in combination with other materials. A typical example is foam used to protect the edges of packages, incorporating integral or subsequently bonded strips of wood, chipboard, or hardboard. Combinations with paper or cardboard also offer interesting alternatives in many instances.

Fig. 22:
Combination pack

Fig. 23:
Carrying handle to ensure safe transport

Fig. 24:
Multiple-component packs protect the contents and are attractive in appearance

Protection against impact and stacking

Much care is necessary in designing and constructing foamed packaging units if these have to be stacked or are intended for delicate articles sensitive to impact. As the deformation diagram (Fig. 11, page 9) shows, the mechanical properties of Styropor foams enable these to be used for load-bearing applications as well as for cushioning materials. Here, the desired function is governed by the level of the applied load.

The deformation curves in Fig. 11 show that Styropor foams show very little deformation at compressive stresses up to about 0.1 N/mm^2 (14 psi.) (about 1 kg / cm^2). This stress range is exploited for compression resistant packages.

If the foam is subjected to bigger loads, it will become deformed and act like a cushion. Optimum use of these deformation characteristics can be made at deformations of 50-60 %.

The following sections deal not only with the more general aspects of moulded Styropor packs but also with the dimensioning and construction of compression resistant and shock absorbent packages. Finally the calculation of thermal insulation of Styropor foam packs is explained and illustrated with various examples.

Checklist for Packaging Design

First of all we must define all the conditions to which a packaging container is exposed and the demands made on the package. These include, for example:

- inside dimensions and contours
  (… how must the item inside be supported - does it have to be enclosed around?)

- stackability of the packs
  (… how high will the stacks be, and how great the stacking pressure what additional stacking aids have to be taken into account?)

- protection against impact
  (… how delicate is the item being packaged – what maximum drop heights can be expected during transport?)

- protection against heat and cold
  (… what temperatures will the goods withstand – how high are the am bient tem peratu res and how long will the package be in transit?)

- strength of the pack
  (… what are the expected storage and transport conditions – and is transport by sea or on land?)

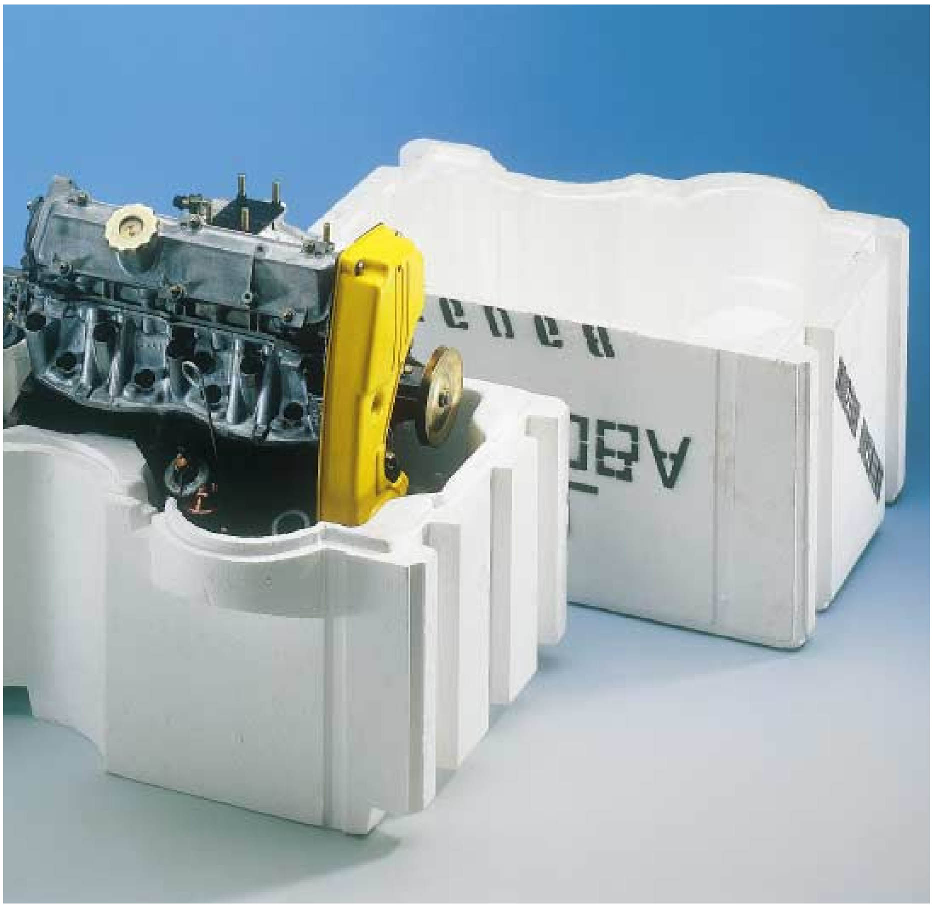
- special conditions
  (… are the packaged goods delicate or perishable?)

Fig. 25:
Shrink-wrapped foam pack

- also to be considered is the streamlining of packaging and transport: putting the items into the pack must be made easy;external package dimensions i must be in line with methods of stacking and transport; loaded pallets should fit comfortably into the transit containers; if there are several parts these should be clearly arranged; one should be able to close packs quickly; stor age and transport units should be streamlined; packs should be attractively designed and produced to promote sales; all requirements on the part of trade and consumers should be taken into consideration.

Other factors of major importance for the packaging manufacturer are batch size, density, dimensions and permissible tolerances.

The design of a package is therefore determined by external influences, the type of goods being packaged as well as economic considerations.



Structural reinforcements

The strength of Styropor mouldings can be increased not only by using a higher density material but also by means of certain structural measures.

One can, for example, make the walls thicker. Reinforcing ribs, protrusions and similar elements can also be incorporated. Reinforcing ribs, unlike the ribs used for cushioning purposes, are made semi-circular so as to minimise the risk of mechanical damage. Finally, moulds which might cause notches should be avoided.

Two examples which illustrate these different factors are the pack for medicines and for an engine block.

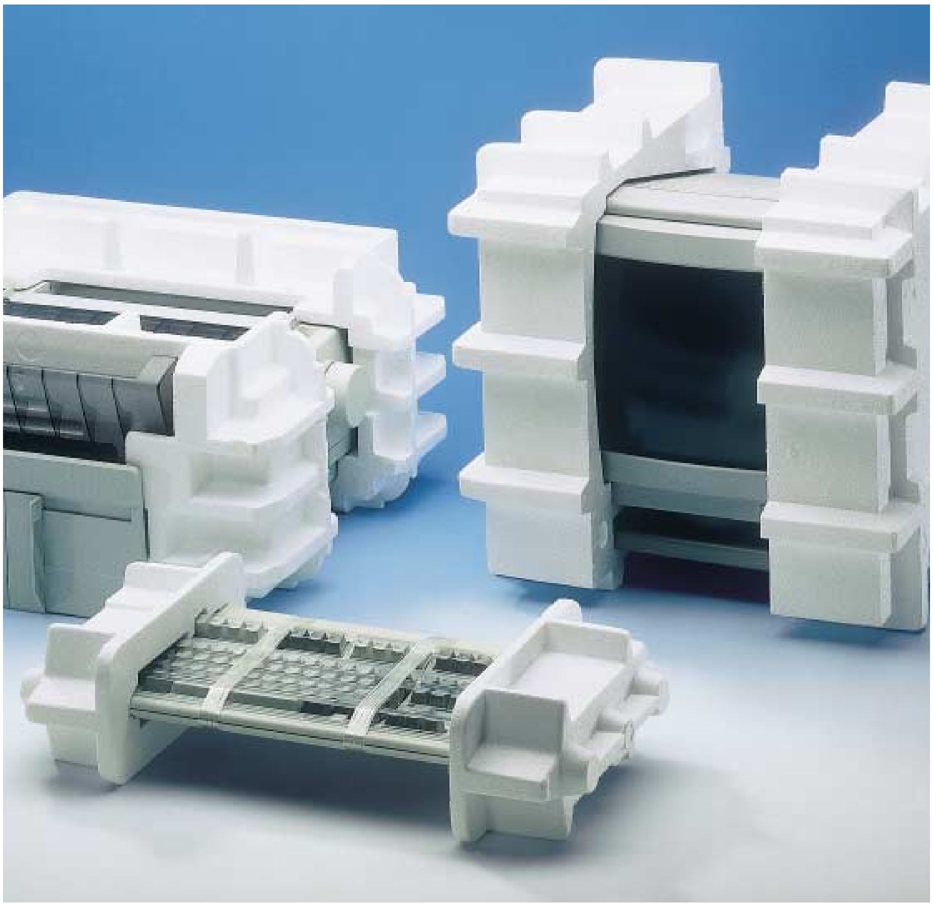


Fig. 26:
All-round pack for car engines

Fig. 27:
Packs with side cushions to protect the contents against impact

Shock Absoption

One of the most important functions of a package is to protect an article against damage when it is dropped or subjected to impact. This is achieved by the deformation of the cushioning elements, which reduces the forces acting on the unit. The various influencing factors and our design recommendations are described in the following pages.

In order to raise a body with a weight of m to a certain height h the energy required is given by $E = (m \cdot g)\,h$. When the body drops down from height h, this energy is released again. The magnitude of the force acting on the body will depend on the braking distance and the time needed to bring the body to a halt.

Fig. 28 shows that the maximum force acting on an ideally cushioned body, i.e. in the theoretically most favourable case, is given by the expression

$h / d \cdot (m \cdot g)$.
The variation factor h / d relative to the force acting on the body at rest is referred to as the impact factor G, or the G value

In an ideal spring (force ~ total thickness) the G value is already twice as great as in an ideal cushion of the same thickness. This is because of the unfavourable force profile. If the cushion deformation is 50%, only 25 % of the drop energy is transformed. Much greater forces are therefore required to transform the remaining 75 % of energy. The requirements for a good cushioning material can be derived from the adjoining diagrams. These are summarised below:

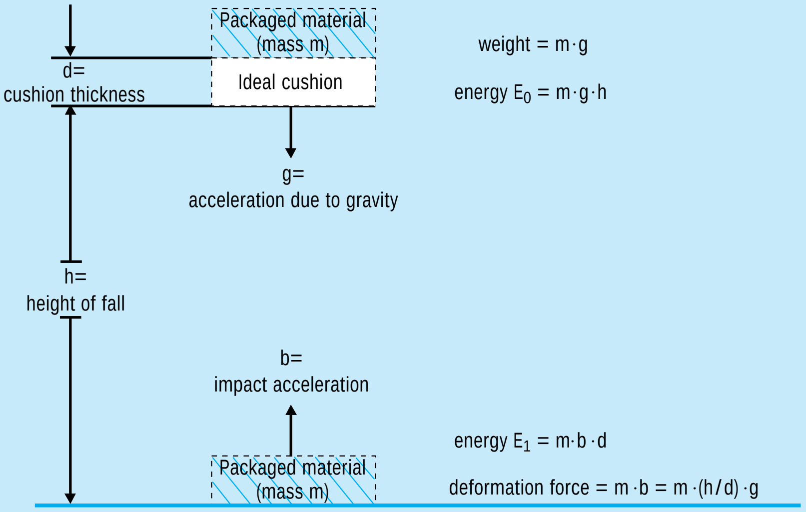
- increase of the deformation resistance to a specified value for a short deformation distance
- as constant a deformation resistance as possible over a maximum deformation distance.

Fig. 27:
Multi-unit pack for
television picture tubes

Styropor foams satisfy these conditions particularly well compared with other cushioning materials. As the compressive stress-deformation diagram (Fig. 11) shows, deformation resistance of Styropor foam builds up very quickly and changes relatively little up to about 60 % deformation. In correctly dimensioned packs this leads to exceptionally low G values.

In contrast to this, values for deformation resistance vary very widely between the start of deformation and about 60% deformation in the case of soft foam materials according to the characteristic in Fig. 28 (bottom). The minimum G values for cushioning elements having the same thickness are therefore higher (i.e. not as good) as those of Styropor foam.

Illustration of characteristic parameters with reference to the example of an ideal cushion



(1) An ideal cushion deforms completely under the stress of a fall (d = 0); the impact acceleration during deformation of the cushion is constant in this case until the position of rest is reached.

(2) $E_0 = E_1 = m \cdot g \cdot h = m \cdot b \cdot d$; from this it follows that $b/g = h/d$
b/g = impact acceleration (impact factor or G value) as a multiple of the acceleration due to gravity.

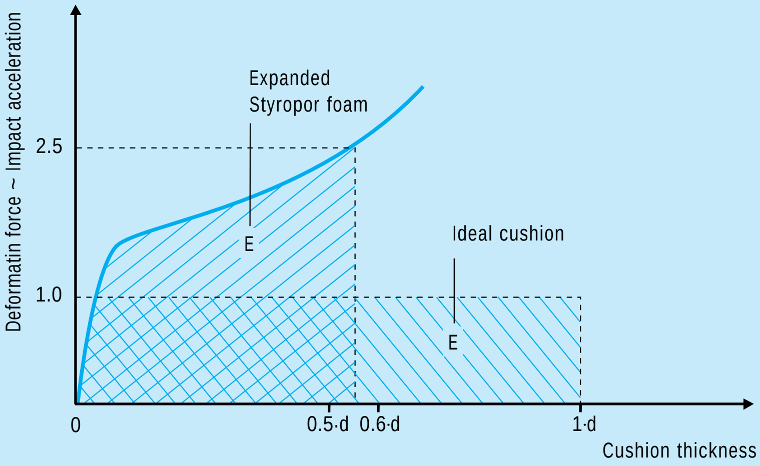


Fig. 28:
Ideales und reales Polstermodell.

Design of cushioning elements

The damping capacity of a cushioning material is influenced not only by its special characteristics but also by the loads to which it is subjected. This behaviour is illustrated in Fig. 31, using as an example a person diving into water from a spring board:

- In the case of a “belly flop” the depth of immersion, i.e. the braking distance, is at a minimum. The diver notices that a relatively great force is acting on his body.

- In the case of a headlong dive, the force acting on the body will initially be at a minimum. Water here acts as a cushioning material and brakes the bodybut only slowly. At the end of the cushioning material there is abrupt damping with a great deal of force acting on the person’s head, which is the impact surface.

- The most favourable behaviour occurs at a very specific diving angle. Here, the body uses the available cushioning distance to achieve even braking. The resultant braking forces and G values are at their lowest in this case.

If there are any changes in the original conditions, e. g. if the height of the diving board, or the diver’s weight, or the depth of the water are different – then the diving angle will also have to be different if the body is to be subjected to a minimum load. If the ratio of diving board height to depth of water (h / d) increases, a smaller diving angle will have to be chosen (bigger load acting on the body) in order to convert the diving energy along the available diving distance.

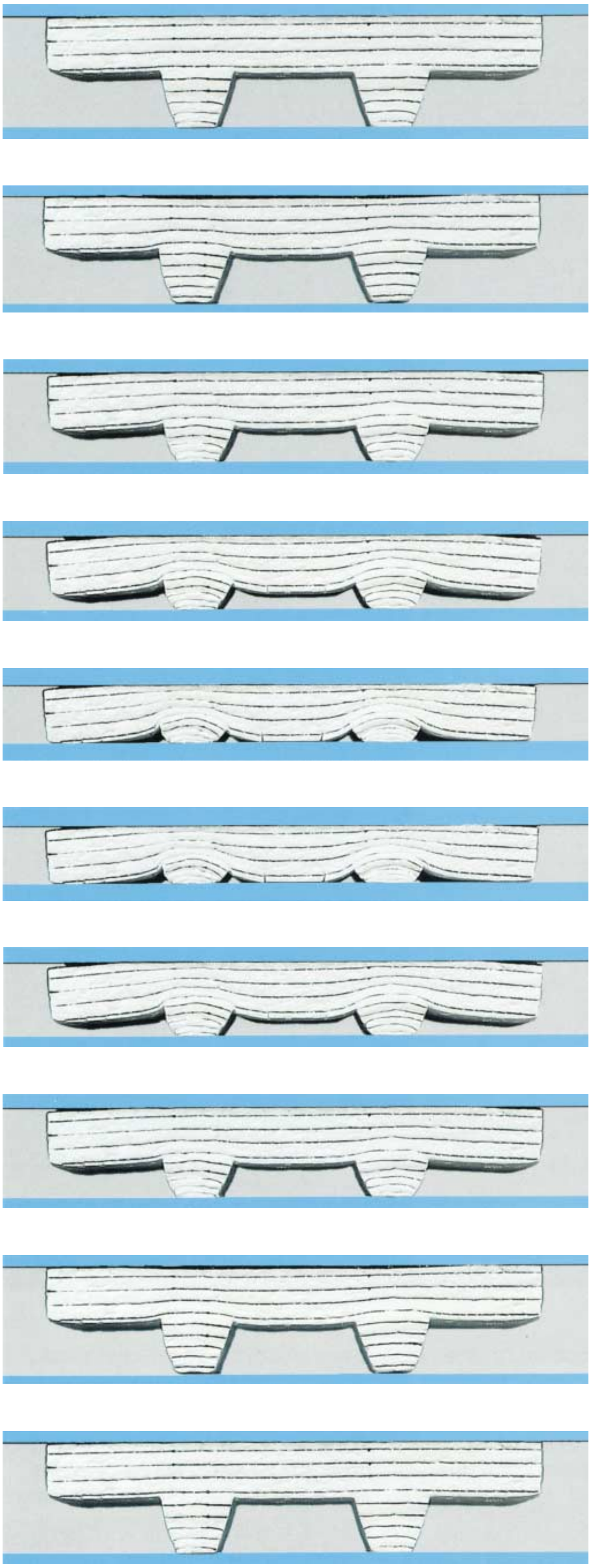


Fig. 29:
Deformation and recovery of cushioning ribs (experiment using a press)

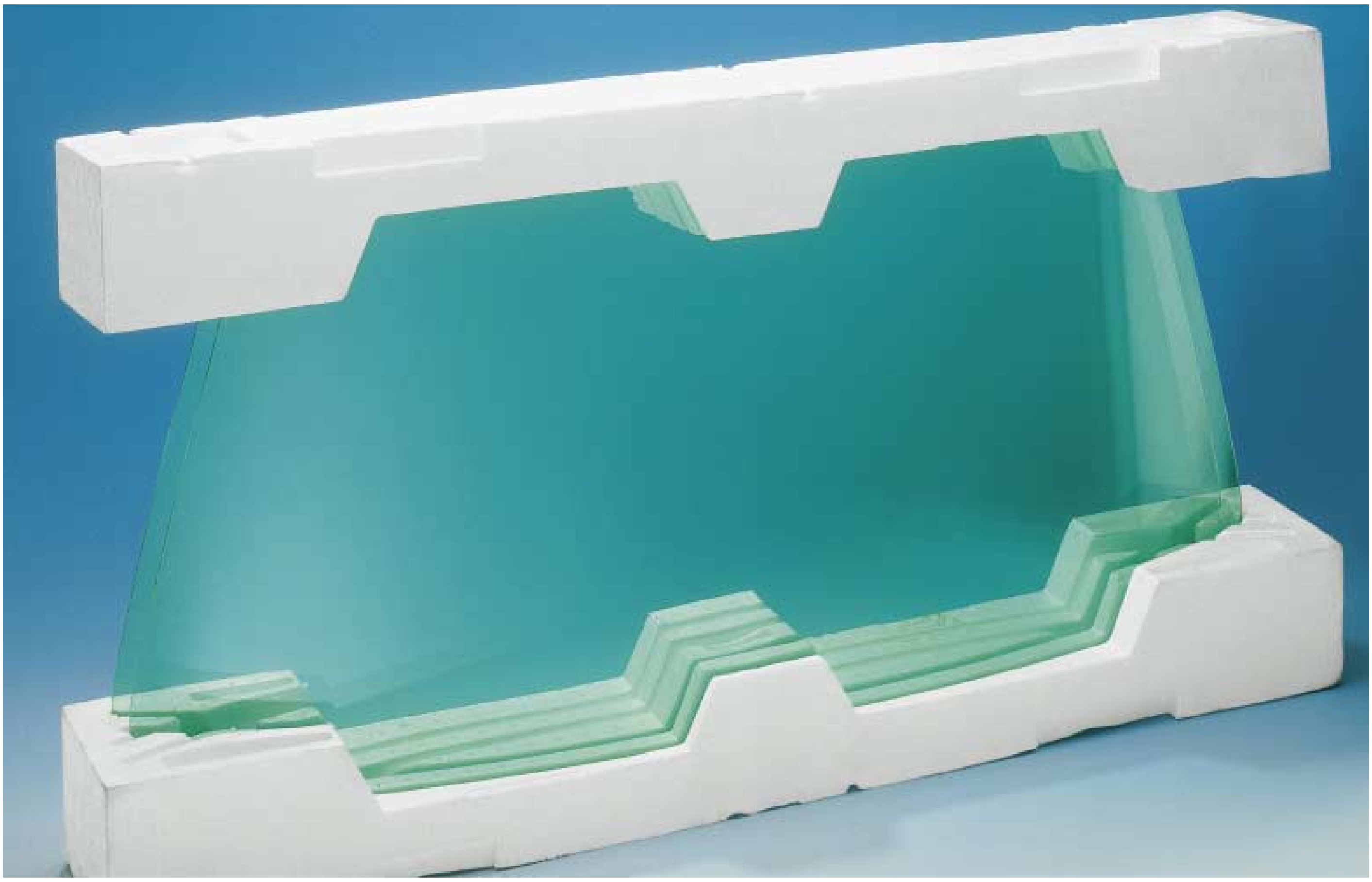


Fig. 30:
Recesses enable this pack to be used for several car window panes

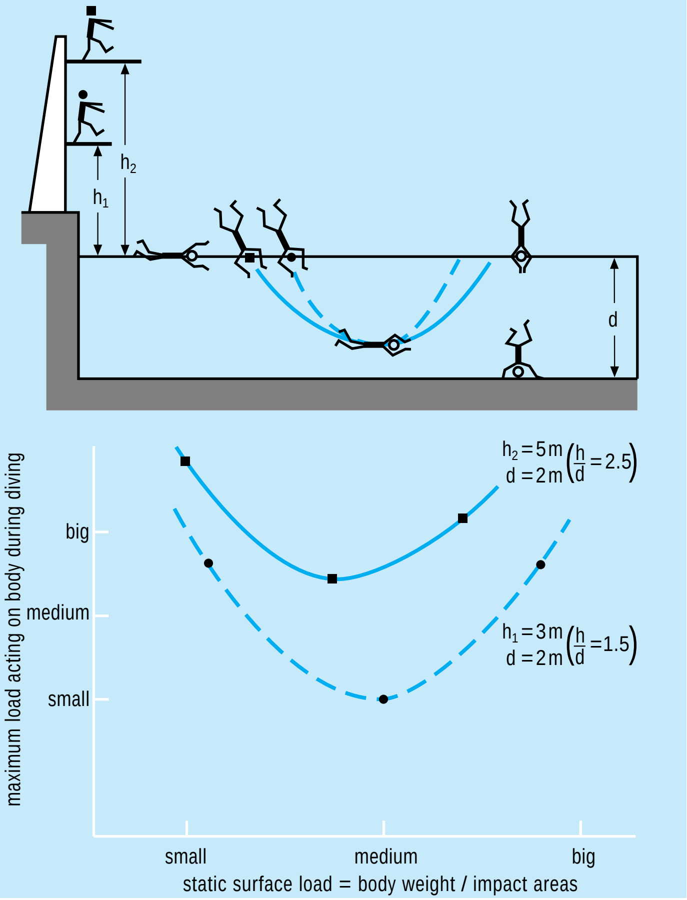


Fig. 31:
Cushion model – “diving from a springboard”

When a package is dropped, similar events are observed. The cushioning properties can be matched to requirements by judicious choice of foam density and package dimensions.

Extensive trials have been carried out to determine the foam's damping properties for different loads, cushion thicknesses, drop heights and densities. The results were converted into cushioning curves which are recommended in DIN 55471 Part 2 as a basis for dimensioning foam packages.

The characteristics given in the diagrams have the following significance:

Static surface load

$$= \frac{\text{weight of packaged item in N}}{\text{contact area in cm}^2}$$

Impact factor G = G value (this is the factor by which the actual weight of the packaged item increases during impact). The maximum permissible G value for any given packaged article is called the "packaged item sensitivity" .

$$\frac{h}{d} = \frac{\text{drop high in cm}}{\text{cushion thickness in cm}}$$

The adjoining examples show how cushioning diagrams can be used for dimensioning Styropor foam cushioning elements.

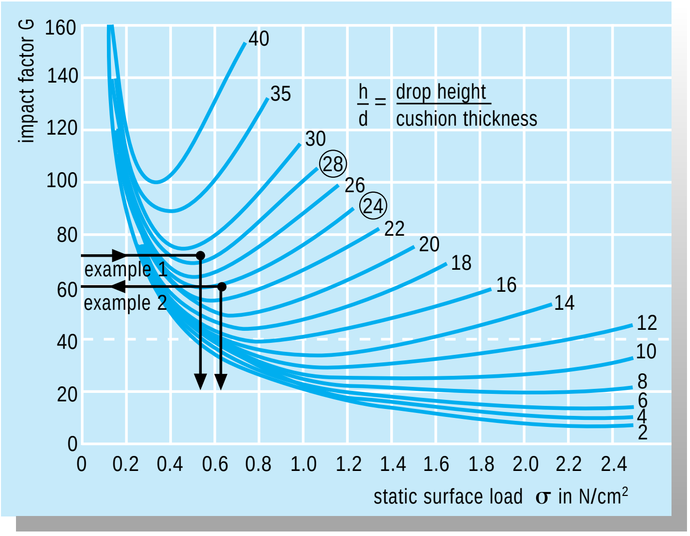


Fig. 32:
Cushion diagram for foams made of EPS 20 (DIN 55471, Part 2).

Influencing factors	Units	load for optimum cushioning	
		example 1	example 2
Weight of packaged goods (m)	kg	10	10
Cushion area (A)	cm²	?	?
Cushion thickness (d)	cm	?	4.2
Drop height (h)	cm	90	100
Impact factor G (Sensitivity of packaged goods) (G)	–	70	?

Fig. 33:
Calculation example with the aid of the cushioning diagram for 20 kg/m³ (1.25 pcf) foam

example 1
(load for optimum cushioning)

known:
RD = 20 kg / m³
m = 10 kg (m · g = 98.1 N)
h = 90 cm
G = 70

required: A und d
from cushion diagram:

[1] h / d = 28
σ = 0.51 N / cm²

Calculations:

$$d = \frac{h}{(h/d)} = \frac{90 \text{ cm}}{28} = 3.2$$

$$A = \frac{m \cdot g}{\sigma} = \frac{98.1 \text{ N}}{0.51 \text{ N/cm}^2} = 192 \text{ cm}^2$$

example 2
(load for optimum cushioning)

known:
RD = 20 kg / m³
m = 10 kg (m · g = 98.1 N)
d = 4.2 cm
h = 100 cm

h / d = 24

required: A und G
from cushion diagram:

G = 60
σ = 0.62 N / cm²

Calculations:

$$A = \frac{m \cdot g}{\sigma} = \frac{98.1 \text{ N}}{0.62 \text{ N/cm}^2} = 158 \text{ cm}^2$$

---

[1] $1\text{N} = \frac{1 \text{ kg} \cdot \text{m}}{\text{s}^2}$

The weight of a 1 kg mass is given by:

$$m \cdot g = 1 \text{ kg} \cdot \frac{9.81 \text{ m}}{\text{s}^2} = 9.81 \text{ N}$$

Apart from cushioning diagrams there are other, simpler ways of determining optimum cushion thickness and surface area. The basis for dimensioning cushioning elements is formed by the minima of the cushioning curves (Fig. 32). One cannot therefore obtain structural values differing from optimum figures by this method.

The calculated cushion surface areas are, in most cases, smaller than the surface available to support the packaged item. This must therefore be compensated by appropriate packaging design (Fig. 60). In the case of ribs and knobs, the following should be noted:

- Ribs and knobs, and the depths of the cavities into which they fit should take up between 50 and 60% of the calculated total cushion thickness.
- Where ribs and knobs are incorporated, the calculated cushion thickness should be increased by a factor of 1.1.
- The cushioning area is taken to be the area at the mean rib height.
- The flank angle of ribs and knobs should be about 15° and the root radii about 10 mm (0.40 in.).

Design recommendations

Packaging calculations provide information about required cushion thicknesses, cushion surface areas and foam densities. This information has to be converted into a suitably shaped package, with due consideration of all package requirements. The most common kinds of packaging are shown in Fig. 35. The special features of these packs are:

- Design No. 1
  has smooth outside surfaces and is ribbed on the inside. All that is needed here is adhesive tape or sleeves made of plastics film or cardboard to seal the pack.
- Design No. 2
  enables the packaged item to fit snugly into the pack. Ribbed on the outside, this type of pack ensures that the article inside is securely fixed and will withstand even the severest knocks during transit.
- Design No. 3
  is a partial pack with two side shells or top and bottom shell. This type of pack is particularly suitable as a shock absorber and is normally placed inside a cardboard or corrugated cardboard box.
- Design No. 4
  shows edge and corner protectors which are used especially for furniture and large units. In addition, they are used as general purpose protectors against impact.

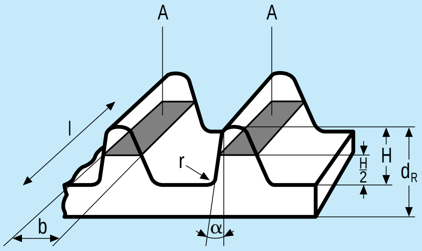
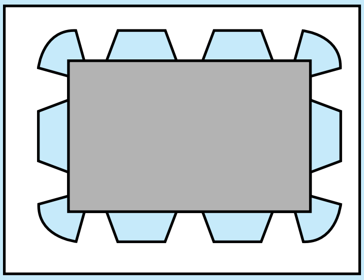
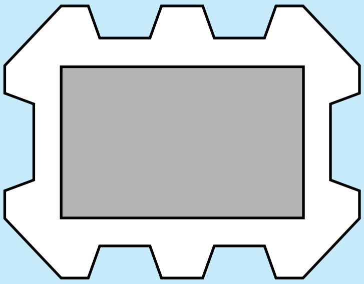


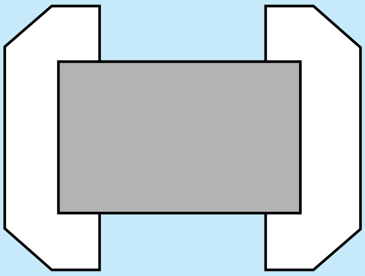
Fig. 34:
Guidelines for correct rib design



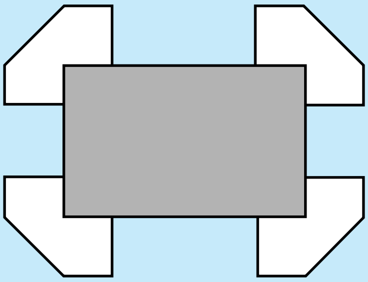
1 full-wrap pack with ribs on the inside



2 full-wrap pack with ribs on the outside



3 side cushioning elements



4 corner cushioning elements

Fig. 35:
Different designs for shock absorbent packs

Compressive Strength

Styropor foams are classified as rigid foams in accordance with DIN 7726. They therefore exhibit maximum compressive stress with low deformation. It is very easy to influence the compressive stress values by means of density. Moulded packaging units – including self-supporting packs as well as inserts – can therefore be economically produced.

Fig. 11 shows the high loadbearing capacity of Styropor foam which is widely used for packaging fish, fruit and vegetables (Figs. 13, 15 and 16).

The most widely used combination packs consist of collapsible corrugated cardboard boxes with Styropor foam inserts. Maximum use is thus made of a foldable outer box combined with foam moulded cushioning inserts.

Fig. 38 demonstrates the great contribution made by Styropor foam inserts towards increasing the compression resistance of collapsible corrugated cardboard boxes. This is even more evident under damp conditions because even direct contact with water will not affect the foam’s strength in any way.

Fig. 36:
Compression resistant packaging for refrigerators

Design of Packs for Load Bearing Applications

The compressive stressdeformation curves shown in Fig. 11, page 9 were obtained in tests with constant rate of deformation in accordance with DIN 53421. Under actual practical conditions, however, packages are subjected to entirely different kinds of stress, such as long-term and dynamic stresses – and this is why the compressive stress figures we have given cannot be used for dimensioning packages.

Figures that can be used in the design of packs are specified in DIN 55471, Part 2 (Table 3). These enable the designer to calculate the permitted loads to which Styropor foam packs can be subjected, using the following equation:

$$\sigma_d \geq \frac{F_{max}}{A}$$

σ_d permissible compressive stress in N/mm^2

F_{max} maximum stress in N

A surface area under stress in mm^2

The important point to note is that the figures given in the above mentioned standard are maximum permissible compressive stresses at a standard temperature and humidity of 20 °C (68 °F) and 65 % respectively according to DIN 50014. If temperatures are higher, lower compressive stresses will have to be laid down.

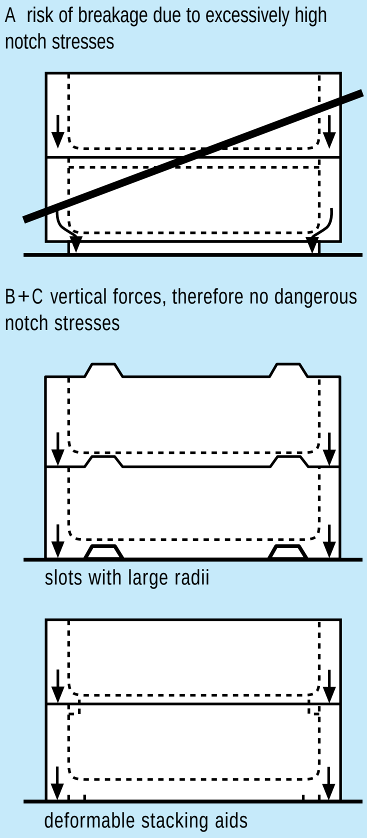
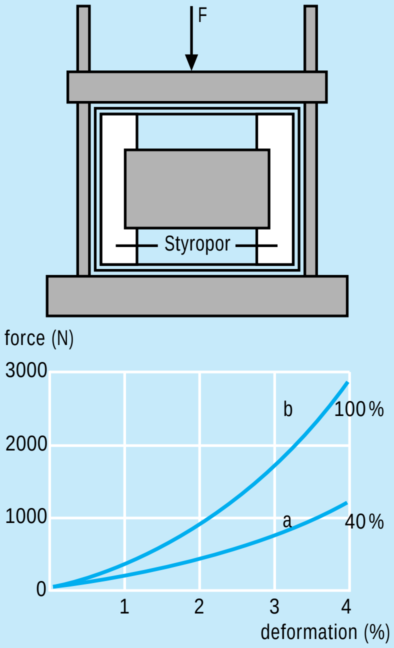


Fig. 37:
Stacking aids



Force-deformation diagram: Test pieces
a. collapsible, corrugatedcardboard box (2.7)
L x W x H = 32 x 29 x 28 cm
(12.6 x 11.4 x 11.0 in)
b. collapsible, corrugatedcardboard box (2.7)
with two Styropor foam side shells RD 20,
d = 9 cm (3.5 in), L x W x H = 32 x 29 x 28 cm
(12.6 x 11.4 x 11.0 in.)

Fig. 38:
Force-deformation diagram

Fig. 39:
Correctly designed stacking aids

Calculation

A Styropor pack is to be subjected to a maximum load (FmaX) of 2000 N. What would the supporting surface area have to be for foams with densities of 20, 25 and 30 kg/m³ (1.25, 1.56, and 1.87 pcf).

This is calculated using the following equation:

$F_{max} \leq \sigma_{d,\,max} \cdot A$

F_{max} = maximum stacking load

$\sigma_{d,\,max}$ = maximum permissible compressive strength (see table 2)

A = supporting surface area (i.e. load-bearing area of foam pack)

for RD 20 we have:

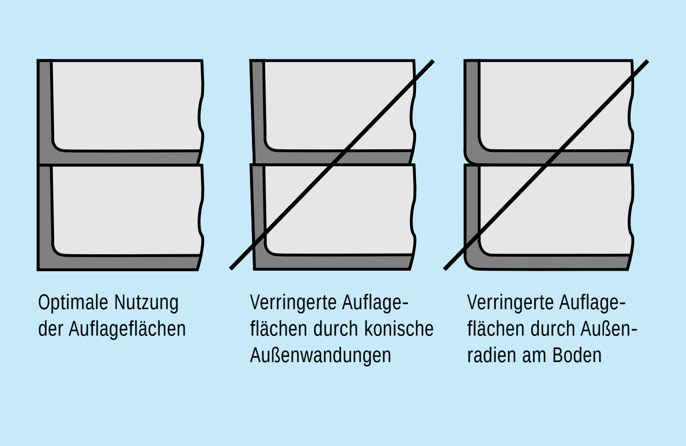
$$A \geq \frac{2000\ \text{N}}{0.039\ \text{N/mm}^2} = 51282\ \text{mm}^2 \approx 513\ \text{cm}^2$$

for RD 25 we have:

$$A \geq \frac{2000\ \text{N}}{0.055\ \text{N/mm}^2} = 36364\ \text{mm}^2 \approx 364\ \text{cm}^2$$

for RD 30 we have:

$$A \geq \frac{2000\ \text{N}}{0.071\ \text{N/mm}^2} = 28169\ \text{mm}^2 \approx 282\ \text{cm}^2$$



Optimale Nutzung der Auflageflächen

Verringerte Auflageflächen durch konische Außenwandungen

Verringerte Auflageflächen durch Außenradien am Boden

Fig. 40:
Design recommendations for outside contours

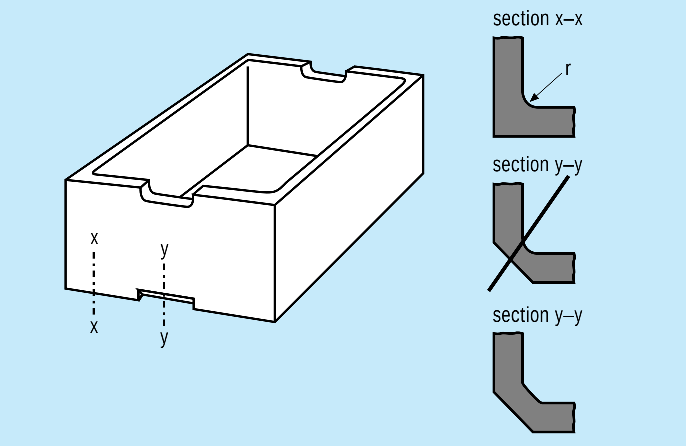


Fig. 41:
Design recommendations for inside corners and edges

Design recommendations

In designing Styropor foam packs the following points should be noted in addition to ensuring that the permitted compressive strength is adhered to:

- The load-bearing walls of the foam packs must pass the stacking forces down to the floor vertically and in a straigth line. This is specially important when designing stacking aids. (Fig. 39).
- All edges and corners inside the pack, as well as recesses in the walls and base should have as large a radius as possible (10 mm (0.39 in.) or greater) (Fig. 40).
- In order to obtain the largest possible supporting surface area, the pack's outer edges should be right-angled (Fig. 41).

Table 2: **Permitted compressive stresses**

	Foam grade and respective values				
Properties	EPS 20	EPS 25	EPS 30	EPS 35	EPS 45
Permitted compressive stress σ_d in N / mm²* – at nominal density according to DIN 55471 Part 1	0.039	0.055	0.071	0.087	0.119

* 1 N / mm² = 1000 KPa

Thermal Insulation

Fig. 42:
Safe transport of highly perishable goods in thermally insulating boxes made of Styropor foam

Fig. 43:
Heat insulating pack for pharmaceutical preparations

Where goods have to be protected from temperature extremes during transport and storage, or where they have to reach their destination either hot or cold, thermally insulating packs must be used. This is an obvious application for Styropor foams since the material possesses outstanding thermal insulating properties, thanks to its closed-cell foam structure consisting of microscopically small air bubbles.

The important property of thermal insulating materials is the thermal conductivity. The figures for Styropor foam - which depend on the foam density and mean foam temperature – are listed in Table 3 and in DIN 55471, Part 2.

From the thermal conductivity, the pack dimensions, the characteristics of the packaged items and prevailing temperature conditions it is possible to calculate the time needed for a particular maximum temperature to be reached. Here one distinguishes between two different thermal insulation conditions, depending on the temperature profile of the packaged goods. Special mathematical relationships enable these to be calculated. These conditions are as follows:

- The temperature difference between the packaged goods and their surroundings remains nearly constant for a specific period of time, e. g. if ice is placed inside the pack (Fig. 42 and calculation example).
- The temperature difference between the packaged goods and their surroundings decreases whilst the goods are stored. This happens if no ice is placed inside the pack (Fig. 43).

The formulae for these calculations are given in Fig. 45 (page 31) and in DIN 55471, Part 2.

BASF has developed programs for micro and personal computers, which enable the required data to be determined easily and quickly.

To explain the significance of the different influencing factors, the most important variables from the adjoining example were each altered by 20 % and the effect on the maximum thermal insulation period determined (Fig. 44).

From the results obtained, and the mathematical relationships, the following recommendations can be derived for the design of thermally insulating packs:

- By adding ice to refrigerated packs the maximum thermal insulation period can be increased considerably. The use of cooling accumulators should always be checked.
- Reducing the inside surface area of the pack will prolong the thermal insulation period. These surfaces should therefore be as small as possible – something which can be achieved by carefully matching the pack to the contents and making the pack as near to cubic in shape as possible.
- If the weight of the goods being packaged is increased without changing the shape and size of the package, the maximum thermal insulation period will increase in the same ratio.
- Every increase of a pack’s wall thickness will inevitably increase its maximum thermal insulation period. The degree of improvement is also influenced by the heat transfer coefficient and must therefore always be determined.
- Every increase in density in the range of 0 to 40 kg/m³ (0 to 2.50 pcf) causes the maximum thermal insulation period to increase. Here, too, the degree of improvement achieved is influenced by the heat transfer coefficient and must therefore be determined in each case.
- If the dimensions of the item to be packaged, and the volume of acubic pack are increased by the factor x, the maximum thermalinsulation period will increase by a factor $\sqrt[3]{x}$ One should therefore always use the biggest possiblepackaging unit.

Table 3: **Thermal conductivity λ in W/(m · K)***

Foam grade	mean foam temperature in °C			
	+50	+10	±0	–50
EPS 15	0.042	0.037	0.036	0.029
EPS 20	0.040	0.035	0.033	0.028
EPS 25	0.038	0.034	0.031	0.027
EPS 30	0.037	0.033	0.031	0.027
EPS 35	0.037	0.033	0.031	0.027
EPS 40	0.037	0.033	0.031	0.027

*The thermal conductivity increases with moisture content

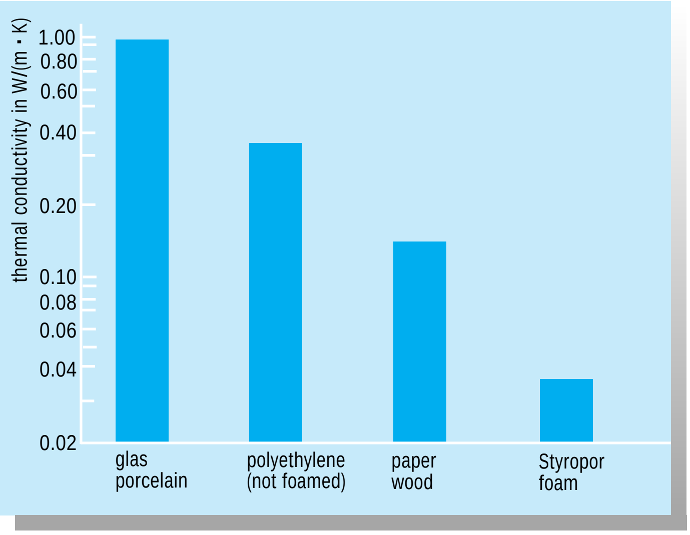
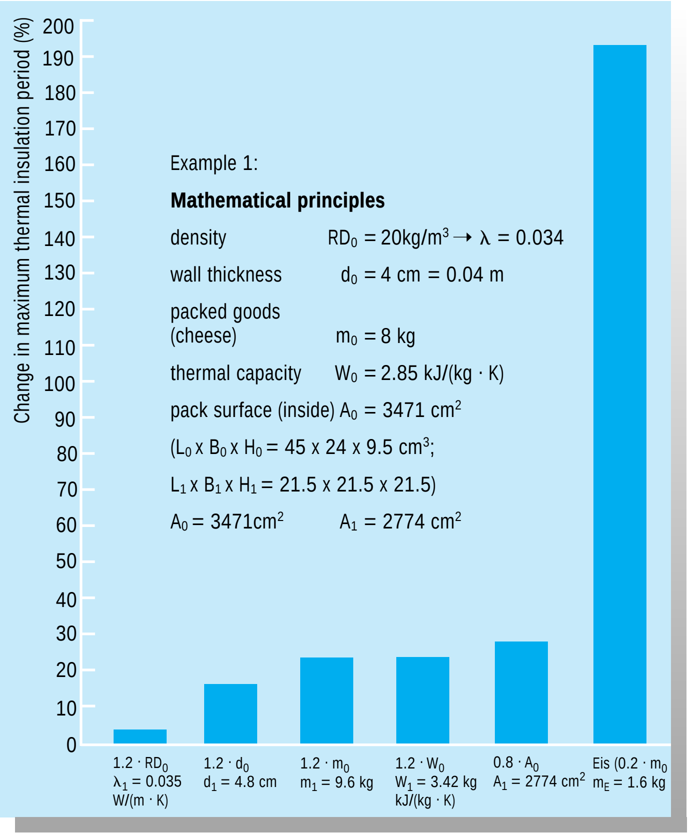


Fig. 43:
Thermal conductivity of various packaging materials



Example 1:

Mathematical principles

density $RD_0 = 20 kg/m^3 \rightarrow \lambda = 0.034$

wall thickness $d_0 = 4$ cm = 0.04 m

packed goods
(cheese) $m_0 = 8$ kg

thermal capacity $W_0 = 2.85$ kJ/(kg · K)

pack surface (inside) $A_0 = 3471$ cm²

($L_0 \times B_0 \times H_0 = 45 \times 24 \times 9.5$ cm³;

$L_1 \times B_1 \times H_1 = 21.5 \times 21.5 \times 21.5$)

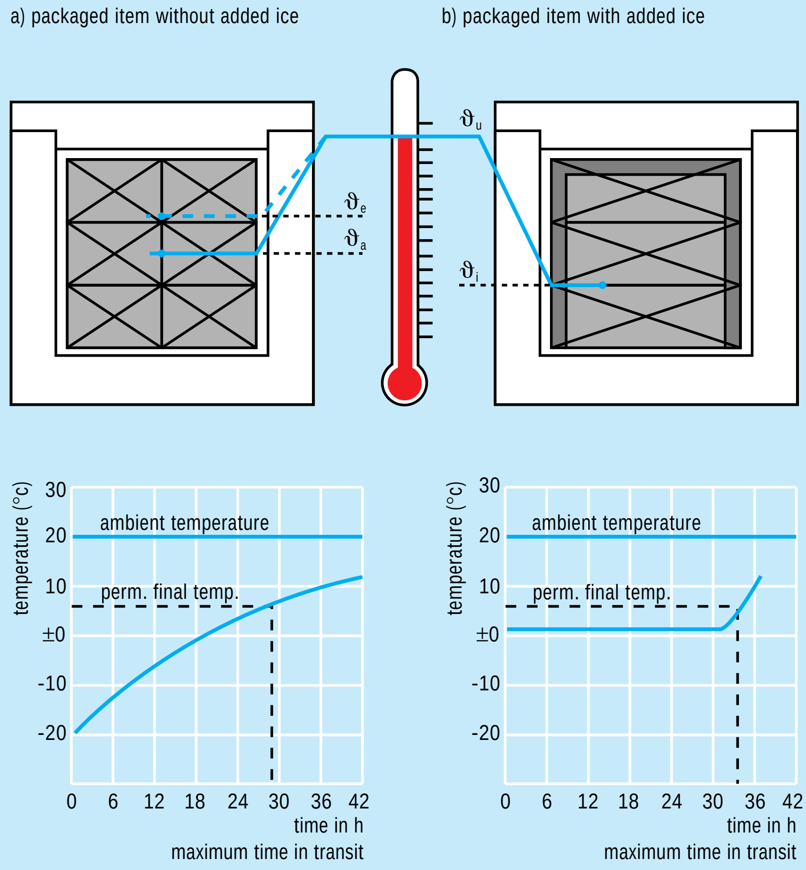
$A_0 = 3471$cm² $A_1 = 2774$ cm²

Fig. 44:
Important factors which influence the maximum thermal insulation period (variation factor 1.2 bzw. 0.8).

Design recommendations

In calculating the dimensions etc. of heat insulating packs it is assumed that there will be no temperature differences inside the pack. To ensure that this will indeed be so, the following points should be noted when designing such packaging units:

- The top and bottom parts of the pack should be made to fit together so that the pack is airtight, e. g. by using tongue-and-groove joints .
- The items to be packaged should fit snugly into the pack and be arranged cubically if at all possible in order to obtain a small surface area/volume ratio.
- The coolant – ice – should be placed at the highest point inside the pack if one can be certain that the packaged item or items are firmly fixed and cannot move. If the position of the contents inside the pack is uncertain, the ice should at least be distributed along the four walls.
- Ribs should be incorporated inside the pack to help in maintaining the temperature of the contents at a constant level.



mathematical formula without added ice

$$t = m_v \cdot c_v \cdot \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \ln \frac{\vartheta_u - \vartheta_a}{\vartheta_u - \vartheta_e}$$

mathematical formula with added ice

$$t = m_k \cdot s \cdot \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \frac{1}{\vartheta_u - \vartheta_i}$$

		Units	**Hints**
A	Heat transfer area	m²	inside surface area of pack
ϑ_a	Temperature of contents at start of thermal insulation period	°C	Temperature during packing
ϑ_e	Temperature of contents at end of thermal insulation period	°C	Temperature when unpacking
ϑ_i	Temperature inside the pack	°C	
ϑ_u	Mean ambient temperature	°C	–
c_v	Specific heat of packaged goods	kJ / (kg · K)	
d	Wall thickness of pack	cm	–
m_k	Weight of thermal ballast	kg	–
m_v	Weight of packaged goods	kg	
s	Latent heat of transformation of ballast	kJ / kg	
t	Thermal insulation period	h	–
1 / α	Heat transfer resistance on either side of the pack's walls	m² · K / W	
λ	Thermal conductivity of the foam	W / (m · K)	see Table 3
	Umrechnungsfaktor	1Wh = 3,6 kJ	

Fig. 45:
Methods of calculating thermal insulation of Styropor foam packs

Packages and their contents

In designing a pack, the possibilities of adverse interactions between the pack and its contents should be checked. These also include indirect effects due to special environmental conditions. The following are of special interest in this connection:

- Styropor foams do not directly affect other substances and materials because they are high polymer based. Blowing agent residues in the foam can sometimes be a nuisance because of their smell, but they will not directly affect the packaged contents because of the chemical composition of the blowing agent and because of the extremely small amounts of blowing agent residue. The recommendations issued by the German Federal Public Health Office state that up to 2 g of blowing agent residue per litre of foam do not represent a health hazard. The actual amounts of residual blowing agent that occur are less by about a power of ten.
- Moulded Styropor foam will permit the passage of gases. This is an advantage in the packaging of fresh meat and fish and other perishable foods containing protein, since the constant addition of oxygen prevents anaerobic microorganisms, which cause decay, from developing. This means that organisms such as Chlostridium butolinum cannot decompose the proteins in the food, so that no foul smell of decay is produced, as is the case with gas-impermeable packs.
- The reverse effect, namely the maintenance of a certain gas atmosphere, is important in the storage of fruit. To slow down the ripening process, the fruit's metabolism is slowed down by increasing the carbon dioxide content of the surrounding atmosphere. Since carbon dioxide is formed by the fruit as a product of metabolism, it follows that an increased CO_2 concentration will automatically be produced in sealed foam boxes. This will depend upon the temperature, i.e. on the metabolic rate.

Fig. 46:
The packaging material in no way affects the pack's contents

Abb: 47:
Wine bottle packs

- Among the indirect effects is also the influence exerted by water, which is present in small quantities in freshly foamed moulded parts.

  Moulded foam produced on modern, automatic machines, will normally contain less than 0.1% by volume of residual moisture after being left for a day at room temperature. This extremely small amount of moisture has no effect on most types of packaged goods. Where goods are particularly sensitive to moisture however, they must be protected not only against residual moisture in the pack but also against atmospheric humidity. Here, polyethylene bags containing a desiccant have proved effective.

- In view of the chemical resistance of the foam (Table 1, p. 11), there is little likelihood of packaged goods affecting the foam pack. The only substances requiring care are fats, plasticisers and organic solvents. If Styropor foam packaging is allowed to come in contact with plastics containing plasticiser, or painted surfaces, they can stick together at the points of contact. A white coating can also be formed, due to migration of plasticiser into the foam surface which then softens and becomes sticky. Most of the plasticisers contained in flexible PVC products will attack Styropor foam, apart from certain speciality plasticisers such as the Palamolle range made by BASF. The people responsible for doing the packaging do not always have any influence on the choice of plasticiser and the best way of overcoming the problem of plasticiser migration is to use interlayers of polyethylene film or paper.

- Styropor foams will come into contact with fats and grease for example when they are used to pack greasy foods or metal parts which have been smeared with grease to prevent corrosion. The foam will tend to be more affected as the temperature rises. Cooking fats will not, however, attack the foam at normal room temperature 25°C (77°F). It is best to use Styropor FH grades, which have enhanced resistance to fats and grease, where there is a possibility of contact with these substances. In this case one should check how the foam reacts to different transport and storage temperatures .

Test Methods and Regulations

The stresses and conditions to which a pack is subjected vary considerably and cannot be comprehensively determined. For practical purposes it is best to find out typical critical loads for specific storage and transport conditions and use these as test criteria. Only loads likely to occur during normal handling should be considered. Exceptional loads, e. g. those resulting from incorrect handling or accidents should not be used as criteria since these necessitate measures which would be totally uneconomical. Test programmes for packages are given in DIN 55439, Parts 1 and 2, Supplement 1, available from Beuth Verlag GmbH, Burggrafenstraße 6, D-1000 Berlin 30, Germany. Phone: (0 30) 26 01-2 60.

Cost effectiveness

Six important points must be noted in calculating costs:

- the price of a pack, including all its components
- the cost of assembling, sealing, addressing, marking, including packaging checks
- in-plant transport costs
- transport costs
- damage to packs, and the resultant insurance costs
- number of packs involved.

In many cases the purchase price of a pack amounts to only a fraction of the total packaging costs. A simple cost comparison between different kinds of packaging is therefore insufficient when calculating costs.

The receipt of goods in undamaged condition is extremely important, especially in the case of well known, familiar brands. This, too, affects packaging costs because the pack and its contents must reach the customer as a completely intact unit. This is what he expects from a brand name and this is what he must get. Careful package design is therefore vitally important.

The cost effectiveness of a pack must also be viewed against the background of expensive claims. Cheap packs, which are easily damaged and thus fail to do their job properly can prove to be expensive in the long run.

Many of the requirements we have mentioned can be fulfilled by using Styropor packs, which are economic in use.

Table 4 lists the Styropor properties which have to be assessed in relation to cost, in order to arrive at an objective profitability comparison.

Tabelle 4: **Packaging characteristics of Styropor foam**

Properties	Applicational advantages and possibilities	Examples
Closed-cell characteristics	buoyancy of the air enables maximum use to be made of the PS cell structure. High strength and rigidity despite light weight	small raw material requirements
	presence of air inside the cells imparts cushioning and thermal insulation properties to the foam	stoßdämpfende Verpackungen wärmedämmende Verpackungen
	no absorption of moisture	waterproof moulded parts
Light weight, density normally between 20 and 30 kg / m^3	low transport costs low and constant tare which in many cases is negligible	advantageous for sending goods by post and by air the tare can be set on the scales. Fruit and vegetable trays and fish boxes are easily filled
Strength depends on density but shows little variation	packs can be designed to provide the required protection and strength. This means: optimisation of the amount of material needed, protection of the packaged goods, low breakage rate and few claims	
Compressive strength	compression resistant packs with good buckling resistance and stackability	stackable fruit and vegetable trays fish boxes packs for heavy items such as car engines and gear units, machine parts, heavy household appliances
Definable shock absorbing capacity	cushioning effect can be calculated, thereby ensuring reliable cushioning effect	packs for electrical instruments, stereo equipment, television sets and measuring instruments, glass and porcelain articles and the like
Low specific cushioning factor	cushioning elements can be thin, so that cushioned items need little space	
Specific energy absorption capacity increases with density	cushioning elements require little material, excellent protection in case of edge and corner impact	
Wet strength	strength is not affected by wet or damp conditions as is the case with cellulose-based packaging materials	pallets for transporting plants, fruit and vegetable trays, fish boxes
	empty and full packs can be stored in the open, provided contents are not affected by damp	savings in storage space
Low-temperature resistance	no embrittlement at low temperatures	packs for deep frozen goods
Thermal insulation $\lambda = 0{,}03$ W / (m · K)	cold and heat insulation effect can be calculated. Protection against rapid temperature changes ensures that packaged contents are subjected to minimum temperature differences	packs for highly perishable foods and other substances sensitive to high temperatures such as fish, seafood, dairy products, icecream, deep-frozen foods, hot ready meals, pharmaceutical and biological preparations
Heat resistance at 80°C under compressive stress up to 2 N / cm^2	combination with shrink wrapping film, transport of hot contents	shrink wrapped items, transport of hot meals
Chemical resistant with few exceptions, dust-free, hygienic, permitted for food packaging	foam has no effect on packaged contents or the environment, and is not affected by contents, by aggressive atmospheres or damp. Non-corrosive	food packs, outer packaging for chemicals, pharmaceutical preparations and cosmetics environment-friendly disposal
Attractive appearance	attractive presentation of goods, underlining product quality	attractive food and display packs
Environment-friendly	ground packaging waste can be recycled	soil conditioning, drainage, composting, re-use in the production of block foam and moulded parts. Can be re-converted into polystyrene by sintering and melting
	normal methods of disposal can be used	tipping on landfill sites, energy recovery by incineration

Recycling and disposal

It is an undisputed fact that Styropor foam waste can be recycled or disposed of without any problem, provided the right methods are used.

In-plant Styropor waste has, incidentally, always been recycled by Styropor processors and fabricators. Now, however, used Styropor packs are being increasingly returned to the manufacturers via dealers or through communal collecting centres. This scrap can easily be recycled by being passed into the production cycle and converted into new products.

Heavily soiled packs which are unsuitable for material recovery can be easily disposed of by incineration, composting or dumping on landfill sites.

The most important methods of recycling and disposal are described in detail below.

Recycling

Ground, clean foam waste can within certain limits and for certain types of products, be reused in the foam moulding of blocks etc. by adding it to the virgin material.

Production of Styromull®

Styromull is obtained by grinding Styropor. The size of the resultant pieces should be between 4 and 25 mm, depending on the intended use. Styromull is officially recognised as a soil conditioner which is being successfully used to improve the quality of garden soil, as an aid in compost making, as a filter medium in pipe drainage and as a filler in slit drainage.

Sintering, melting, granulation

Styropor foams can easily be converted back into compact polystyrene by sintering and melting techniques involving the use of heated rolls, screw extruders or Diskpack plasticators. Here, the material is heated for a time to above its melting point. The foam can also be compressed in its softened state below its melting point, through the combined action of pressure and frictional heat in a rotary compacting unit. In this case, heat acts upon the material only for a few seconds. The resultant recycled material may be used for making injection moulded parts.

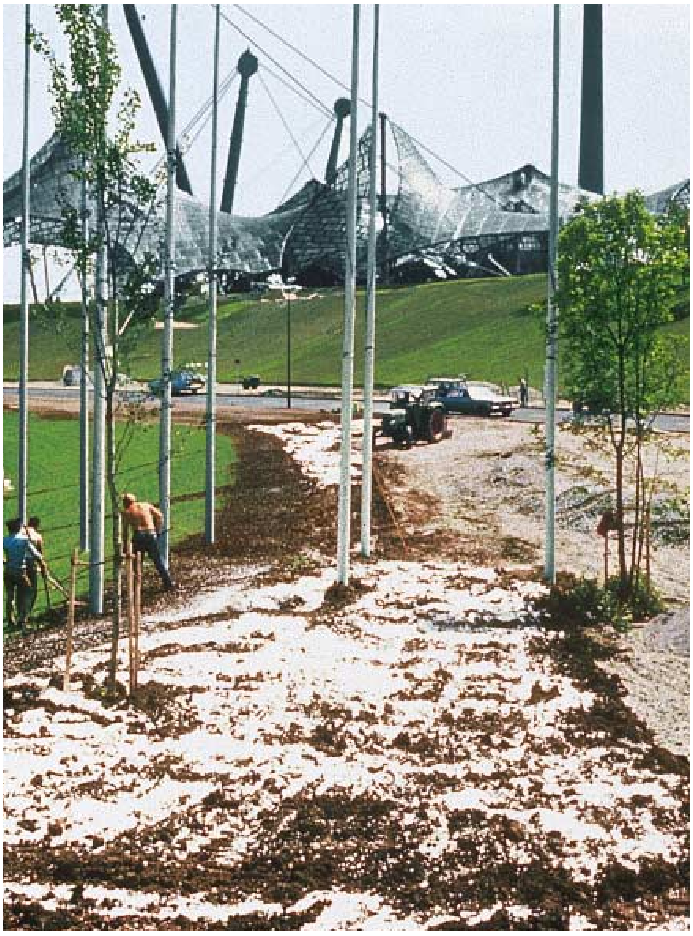


Fig. 48:
Soil improvement with Styromull (Olympia grounds, Munich).

Incineration

Styropor foam can be incinerated in municipal and communal refuse incinerators at the usual temperatures of about 1000 °C. Carbon dioxide and water are formed in the process, and there is no residue. The foam should be chopped up coarsely and mixed with the other refuse. When flame retardant foam waste is incinerated, small quantities of halogen compounds are produced which, however, do not noticeably affect the composition of the flue gas. Indeed, these flue gases are less toxic than these produced when other organic substances such as wood or paper are burned.

The high energy contents of foams enable the amount of extra heating to be reduced –1 kg Styropor saves 1.2 – 1.4 litres of fuel oil. In bigger plants, foam waste can also be used as a source of steam, provided that the steam generator is equipped with a special combustion chamber and special controls. Styropor foam should not be burned in the open air because of the large amounts of soot formed.

Dumping

Styropor foam waste can be dumped in regulated landfill sites. The waste material should be cut up into small pieces in order to save space, prevent the formation of air pockets in the rubbish dump and to make compaction easier. This will also encourage ventilation of the dump and improve decomposition of other organic substances in the dump.

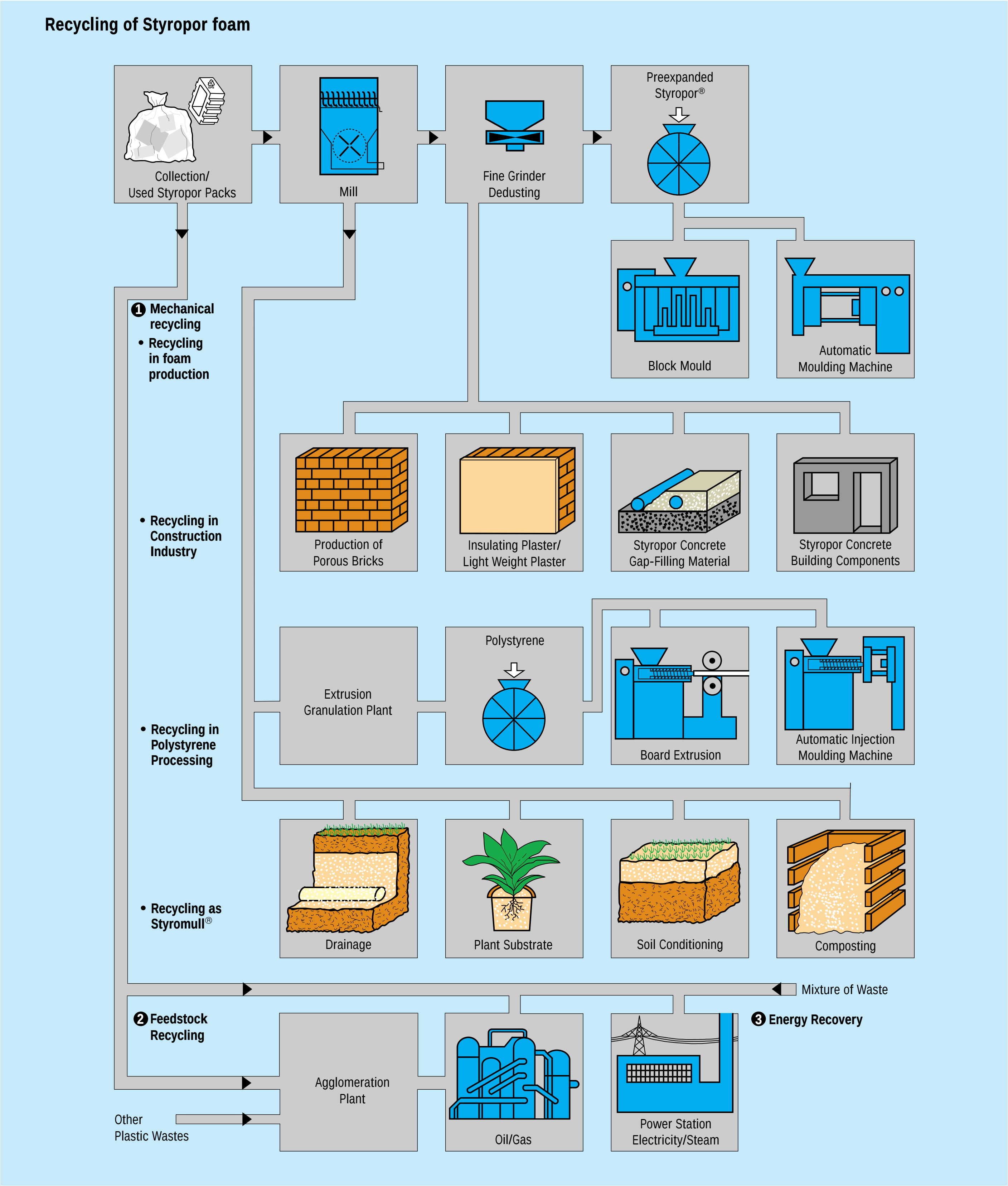


Fig. 49:
Recycling of Styropor foam

① Material recycling
② Feedstock recycling
③ Power generation

Conclusion:

The disposal of Styropor foam waste does not harm the environment, provided adequate measures are taken. Its high energy content can be exploited in refuse incinerators or special combustion chambers. Even better, however, is to recover the starting material, as we have described above.

Table: **Physical properties of Styropor® foams for packaging**

Properties 1)	**Test standard**	**Unit**	**Test result**		
Density	EN ISO 845	kg/m^3	20	25	30
Thermal conductivity at +10 °C	DIN 52612	mW/(m · K)	33 – 35	32 – 34	31 – 34
Compressive stress at 10 % compression	EN 826	kPa	110 – 140	150 – 200	200 – 250
Permitted compressive stress for packaging calculations	DIN 52612	kPa	39	31 – 34	71
Flexural strength	EN 12089	kPa	260 – 360	360 – 460	460 – 560
Shear strength	EN 826	kPa	230 – 330	300 – 400	380 – 480
Tensile strength	DIN 53427	kPa	120 – 180	160 – 200	210 – 260
Modulus of elasticity in compression	EN 826	Mpa	3.5 – 4.5	5.0 – 8.5	7.5 – 11.0
specific custioning factor, C*	DIN 55471, Teil 2 2)	1	2.5	2.5	2.5
specific impact resistance capacity e*	DIN 55471, Teil 2 2)	kJ/m^3	150	200	250
Coefficient of linear expansion		1/K	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$
Specific heat capacity	DIN 53765	J/(kg · K)	1210	1210	1210
Water absorption when immersed in water					
after 7 days	DIN 53 434	Vol. %	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapour diffusion flow density	DIN 52 615	1	55	75	85

1) corresponding to Test Norm

2) corresponding DIN 55471, Part 2

$1\ N/mm^2 = 1000\ KN/m^2 = 1\ MPa = 1000\ kPa$

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed .

Better together –

Together better

BASF Foam-Technology

http://www.basf.de

Note:
You will find more information on
Styropor in the Technical Information
leaflets available on CD-ROM.
KSR/MK – D 219
Tel.: +49-621-60-9 90 38
Fax: +49-621-60-7 22 26

BASF Aktiengesellschaft
Geschäftseinheit Styropor
67056 Ludwigshafen
Germany

Styropor®

38188 February 1996 (JWF)

1 Styropor brochures/ Information

Films about Styropor

Apart from our extensive technical literature, there are also some video films available for the wide field of Styropor processing and applications of the expanded foams produced from it.

These films are available free of charge to BASF customers as well as to consumers and converters of expanded Styropor foam, schools, local authorities, architects, civil engineers, and other interested parties.

Please address your inquiries to
BASF Aktiengesellschaft
ZOA/GH – D 107
D-67056 Ludwigshafen,
Germany
Telephone: (06 21) 60-9 99 40
Fax: (06 21) 60-2 14 98

Alternatively, for countries outside of Germany, please apply to the Public Relations Department of your nearest BASF office.

When placing your order, please quote the film title or the stock number, the type of television (PAL, NTSC or SECAM), and the language version.

Brief descriptions of the films

"Styropor® naturally –"

Styropor for insulation and building

About 40 % of our energy consumption is still accounted for by building heating and air conditioning. Rigid foams made from Styropor make a substantial contribution towards saving energy and thus to environmental protection. From rigid foam made from Styropor, architects and engineers have created large-area building elements for roofs, curtain walls and prefabricated houses, insulation systems for thermal and footfall-sound insulation, and foundation structures for road construction.

Technical data

VHS, 27 minutes
German, English, French, Italian, Spanish and russian PAL

Design by V. Bergmann,
F. Hohwiller, R. Schüler, K. Brandes, and E. Storek
Production: Bergmann-Film, Hamburg
Year of production: 1988
Stock No. 52

"Styropor® concrete"

Styropor concrete is a lightweight concrete with expanded polystyrene particles as filling material. The following potential applications are presented.

Extremely light insulating mortar, plasters for thermal insulation, insulating concrete for underfloor applications, engineering insulation, flat roof insulation, thermally insulating support layers in roads and railways, large-size elements for walls in buildings, hollow blocks and hollow bricks, and structural lightweight concrete.

Technical data

VHS, 24 minutes
German, English, French and Spanish
Design by W. Grünwald, W. Huber, and G. Günter
Production by Grünwald-Film, Wiesbaden
Year of production: 1977
Stock No. 92

"Styropor® ...

... then you can pack"

Protecting packaging – using packaging

Sophisticated electronic instruments and cream cakes have one thing in common. They require packaging that has been made to measure. In some cases, the subject of concern is the production pallet, which also acts as packaging. In other cases, it is protection against defrosting. Styropor packaging protects glass and ceramic articles against impact loads. They enable secure stacking and simplify the transport of heavy goods. … There need be no worries about unpacking either. Used packing can be recycled, e. g. to make polystyrene injection moldings and lightweight concrete building elements.

Technical data

VHS 18 minutes
German, English, American, French, Italian and Spanish
Design by H. Dönicke, E. Klement, and H.-J. Motzkus
Production by M-Filmproduktion für Industrie und Werbung GmbH, Constance
Year of production: 1990
Stock No. 15

"Styropor® in road construction"

A light material for the GEOFOAM building method

In the 1960s, rigid Styropor foam was used for the first time in road construction – initially as a protective layer against frost. Nowadays, both foundation engineering and road construction exploit the advantages offered by the low bulk density of rigid Styropor foam as a lightweight insulating material for subsoils prone to subsidence. The weight is only about a hundredth of that of conventional insulating materials. By this means, the pressure exerted on the soil is reduced, making possible a mode of construction which is largely free of subsidence.

After many years of application abroad, this building technique was further developed on the basis of trials at the Bundesanstalt für Straßenwesen (German federal institute for highway systems) up to the point where it could be adopted in practice in Germany. The trials were carried out at experimental building sites in North Germany. In 1995, a the German research association for highway and traffic systems issued an instruction notice on the use of EPS in highway construction and covering the planning, invitation to tender, and implementation of this method of construction. The film takes the construction site on the western Emden bypass on the A 31 as an example to illustrate the building technique and reviews other potential applications.

Technical data

VHS, 16 minutes
German, English and Spanish

Designed by S. Hohwiller,
G. Beinbrech
Production by
BASF Aktiengesellschaft, Ludwigshafen
Fingado Film + Video Mannheim
Year of production: 1995
Stock No. 124

You will appreciate that we are very interested in receiving feedback about the use of our films.

Following return of the films, we would appreciate a note giving details about the nature of the audience and the impact that the presentation had.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

BASF

31295 January 1995

Transport Guidelines

Styropor, BASF's, expandable polystyrene, (EPS) contains a flammable, volatile blowing agent. It is heat sensitive (elevated temperatures are to be avoided), has a limited storage life (six months in sealed steel drums or one month in fiberboard containers) and requires ventilation during storage and transport.

1 Packaging

Choices available are either

- "Oktabins" (fibreboard containers) as a palletized unit, net contents 1 metric t, Dimensions: Height 1.80 m, Width 1.13 m, or
- steel drums, net contents 125 kg.

Some special products have divergent weights.

Standard grades are packed in fiberboard containers and drums, special grades are only available in drums. Local sales offices can give details.

Several types of Styropor can be delivered in road tankers. This is a very economical mode of shipment for large quantities, and also avoids the expense of containers and their subsequent disposal.

2 Transport

National and international transport regulations are to be observed.

2.1 Styropor is treated as a hazardous material in transport

Germany

Road:	Class 9 No. 4c, GGVS (Gefahrgutverordnung Straße = German hazardous goods ordinance for transport by road)
Rail:	Class 9 No. 4c, GGVE (Gefahrgutverordnung Eisenbahn = German hazardous goods ordinance for transport by rail)

Internationally:

Road:	Class 9 No. 4c, ADR
Rail:	Class 9 No. 4c, RID
By sea:	Class 9 IMDG, UN No. 221
By air:	Class 9 IATA/DGR, No. 2211

2.2 Delivery

Styropor is delivered carriage paid through the agency of haulage contractors commissioned by BASF; exceptionally, the buyer may arrange collection.

2.3 Storage en route

betweem collection from the manufacturer and delivery to the customer:

- Packed in steel drums, Styropor may be so stored, provided it is adequately ventilated.
- for Styropor in Oktabins this is not permissible owing to international regulations for hazardous substances in containers.

2.4 Road transport

- Styropor must not be conveyed in closed vehicles; a good current of air is needed – use tilt-top or curtain-sided vehicles.
- The width of the cargo area must be at least 2.30 m.
- Provide the goods with complete weather protection.
- Carry five crosshoops or load straps.
- Convey Oktabins (fiberboard containers) to the consignee without delay or transshipment.
- Protect the packaging against projecting nails, sharp edges, etc. Dispatch the lorry completely empty for loading. No other cargo may be loaded along with Styropor.

- The driver is given an Emergency Data Sheet.
- Instruct the driver to check his load from time to time during the journey.
- Ensure that any relief driver is *completely familiar* with his duties under the regulations and that he receives the *Emergency Data Sheet* on taking over.
- In the event of repairs to the lorry, work on the electrical system and in what are called firehazard tasks (e.g. using naked flames or arcs), the vehicle should first be unloaded.

2.5 Delivery by rail

Only direct rail delivery is possible, i.e. the customer must have his own siding.

3 Terms for collection by buyer

The order must be placed at least ten days before the proposed collection date. Once a date has been agreed, goods cannot be reserved for more than three days beyond that date. In case of delayed collection, the customer should get in touch with BASF, so that new arrangements can be made, if they prove necessary.

4 Fiberboard boxes

Fiberboard boxes (Oktabins) are soft containers.

In order to transport the load without damage care has to be taken to:

- convey them only as complete loads;
- load no other goods on the same vehicle;
- order them only in multiples of 2.

5 Storage at the converter

Do not store incellars

The air in the storeroom should be changed every hour.

Containers:

- The store needs to be roofed and adequately ventilated.
- protect them against direct sunlight, rain or snow, or frost and against damage.
- fiberboard containers should be stacked no more than two high and only if a load distributor is placed between them; in winter do not stack in two tiers in open sheds.

The manufacturer’s guarantee for the storage life of the sealed original containers prior to processing: drum – 6 months; fiberboard container – 1 month.

The following precautions are necessary in the stores:

- ban naked flames, welding grinding drilling and all other tasks posing the threat of fire:
- avoid electrostatic charging;
- forbid smoking (enforce the prohibition);
- conducting measurements for pentane with an explosimeter (Auer, Dräger, GfG) is recommended.

In Germany, “The special safety rules for plants manufacturing and processing rigid polystyrene foams“ apply; these have been drawn up by the expert comittee on fire in the national association of property insurers together with the insurance comittee of the Confederation of German Industry.

Outside Germany, note should be taken of the following, in addition to any other regulations or recommendations in force. Where Styropor is held in fiber boxes, extensive ventilation is necessary due to the escape of blowing agent vapor. Ventilation by extraction of explosive blowing agent/air mixtures near floor level is recommended. The electrical installations in these storage rooms must comply with the regulations in force for flammable processing fluids (e.g. VDE 0100, Section 50N in Germany).

6 Passage of risk

Risk passes to the buyer as soon as the goods ordered are handed over to the shipping company for delivery, regardless of who bears the costs of delivery (which is BASF, as a rule).

If the goods suffer damage during conveyance by a haulage contractor, the buyer must establish his claim against the contractor direct and within the particular time periods provided for this purpose. Any arrangements for insuring the goods while they are in transit or thereafter must be made by the buyer.

7 National and international law

All relevant national and international legislation is to be observed.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

BASF

Technical Information

Styropor®

100

BASF Plastics

28029 May 1998

3 Properties/Tests

General properties; Packaging

Contents

For the best use of cellular material made from Styropor, its properties need to be known thoroughly. Although this is a material with many desirable characteristics, not everyone is as familiar with its use as he probably is with the use of traditional materials such as wood, glass, metals, or fibreboard.

Cellular material made from Styropor is obtained by fusing together expanded polystyrene beads; it has closed cells. It is a “rigid” cellular material and in standards such as DIN 7726 it is so designated.

The air-filled cells of this material, the ease with which it can be moulded into almost any shape, and the economic processes involved suit it admirably to the lasting protection of goods of all kinds, no matter how delicate they may be, ensuring that they pass safely from manufacturer to user.

The aim of this Technical Information Bulletin is to indicate the many properties that are relevant to the use of expanded Styropor as a packaging material.

1 Labelling

Packagers need more information than that provided simply as a guide to recovery and reuse. DIN 55471 Part 1 caters for this by requiring a raised inscription such as this:

Cellular plastic DIN 55 471

– EPS 20 B – F

EPS (expanded polystyrene) is self-explanatory.

The figure 20 gives the nominal density in kilograms per cubic metre (the permissible range of values is therefore 17.5 – 22.5 $kg \cdot m^{-3}$).

The code B shows that the maximum volume fraction of residual water is 0.1%.

The code F shows that the moulding meets the requirements of DIN 53 438 Part 3 Class F 1 regarding burning behaviour (i. e. it contains an effective flame-retardant system whose action has not been vitiated by, say, silicone mould-release agent).

2 Physical properties

Most of the physical properties of expanded Styropor are dependent on the density of the material and, to a greater or lesser extent, processing conditions.

Compressive strain

For materials such as expanded Styropor, which displays elastic and plastic deformation, stress increases with strain. In the case of compression, it is customary to compare expanded Styropor and other rigid cellular materials by quoting the compressive stress resulting immediately in a given compressive strain (10%, say – cf. Table 1).

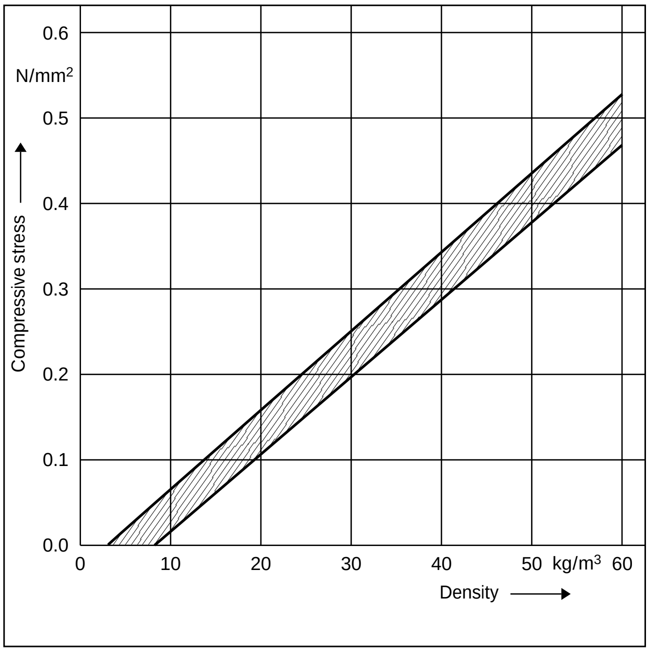


Fig. 1 (above) Stress for compression of 10%, σ (0.1), vs density, ϱ

The compressive stress needed for immediate compression by 10 % varies linearly with density in the case of cut specimens of expanded Styropor, as shown in Fig. 1.

When specimens with moulded skins (smooth, somewhat denser surface layers) are tested, the stresses are slightly lower than for cut specimens of the same average density. Although moulded skins confer practical advantages, these are not reflected in the results of compression tests; the average density can only be the same if less dense inner layers compensate for the denser outer layers.

As compression is increased from very low to very high values, the stress curves shown in Fig. 2 are obtained.

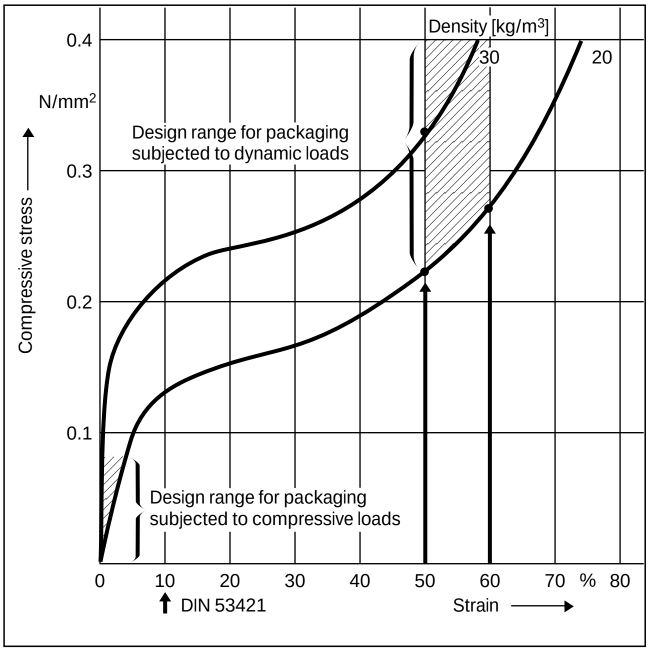


Fig. 2 Stress, σ, vs strain, ε, in compression

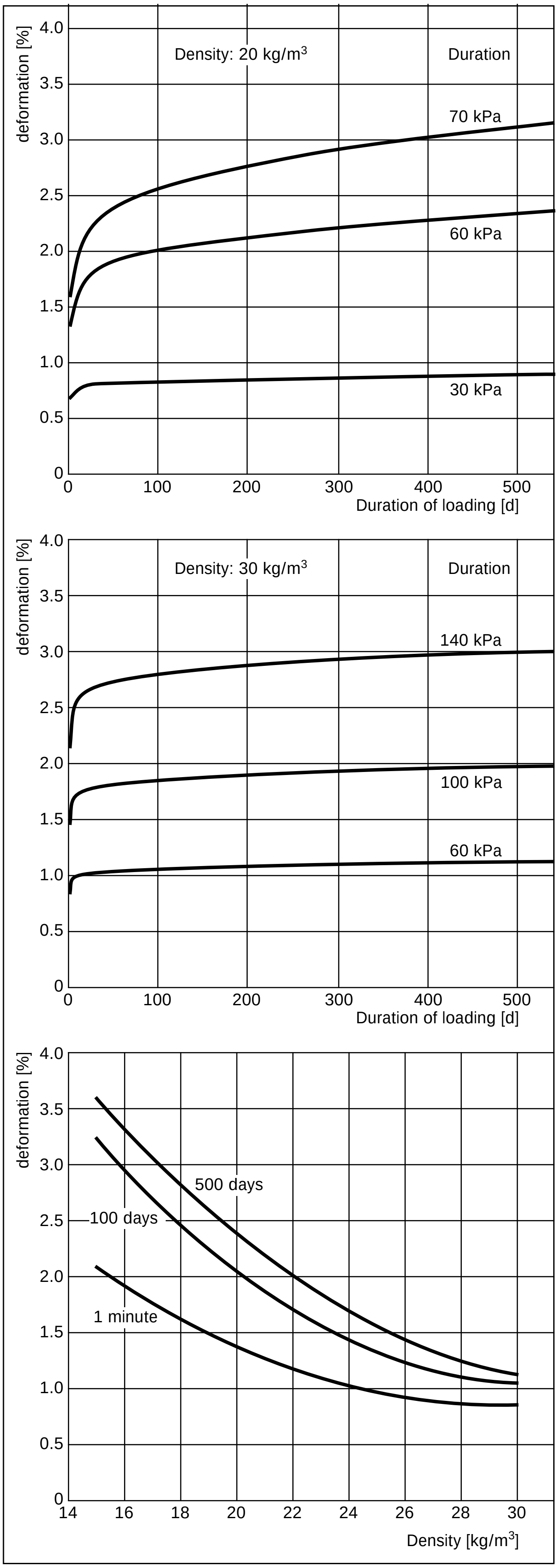


Fig. 3 Compressive creep: strain, ε, vs time, t, or density, ϱ

If the compression of expanded Styropor is measured over long periods, it is found to be time-dependent, as shown in Fig. 3.

Freshly made expanded Styropor resists compression much less well than matured material. Initially, the stress needed for compression by 10 % is only seven-tenths of the final value, attained after about four weeks, but after 24 h the equivalent stress will have risen to nine-tenths of the final value.

The comparatively rapid increase in stiffness during the first day is due to the diffusion of air into the cells, following the pressure drop when the material is first made. Subsequent increases in stiffness may be attributed to loss of the remaining expanding agent.

Tensile strength

Although tensile strength is one of the properties most affected by processing conditions (the others are flexural strength and shear strength), the mean value for any given density does increase linearly with density, as shown in Fig. 4.

The two dotted lines indicate typical 95 % confidence limits, but they may be closer together or further apart, depending on the uniformity of the starting materials and processing conditions. Tensile strength is particularly sensitive to variations in the degree of fusion of the expanded Styropor beads.

Flexural strength

Flexural strength also increases linearly with density, as shown in Fig. 5. The actual deflection at break decreases with density and is also diminished by reduction in the degree of fusion – the material becomes more brittle.

Thermal properties

Expanded Styropor being a thermoplastic, its mechanical properties are affected by temperature. This is illustrated by Fig. 6, which shows how the stress needed for 10 % compression varies with temperature relative to its value at 20 °C.

Measures of the “heat resistance” of expanded Styropor include that of DIN 18 164 Part 1, which requires that specimens subjected to a given compressive stress for 7 d at 20 °C should not undergo further compression exceeding 5 % when the same stress is maintained at a specified higher temperature (e. g. 80 °C) for another 7 d. In the density range 20 – 30 $kg \cdot m^{-3}$ the results of such tests do not depend on density (cf. Table 1). Unstressed

Fig. 4
Tensile strength, σ_T, vs density, ϱ

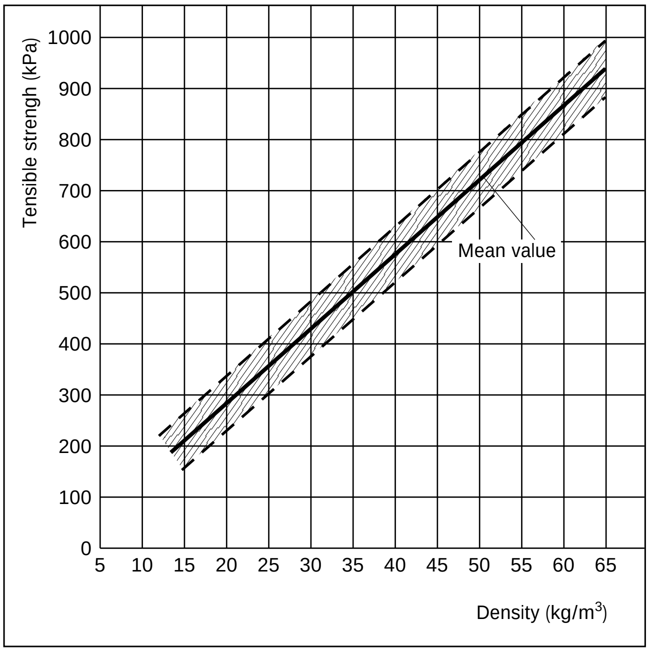


Fig. 5
Flexural strength, σ_F, vs density, ϱ

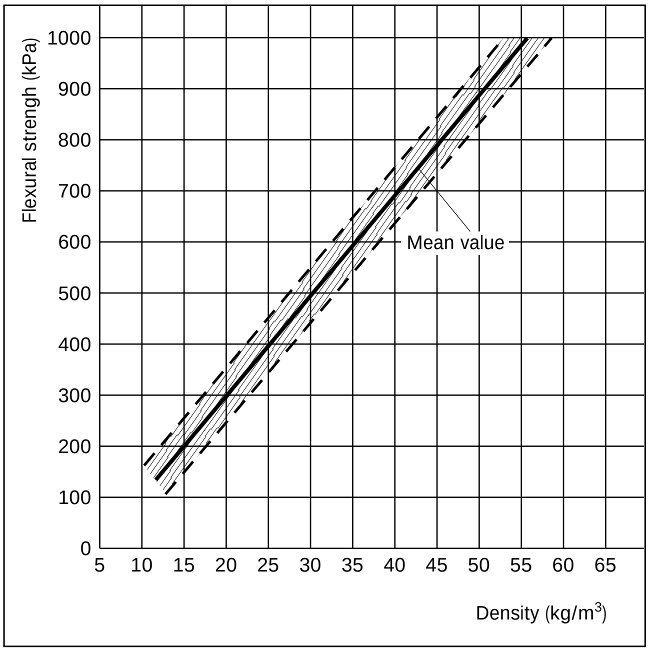


Fig. 6
Stress for compression of 10 %, σ (0.1), relative to value at 20 °C vs temperature, ϑ

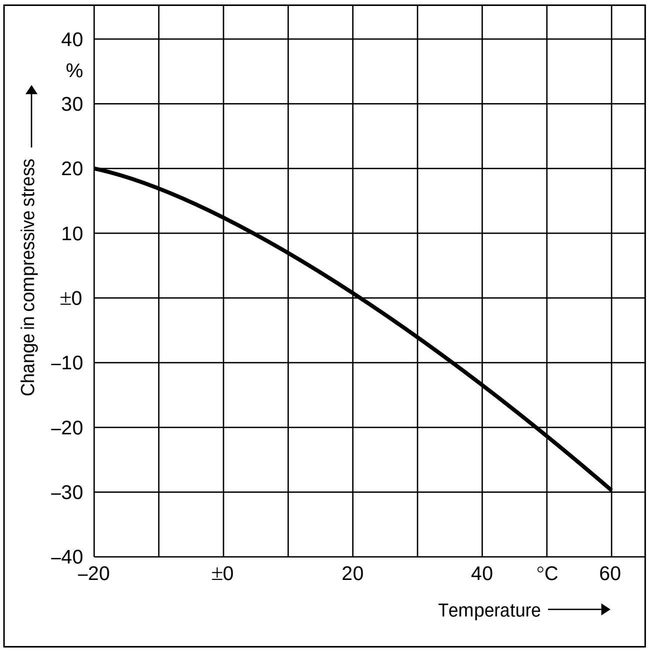


Table 1 Physical properties of expanded Styropor

Properties1)	**Test standard**	**Unit**	**Test result**		
Density	EN ISO 845	kg/m^3	20	25	30
Thermal conductivity at 10 °C	DIN 52 612	$mW/(M \cdot K)$	33 – 36	32 – 36	31 – 35
Compressive stress at 10% compression	EN 826	kPa	110 – 140	150 – 200	200 – 250
Permitted compressive stress for packaging calculation	DIN 52 612	kPa	39	31 – 34	71
Flexural strength	EN 12 089	kPa	260 – 360	360 – 460	460 – 560
Shear strength	EN 826	kPa	230 – 330	300 – 400	380 – 480
Tensile strength	DIN 53 427	kPa	120 – 180	160 – 200	210 – 260
Modulus of elasticity in compression	EN 826	MPa	3.5 – 4.5	5.0 – 8.5	7.5 – 11.0
Specific cushioning factor, c*	DIN 55 471, Part 22)	1	2.5	2.5	2.5
Specific impact resistance capacity, e*	DIN 55 471, Part 22)	kJ/m^3	150	200	250
Coefficient of linear expansion		1/K	$5-7 \cdot 10^{-5}$	$5-7 \cdot 10^{-5}$	$5-7 \cdot 10^{-5}$
Specific heat capacity	DIN 53 765	$J/(kg \cdot K)$	1210	1210	1210
Water absorption when immersed in water after 7 days	DIN 53 434	Vol. %	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapour diffusion flow density	DIN 52 615	1	55	75	85

** At 23 °C, r.h. 0% at one face, 85% at the other.*
1) Corresponding to Test Norm
2) Corresponding DIN 55 471, Part 2

expanded Styropor can withstand temperatures up to 100 °C without harm.

All expanded Styropor is an exceptionally poor conductor of heat. The precise value of its thermal conductivity varies (non-linearly) with density and increases with temperature and moisture content.

The specific thermal capacity of dry expanded Styropor is constant; it is not affected by variations in density (cf. Table 1).

The thermal expansivity of expanded Styropor is also independent of density. The value of the linear coefficient is between $5 \times 10^{-5}\ K^{-1}$ and $7 \times 10^{-5}\ K^{-1}$.

Effects of moisture

Although expanded Styropor may absorb minute proportions of water if immersed for prolonged periods (cf. Table 1), it is not hygroscopic. Any water that is absorbed has no effects on the mechanical properties, which are also unaffected by atmospheric humidity.

Expanded Styropor is somewhat permeable to water vapour. Net flow is from the side with the higher partial pressure of water vapour (often the warmer side) to that with the lower partial pressure. The resistance of expanded Styropor to the passage of water vapour may be derived from the value of the relative vapour resistivity, μ, which is the resistivity of the material relative to that of still air at the same temperature. The relative resistivity of expanded Styropor varies with density, as given in Table 1.

Electrical properties

Expanded Styropor is not an electrical conductor, and its resistivity, measured under standard conditions (23 °C, 50 % r.h.) in accordance with DIN 53 482, is of the order of from $10^{12}\ \Omega \cdot$(cm to $10^{14}\ \Omega \cdot$ cm). Its electric strength is up to 2 $kV \cdot mm^{-1}$.

High electrostatic charges may accumulate on expanded Styropor, particularly in dry atmospheres. However, antielectrostatic agents can be incorporated during processing; these reduce the surface resistance of mouldings, which facilitates dissipation of electrical charges.

The relative permittivity of expanded Styropor of density $20-40 \cdot kg \cdot m^{-3}$ is 1.02 –1.04 for all frequencies between 100 Hz and 400 MHz. The tangent of the loss angle is less than 5×10^{-4} for frequencies up to 1 MHz, and for higher frequencies up to 400 MHz it is only 3×10^{-5}.

3 Chemical properties

All types of expanded Styropor, including those made from Styroperl® or Styrocolor® as well as standard material made from Styropor P or F, behave chemically like polystyrene. However, any attack on the exceedingly thin cell walls inevitably proceeds much more quickly than it would on solid polystyrene, and less dense material is attacked faster than denser material. The resistance of expanded Styropor to a variety of common substances is summarized in Table 2.

Expanded Styropor is resistant to water and all aqueous solutions of salts, alkalis, and acids.

Ethereal oils such as those present in both the peel of citrus fruits and whole-fruit drinks attack expanded Styropor, but it is resistant to both vegetable and animal fats. It is also resistant to mineral waxes of the kind used to guard against corrosion, provided they contain no solvent.

Since most organic solvents attack expanded Styropor, particular care must be taken in the choice of adhesives and paints. Plastics containing plasticizers (e. g. flexible PVC) should not be kept in contact with expanded Styropor because of the risk of plasticizer migration.

Through the use of Styropor FH it is possible to make expanded Styropor mouldings whose resistance to aliphatic hydrocarbons is considerably greater than that of materials made from Styropor P or F. Mouldings made from a grade of Styrotherm® also have enhanced resistance to such hydrocarbons. However, before either Styropor FH or Styrotherm® is chosen for any given application, its suitability needs to be checked.

Before expanded Styropor is used in contact with any substance of unknown composition, tests should be carried out. It is usually best to immerse a specimen of the material in the substance concerned and note any changes (e. g. increase in weight, shrinking or swelling) after an appropriate time. The duration of tests can be reduced by carrying them out at temperatures higher than would occur in normal use.

Effects of UV radiation

Prolonged, direct exposure of expanded Styropor to ultraviolet radiation may bring about the changes that most plastics undergo under such conditions. Since however such changes are generally slow, they seldom have any bearing on packaging whose period of use is not out of the ordinary.

4 Fire behaviour

Like all organic materials, expanded Styropor is combustible, and like most packaging materials it is also flammable. Its burning behaviour depends largely on whether the material is made from Styropor P or Styropor F and the way it is used. Other types of material used with expanded Styropor, e. g. those providing additional protection, may influence events greatly.

Expanded Styropor made from Styropor F contains flame retardant, which makes it more difficult to ignite and slows the spread of flame noticeably. It has been subjected to a wide range of tests prescribed in various national standards for building materials and attains the highest classifications possible for combustible materials (cf. TI 130 and TI 131).

The burning behaviour of expanded Styropor made from Styropor P is comparable with that of other readily flammable packaging materials.

Combustion of Styropor F under the conditions prescribed in DIN 53 436 yields no traces of brominated dibenzodioxins, either in the gaseous phase or in the solid residue, only negligible proportions of brominated dibenzofurans, not one of them a toxic substance within the meaning of the [German] Prohibited Chemicals Order 1994.

5 Biological effects

Pentane vapour escapes from Styropor while it is stored and being processed. Ventilation should be provided, particularly when expanded Styropor is cut with hot wires, since pentane and a small amounts of styrene can be released.

The threshold limit values, workplace limits, etc. for both pentane and styrene must be observed (see TI 180.

Expanded Styropor has no nutritive value for animals. It does not rot, is not soluble in water, and it does not give off water-soluble substances which could lead to ground water contamination. If local regulations allow, waste expanded Styropor can be safely disposed of with household refuse by land fill (cf. TI 810 e).

Expanded Styropor has been manufactured and processed for over forty years, and during that time no harmful effects on health have been recorded.

6 Environmental Questions

Environmental questions related to the manufacturing and processing of Styropor beads and the applications of foams made from Styropor are answered in detail in Technical Information Bulletins

TI 180: “Expanded Styropor and the Environment”

TI 181: Environmental Questions that Arise from Building Applications”

7 Food Packaging Regulations

Detailed information concerning food packaging regulations can be found in Technical Information Bulletin

TI 125: “Legal Questions Concerning Food Packaging”.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

BASF Aktiengesellschaft
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Styropor®

22246 January 1998

3 Properties/Tests

General properties; Building

The use of expanded foams made from Styropor requires knowledge of their properties so that they can be employed to optimum effect and to achieve durable functional capability. The properties of conventional materials are already well known: steel can rust, wood can rot, glass breaks and cardboard loses its strength when it becomes moist. But when it comes to Styropor foams, people are often ill-informed. This technical information leaflet tells you about important properties that are relevant to Styropor foam applications.

Overview of contents:

1 Physical properties

Mechanical loads

One important property of Styropor foam is its mechanical strength when subjected to short-term and sustained loading.

Styropor foams are classed as a rigid foams according to DIN 7726. When under load they exhibit the type of viscoelastic behavior that is uncharacteristic of brittle-rigid materials. It is for this reason that the compressive stress at 10% compressive strain (DIN 53 421) is measured instead of the compressive strength (Table 1). However, this value already lies in the region of irreversible compression and is only of use for characterizing the material (e.g., for quality control purposes), since the mechanical properties depend on the bulk density of the foam.

For the load-bearing capacity under sustained loading, the decisive values are those corresponding to less than 2% compressive strain.

The draft European standard on thermal insulation materials for the building trade describes a method for determining long-term values with respect to creep behavior when thermal insulation materials made from Styropor foam (EPS) are subjected to compressive loads. In future this method can be used for estimating the permissible loads in practical applications or for investigating how the material behaves under sustained loading.

The basis for the mathematical treatment of the system is the Findley equation.

For a defined set of conditions, the amount of long-term deformation can be calculated for any loading period; note, however, that extrapolation is only permitted for up to 30 times the actual test period (see diagrams in Fig. 1).

Table 1 also contains values on shear, flexural and tensile strength. These also increase with rising bulk density.

Judgment of the strength of a foamed material is accordingly only meaningful when the latter is associated with the bulk density value.

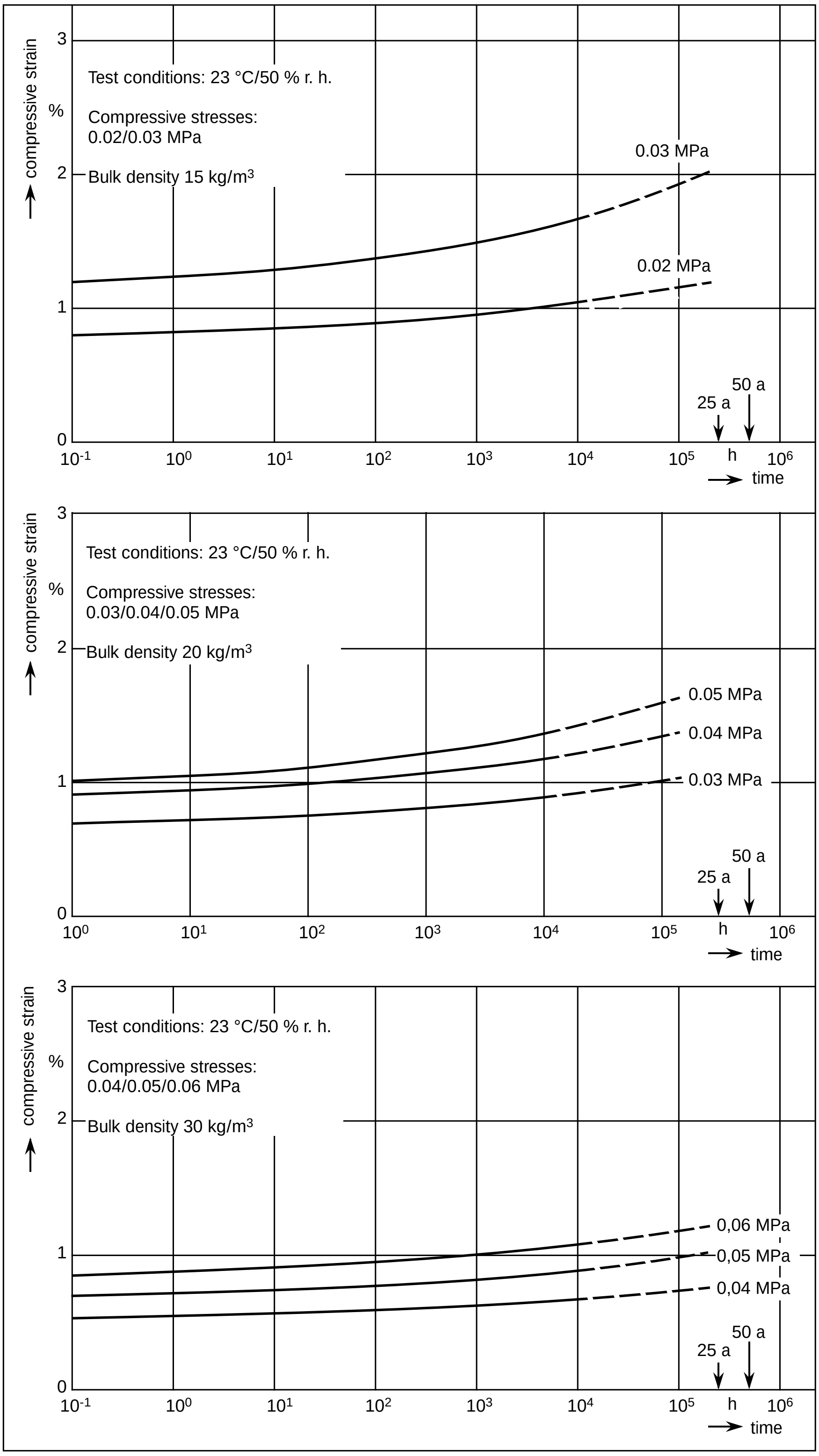

Fig. 1 Compressive behavior over time of Styropor foam with bulk densities of 15, 20, 30 kg/m^3 under various loads.

Heat insulation capacity

A further important physical property of rigid foam made from Styropor is its outstanding thermal insulation capacity with respect to heat and cold. Styropor foam is a polystyrene material made up of polyhedral cells, 0.2 – 0.5 mm in diameter with walls 0.001 mm thick. They are closed on all sides. The foam consists of about 98% of air and 2% of polystyrene. As is well known, the air entrapped within the cells is a very poor heat conductor and so plays a decisive role in providing the foam with its excellent heat insulation properties. Unlike foams containing other gases, the air stays in the cells so that the insulation effect remains constant.

The heat insulation capacity of a material is defined by its thermal conductivity. The thermal conductivity is equal to the quantity of heat (watt-seconds) flowing in one second from the warmer side to the colder side of a 1 m thick layer parallel planar faces each having a cross section of 1 m^2 and maintained at a constant temperature difference of 1 K. The unit is W/(m·K). DIN 52 612 describes how to carry out the measurement. Fig. 2 shows that, provided all other parameters are constant, the thermal conductivity is a function of the bulk density (kg/m^3) of the foam. It is greater for foams of low bulk density, falls with rising bulk density, passes through a minimum value between about 30 – 50 kg/m^3 and after that slowly rises again. The values measured in accordance with DIN 52 612 for Styropor foam with a bulk density of 20 kg/m^3 lie in the range of 0.033 – 0.036 W/(m·K) at 10 °C.

Water and water vapor

A fundamental distinction has to be made between water absorption and water vapor diffusion.

Water absorption

Styropor foam is not hygroscopic, unlike many other foams. Even under water it absorbs only a small amount of water. As the cell walls are impermeable to water, water can only penetrate the foam through the tiny channels between the fused beads. This means that the amount of water taken up depends on how the EPS raw material behaves when processed and on the processing conditions, especially during expansion.

Water absorption is measured accordance with DIN 53 434. For the test, it is preferable to use specimens of the semi-finished and finished moldings to be used in practice. As can be in Table 1, absorption of water is practically independent of the bulk density. After 28 days, the foam absorbs up to about 3 % of its own volume of water.

For most applications, the water absorbed by submerged foam is of little significance and is only of interest in special cases, such as e. g. earthworks, construction of foundations, floats and buoyancy aids, etc.

Water vapor diffusion

In contrast to water, water vapour, which is present in the air as humidity, can, given an appropriate temperature gradient, slowly penetrate (diffuse) into the foam where it accumulates (condenses) as water on cooling. Different materials have varying degrees of resistance to the diffusion of water vapor. The resistance (μS) is a result of the thickness of the barrier (S) and the diffusion resistance factor (μ). The diffusion resistance factor (μ) is a dimensionless number which specifies how many times greater is the resistance of a structural material compared with a layer of air of the same thickness (for air: μ = 1).

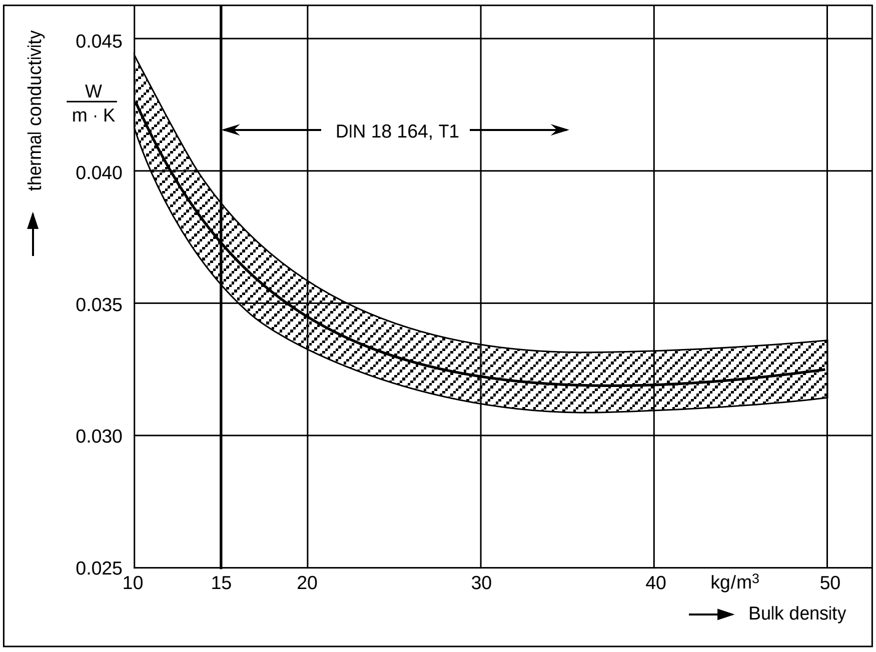

Fig. 2 Thermal conductivity of Styropor foam as a function of bulk density at a mean temperature of 10 °C.

Metals have extremely high diffusion resistance factors, which is why metal foil is used as vapor barriers. The values for all other materials lie between these two extremes of air and metal. Rigid foams made from Styropor have water vapor resistance factors ranging from μ =20 to μ =100 depending on the bulk density (see Table 1 for numerical values according to DIN 4108). When calculating the amount of condensed water for building purposes, the worst-case value is used in each case.

Thermal behavior

There is practically no lower temperature limit for Styropor applications.

Thermally induced volumetric contraction (e. g., in cold room construction) should be taken into account in construction as required. The behavior of rigid Styropor foams at higher temperatures depends on the duration of the thermal exposure and on the mechanical loading on the foam (see Table 1).

Styropor can sometimes withstand short exposure to temperatures well above 100 °C (e. g., bonding with hot bitumen); for longer periods, however, the foam structure begins to soften with sintering.

Dimensional stability

All materials, whether they are raw materials, prefabricated parts or moldings, undergo a certain amount of dimensional change. With Styropor foam, a distinction is made between dimensional changes due to the effect of heat and due to aftershrinkage.

Dimensional change due to the effect of heat

Styropor foam has a thermal expansion coefficient of 5 to $7 \cdot 10^{-5}$ representing 0.05 – 0.07 mm per meter per degree centigrade. This means that a temperature change of about 17 °C causes a reversible change in dimension of 0.1% (1 mm/m).

Special structural measures have to be taken for applications in which dynamic temperature loads occur.

Contraction due to cold also has to be taken into account in Styropor foam. For example, assuming a reference temperature of 20 °C, a part 40 cm in length would contract in this extreme case by about 1 mm when cooled down to – 20 °C in an application. This needs to be borne in mind in construction.

Dimensional change due to aftershrinkage

Freshly expanded foam shrinks partly due to cooling (shrinkage). The contraction of foam which is more than 24 hours old, i. e. after the foam has been expanded, is referred to as aftershrinkage.

Initially, the rate of contraction is relatively rapid and then gradually subsides as it approaches a limiting value, so that no additional structural measures are needed to take account of shrinkage.

The aftershrinkage of Styropor foam panels ranges from 0.3 % to 0.5 % depending on the processing conditions and the bulk density of the foam.

A considerable part of the aftershrinkage of foam panels can be

Table 1 Physical data for foams made from Styropor for construccion

Properties1)	**Test standard**	**Unit**	**Test result**		
Quality assured types	GSH quality conditions		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18 164, Part 1		W	WD	WD + WS
Minimum bulk density	EN ISO 845	kg/m^3	15	20	30
Building material class	DIN 4102		Poorly B 1 flammable	Poorly B 1 flammable	Poorly flammable
Thermal conductivity					
Measured value at + 10 °C	DIN 52 612	mW/(m · K)	36 – 38	33 – 35	31 – 34
Calculated value according to	DIN 4108	mW/(m · K)	40	40	35
Compressive stress at 10 % compressive strain	EN 826	kPa	65 – 100	110 – 140	200 – 250
Resistance to sustained compressive loads at < 2% strain after 50 years	ISO 785	kPa	20 – 30	35 – 50	70 – 90
Flexural strength	EN 12 089	kPa	150 – 230	250 – 310	430 – 490
Shear strength	DIN 53 427	kPa	80 – 130	120 – 170	210 – 260
Tensile strength	DIN 53 430	kPa	160 – 260	230 – 330	380 – 480
Modulus of elasticity (compressive test)	EN 826	MPa	1.0 – 4.0	3.5 – 4.5	7.5 – 11.0
Heat deformation temperature					
short-term	based on DIN 53 424	°C	100	100	100
long-term at 50 kPa		°C	75	80	80
long-term at 20 kPa		°C	75	80	80
Coefficient of linear expansion		1/K	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$	$5 – 7 \cdot 10^{-5}$
Specific heat capacity	DIN 53 765	J/(kg · K)	1210	1210	1210
Water absorption when submerged (by volume)					
after 7 days	DIN 53 434	Vol. %	0.5 – 1.2	0.5 – 1.5	0.5 – 1.5
after 28 days		Vol. %	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapor diffusion rate	DIN 52 615	g/(m^2 · d)	40	35	20
Water vapor diffusion resistance factor	Calculated according to DIN 4108, Part 4	1	20/50	30/70	40/100

** 1 N/mm^2 ≙ 1 MPa*

1) Corresponding to Testnorm

Table 2 Resistance of Styropor foam to chemical agents

Active agent	**Styropor P + F**
Salt solutions (sea water)	+
Soaps solution and wetting agents	+
Bleaching solutions, such as hypochlorite, chlorine water, hydrogen peroxide solutions	+
Dilute acids	+
35 % hydrochloric acid, nitric acid up to 50 %	+
Anhydrous acids, (e.g., fuming sulfuric acid, glacial acetic acid, 100 % formic acid)	–
Sodium hydroxide, potassium hydroxide and ammonia solution	+
Organic solvents such as acetone, ethyl acetate, benzene, xylene, paint thinner, trichloroethylene	–
Saturated aliphatic hydrocarbons, surgical spirit, white spirit	–
Paraffin oil, Vaseline	+ –
Diesel oil	–
Motor gasoline (regular grade and premium grade gasoline)	–
Alcohols (e.g., methanol, ethanol)	+ –
Silicone oil	+

+ – Resistant: the foam remains unaffected even after long exposure.
+ – Limited resistance: the foam may shrink or suffer surface damage on prolonged exposure.
– Not resistant: the foam shrinks more or less rapidly and is dissolved.

expected to occur during storage at the manufacturer's site.

Fig. 3 shows the course of aftershrinkage from the 14th day after the foam has been produced. The final value is reached after about 150 days and lies in the range 1.5 – 2.0 mm/m (0.15 – 0.2 %). These dimensional changes can be tolerated for almost all building applications and, in contrast to thermally induced dimensional changes, are irreversible.

In cases requiring a lesser degree of aftershrinkage, the panels must be stored for an appropriate length of time before being used.

Styropor FH is a grade for making foams with enhanced resistance to aromatics-free hydrocarbons by comparison with other Styropor grades. The suitability of this product for a specific application should be checked in each individual case.

Effects of radiation and weathering

The foam structure becomes brittle after long exposure to high-energy radiation (e. g., short-wave UV, X-rays and γ-rays). The process depends on the type of radiation, its intensity and the exposure time. In practice, only UV is of any interest. Long-term exposure to UV turns the surface of the foam yellow and brittle, rendering it liable to erosion by wind and rain. Such effects can be reliably prevented by simple means such as painting, coating, lamination, etc. Indoors, the amount of UV is so small that no impairment of the Styropor foam occurs, as decades of experience with ceiling tiles have shown.

2 Chemical properties

Styropor foams are resistant to many chemical substances.

Adhesives, paints, solvents and their concentrated fumes may, however, damage the foam. See Table 2 for details of the resistance of Styropor foam to chemicals.

3 Food Packaging Regulations

Detailed information concerning food packaging regulations can be found in Technical Information Bulletin

TI 125: "Legal Questions Concerning Food Packaging".

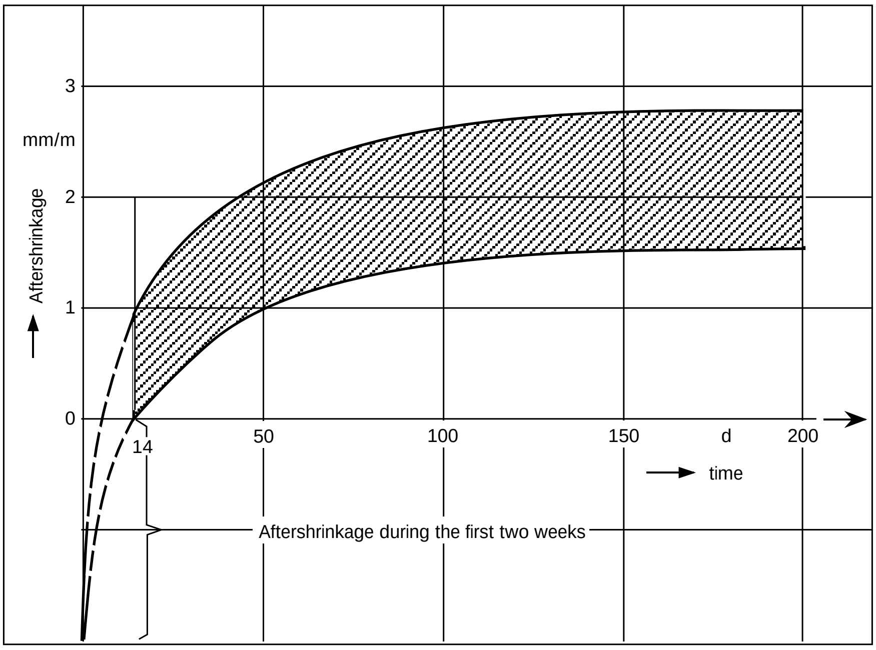

Fig. 3 Course of aftershrinkage of Styropor foam panels over time from the 14th day after manufacture.

4 Environmental Questions

Environmental questions related to the manufacturing and processing of Styropor beads and the applications of foams made from Styropor are answered in detail in Technical Information Bulletins

TI 180: "Expanded Styropor and the Environment"

TI 181: "Environmental Questions that Arise from Building Applications"

Styropor foams can withstand temperatures of up to 85 °C. At this temperature they do not decompose or give off toxic fumes. More information about the behavior of Styropor at high temperatures, its behavior in fires and about the toxicity of thermal decomposition products is provided in our technical information sheet TI 130 "Behavior of expanded Styropor foams in fires".

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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BASF

3 Properties/Tests

Shrinkage and aftershrinkage of Styropor blocks and panels

Whenever expanded foams are produced from Styropor, dimensional changes due to the material and the processing take place after demolding. As in injection moldings and molded parts made from other plastics, a distinction is made between shrinkage and aftershrinkage.

1 Shrinkage

Molding shrinkage is defined as the difference between the internal dimensions of the mold at room temperature and the corresponding dimensions of the expanded foam after it has cooled to room temperature and been stored for 24 h. It is specified in percent with respect to the internal size of the mold.

The shrinkage is essentially caused by the thermal contraction of the expanded Styropor when it cools from the molding temperature to ambient temperature. Shrinkage in length, width and thickness is approximately the same and amounts to about 1%. Higher values or uneven shrinkage can occur under unfavorable processing conditions, e.g. at excessively high steam temperatures. Shrinkage depends on the grade of Styropor used, the length of the intermediate aging period and the bulk density.

Since, moreover, shrinkage is also affected by the processing equipment used, the figures given for shrinkage in this publication can only be regarded as indicative values.

Effect of bulk density

In general, the molding shrinkage of expanded Styropor decreases linearly with bulk density, as shown in Fig. 1. However, two other important factors discussed below are the grade of Styropor used and the duration of the intermediate aging period.

Effect of bead size

As shown in Fig. 2, expanded foams produced from finely pelletized grades shrink somewhat more than those made from coarser beads. However, even different grades with same average bead size can exhibit slight differences in shrinkage values.

Effect of intermediate aging

As the intermediate aging period of the preexpanded beads increases, the shrinkage of the fully expanded foam made from it increases proportionately, although each grade can exhibit certain differences.

Shrinkage values for expanded Styropor of density 15 kg/m^3 typically lie in the range 0.5 – 0.9 % if the preexpanded beads are aged for 24 h; the range of values is slightly higher, 0.6 – 0.95 %, if intermediate aging lasts two days. The values given here are only indicative values and are intended to typify the order of magnitude of the change to be expected. Fig. 3 shows an example of this.

Cooling period in the mold

Cooling in the mold for longer than necessary increases molding shrinkage, but not significantly. If the cooling period is too short (i.e. if the mold is opened too soon), the foam particles produced swell in uncontrollable manner, briefly increasing locally and unevenly in length, width and thickness with respect to the internal dimensions of the mold. As a result, however, subsequent shrinkage is somewhat less.

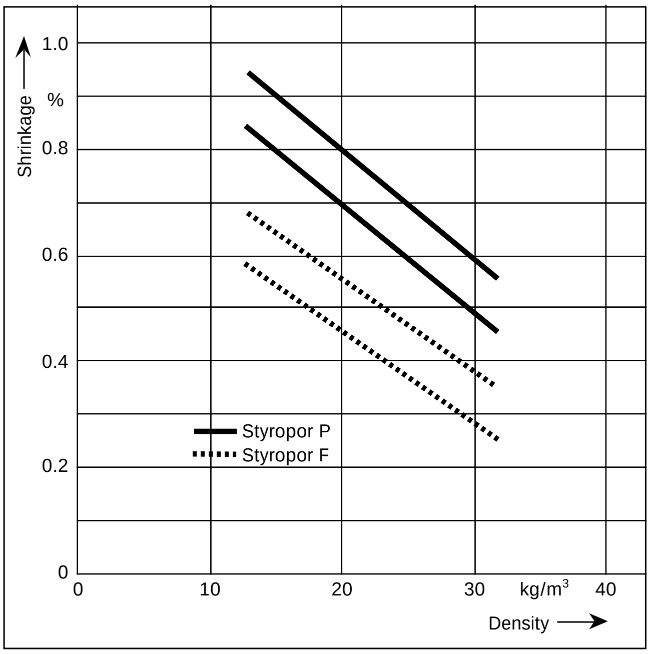

Fig. 1 Shrinkage of Styropor as a function of bulk density (Example of block material after intermediate aging for 1 day)

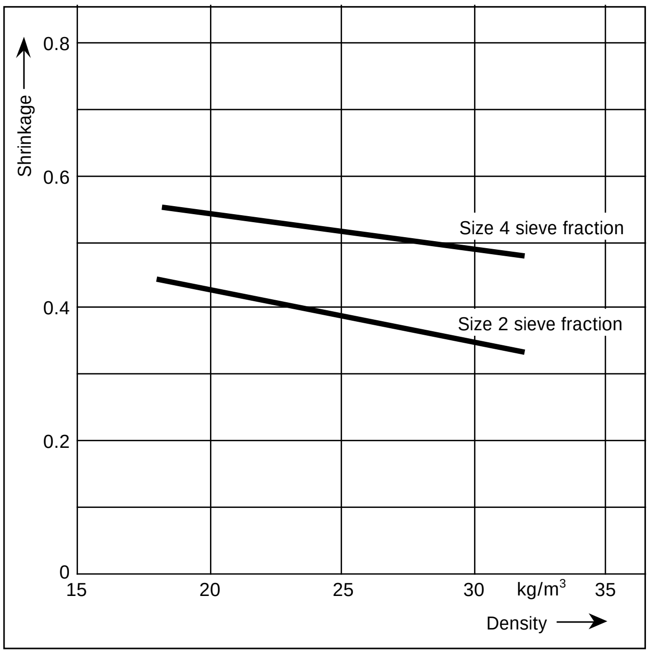

Fig. 2 Effect of sieve fraction on the shrinkage of Styropor (Example of the difference between “size 2” and “size 4” beads)

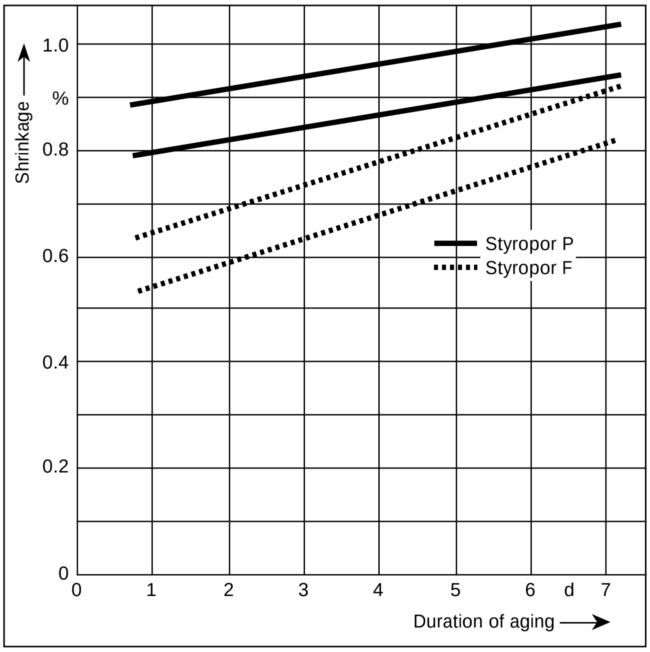

Fig. 3 Effect of intermediate aging on the shrinkage of Styropor (Example of block material having a bulk density of 15 kg/m³)

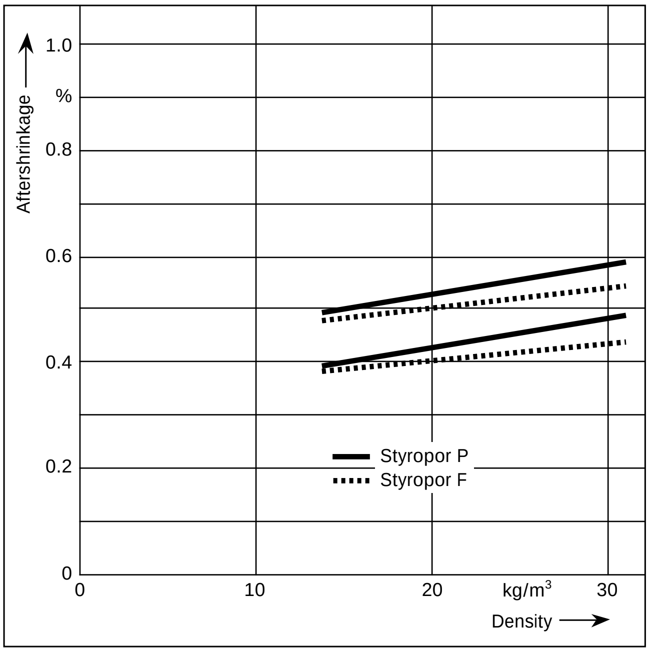

Fig. 4 Aftershrinkage of Styropor as a function of bulk density (Example of block material after intermediate aging for 1 day)

Effect of the product grade used

Typical shrinkage behavior is dependent on the product used. Common to all of these, however, is that shrinkage decreases as the bulk density rises. For intermediate aging of one day, typical values are between 0.5 and 0.9 % at a bulk density of 15 kg/m³ and between 0.3 and 0.6 % at 30 kg/m³. These figures are quoted to give an idea of the order of magnitude of the effect. Special features of individual products are to be found in the relevant Technical Leaflets. An example of the dependence on bulk density is presented in Figure 1.

2 Aftershrinkage

Aftershrinkage is defined as the contraction of an expanded foam commencing 24 h after removal from the mold. It is expressed in percent with respect to the dimensions of the expanded foam 24 h after removal from the mold.

Aftershrinkage is largely the result of loss of residual blowing agent by diffusion from the foam. Provided the Styropor has been processed under the conditions appropriate to the material, aftershrinkage is about the same in all directions of a block or panel. Aftershrinkage is affected by both the bulk density of the material and the duration of the intermediate aging period of the preexpanded beads.

Differences in aftershrinkage between different grades of Styropor are usually small, but can be considerable in certain cases (low-pentane products). However, detailed discussion of the behavior of individual products is not possible here.

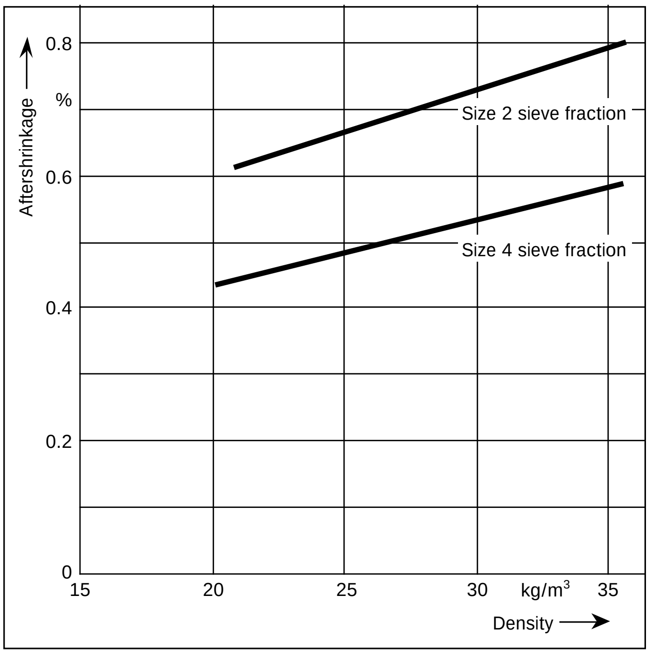

Fig. 5 Effect of sieve size on aftershrinkage (Example of the difference between "size 2" and "size 4" beads)

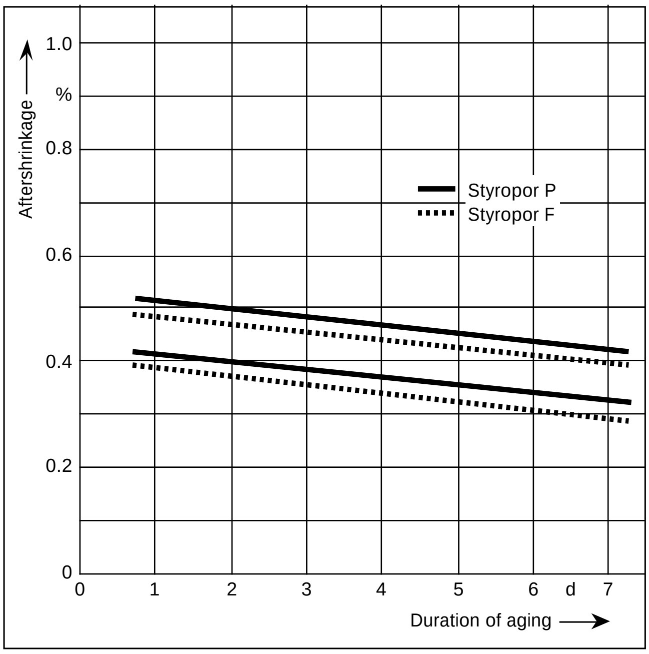

Fig. 6 Effect of duration of aging on aftershrinkage of Styropor (Example of block material having a bulk density of 15 kg/m^3 after storage for 1 day)

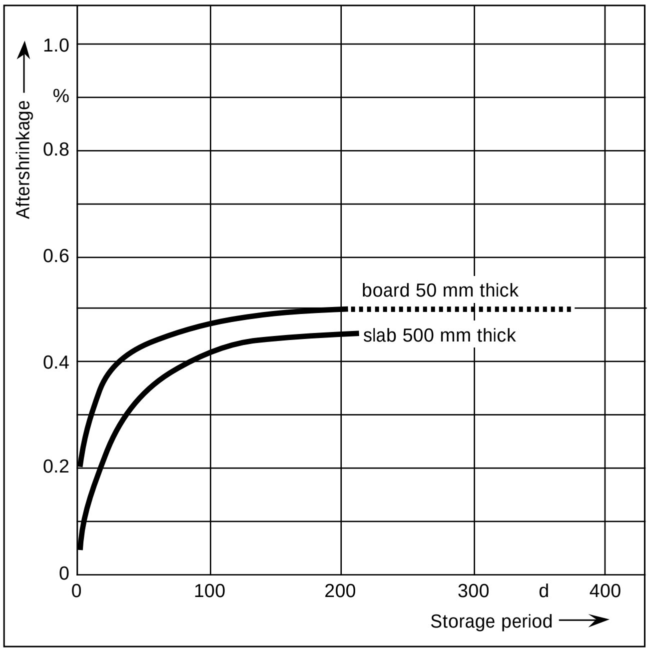

Fig. 7 Effect of panel thickness on aftershrinkage of Styropor (Example of block material having a bulk density of 15 kg/m^3 after storage for 1 day)

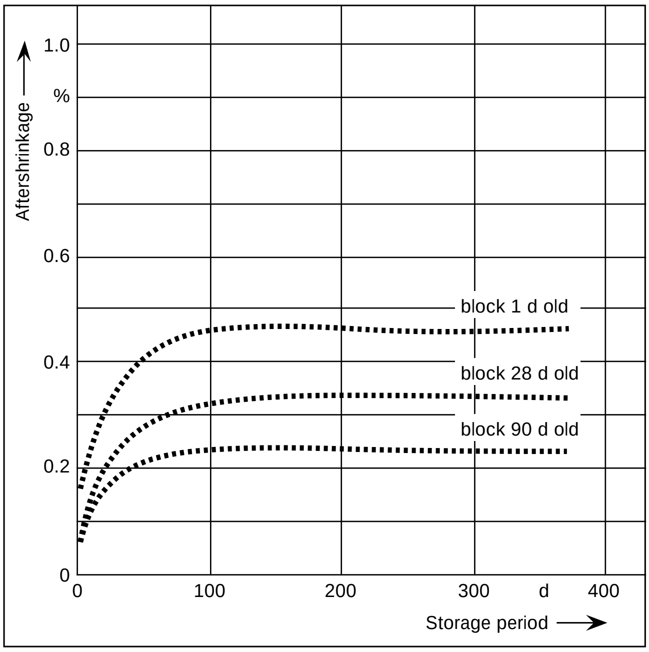

Fig. 8 Effect of storage time before cutting on aftershrinkage of Styropor. Bulk density 15 kg/m^3

Effect of bulk density

It is striking that by comparison with shrinkage, aftershrinkage exhibits exactly opposite behavior, i.e. it increase with rising bulk density. As has already been explained with regard to the effect of the duration of intermediate aging, the effect of the grade of Styropor used cannot be wholly neglected. Figure 4 therefore only provides guidance as to the order of magnitude of aftershrinkage as a function of bulk density.

Effect of bead size

In general, there is a slight increase in aftershrinkage with rising mean diameter of the beads, i.e. it increases in accordance with the sieve fraction sequence 4 > 3 > 2 (Figure 5). However, different grades with the same mean bead size may yield slightly different aftershrinkage values.

Effect of intermediate aging

Figure 6 shows that aftershrinkage is inversely proportional to the duration of intermediate aging. Since the differences in aftershrinkage between different grades of Styropor are not wholly negligible, the trend illustrated in this figure provides only an indication of the effect of intermediate aging time. Details about exceptions such as low-pentane products can be obtained from the relevant Technical Information leaflets.

Serial reexpansion of preexpanded beads has no discernible effect on the level of aftershrinkage. Double expansion only results in a reduction of aftershrinkage when the bulk density of the preexpanded beads is significantly lower than that of material which has been expanded once.

Effect of final expansion conditions and cooling time

The manner in which steaming is carried out can result in the production of foamed materials having properties which are dependent on direction (anisotropic). Thus, e.g. aftershrinkage may not occur evenly in every direction. On the other hand, varying the duration of the cooling cycle has no discernible effect on aftershrinkage.

Effect of panel thickness and storage time

Increasing panel thickness slows down the rate of aftershrinkage as the example in Figure 7 shows. However, panel thickness has no great effect on the absolute amount of aftershrinkage. Increasing the aging of the block before cutting it into panels reduces the absolute amount of aftershrinkage of the panels, but has no effect on the length of time the board has to be aged to attain its final dimensions (cf. Fig. 8). As already noted for the other influencing variables, the dependence of aftershrinkage on storage time is also determined to a certain extent by the nature of the product used. Thus the dependencies shown are intended only for guidance as to the order of magnitude of the effects.

Effect of vacuum

The escape of pentane from the expanded material (cause of aftershrinkage) can occur in principle in two ways:

- by diffusion through the cell walls – a slow process;
- by flowing through narrow channels and interstices between beads. Depending on the size of the available cross sections this can be a relatively fast process. Significant pressure differences between the interior of the foam and the atmosphere (e.g. with the aid of vacuum) have a favorable effect.

Accelerating the escape of pentane

(a) Increasing molding pressure

At expansion pressures > 0.95 bar the penetration of vacuum into the foam is rendered very difficult. If, however, the preexpanded beads are treated with paraffin oil (about 0.2 % by weight), the expansion pressure can be increased to 1.00 –1.05 bar without impairing the penetration of the vacuum into the foam. A short depressurization time (DT) means faster escape of pentane.

(b) Applying vacuum after steaming

The amount of vacuum has a significant effect on DT:

at – 0.3 bar there is almost no effect on DT;

at – 0.5 bar, DT is reduced considerably;

at – 0.7 bar there is a very marked reduction in PET.

The time taken to achieve the desired partial vacuum (e.g. – 0.5 bar, say) is also important. For block molds the best time is 8 s, while for molding machines it should be 3 s.

For the amount of residual pentane in the interstices of blocks (values measured by means of the Exotector supplied by GSG) see the following table.

Effect of product grades

The differences in aftershrinkage between different product grades are seen quite clearly in the flameproofed, low-pentane grade of Styropor in the F 95 series in comparison with the standard F 15 grade. For a residual aftershrinkage of 0.2 %, which is common in practice, the required storage time is reduced.

Figure 9 shows the aftershrinkage in percent against the storage time in days. The advantage of the F 95 Styropor product over the F 15 product can be seen in a shorter time of about one week as opposed to 2.5 weeks for the same residual aftershrinkage of 0.2 %. The shorter storage time thus also has a positive effect on the storage area needed.

Type of mold and residual pentane in blocks

Type of mold	Mold width	Vacuum cooling	Age of block [h]	Residual pentane [ppm]
Vacuum mold	1080	yes	0 24 48	11 500 –12 000 8 000 –10 000 5 000 – 6 000
Conventional mold	535	no	144	> 14 000

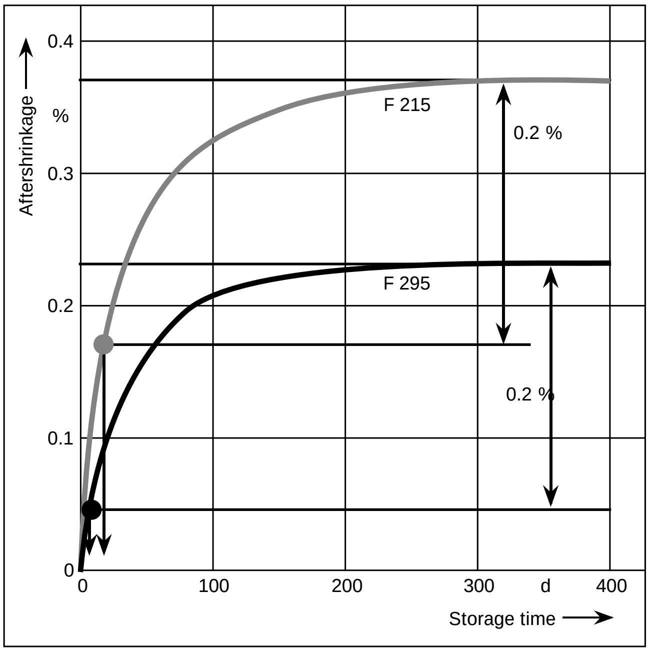

Fig. 9 Aftershrinkage of 50 mm block boards (having a bulk density of 15 kg/m³) made from low-pentane Styropor F 295 in comparison with Styropor F 215

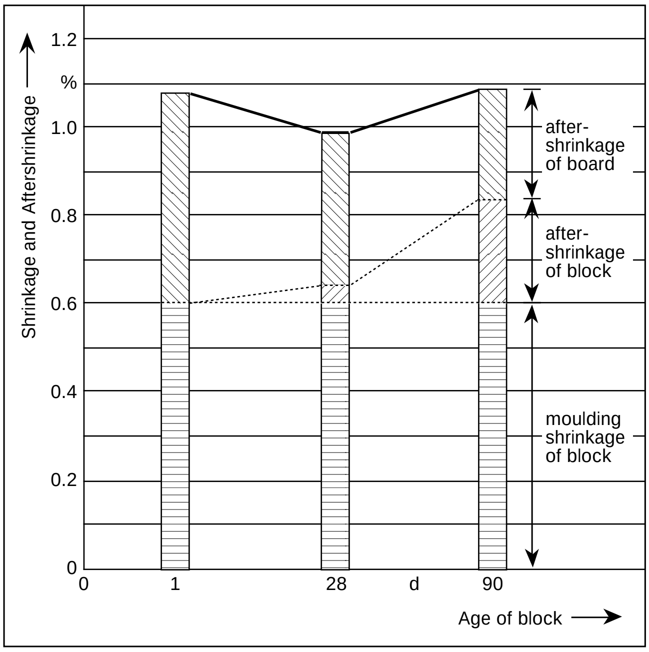

Fig. 10

3 Total shrinkage

The total shrinkage for expanded foam panels made from Styropor is the sum of the following contributions:

- molding shrinkage of the block
- aftershrinkage of the block
- aftershrinkage of the panel.

For different block aging times the total shrinkage always attains approximately the same value as can be seen in Figure 9 showing the results of measurements on blocks and panels made from Styropor.

4 Minimum aging time

Dimensional changes in expanded foam made from Styropor are also caused by temperature differences. The linear coefficient of thermal expansion underlying this behavior amounts to $5-7 \cdot 10^{-5}$ K^{-1} for expanded foams made from Styropor. A temperature change of 15 K thus results in a reversible linear deformation of about 0.1%. In practice therefore, a residual aftershrinkage of the expanded foam panels of 0.1 to 0.2% can be tolerated.

The storage times of panels needed for the aftershrinkage to fall off to this tolerable residual aftershrinkage depend on the duration of the preceding storage in the form of a block. As the block storage time increases, the aging period required for the panels reduces. However, due to the slower aftershrinkage of blocks, the total aging period for the block and panels increases. The total storage period for attaining the tolerable residual aftershrinkage can thus be shortened by shortening the preceding aging of the block.

Note

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Resistance of expanded materials to chemicals

The resistance of expanded foams made from Styropor to chemicals corresponds to that of moldings made from polystyrene. However, because Styropor's cell structure gives the material a greater surface area, damage occurs more rapidly and to a greater extent than is the case with the dense parent polystyrene material. Accordingly, foamed materials of low bulk density are attacked more rapidly and to a greater extent than those of higher density.

In practice (e.g. in the construction or packaging sectors) it is very important to know how expanded materials made from Styropor react to chemical substances in order to prevent faults in application.

Test

The test for resistance is based on DIN 53428 "Testing of expanded foam materials; Determination of the reaction to liquids, vapors, gases and solid materials". In this DIN standard, 5 foam cubes without expansion skin and with sides measuring 5 cm are immersed in the test medium for a definite length of time and changes occuring in the rest samples, e.g. in mass and dimensions, are determined. The exposure time depends on the test medium: for liquids it is 72 hours; for gases 24 hours; and for liquefied gases, at least three hours.

For liquefied gases the immersion temperature is at, or just under, the boiling point of the test medium in question; in other media, immersion takes place at room temperature.

For visual assessment of damage, DIN 53428 suggests a scale of criteria from 0 (no change) to 5 (severely damaged). To provide a simplified overview, the table overleaf contains the following assessment criteria:

+ = unchanged (≙ 0)
= resistant
+– = slight change (≙ 2)
= limited resistance
(small change in dimensions)
– = severely damaged (≙ 5)
= not resistant

If expanded Styropor foams are to come into contact with substances of unknown composition that could contain damaging solvents (e.g. paints or adhesives) it should be ensured in advance that the foam is not attacked by carrying out a trial under field conditions. The trial may be shortened considerably if it is carried out at temperatures above 20 °C (e.g. 50 °C). To obtain clearer evidence of the foam's resistance, the severity of the test conditions can be increased by testing a foam whose density is much lower than that intended for the actual application.

The table overleaf shows the resistance of expanded foam made from Styropor to the most important chemical substances.

Substance	Styropor P & F foams
Sea water	+
Water	+
Alkalis:	
Ammonia water	+
Bleaching solutions (hypochlorite, hydrogen peroxide)	+
Potassium hydroxide solution	+
Lime water	+
Caustic soda solution	+
Soap solutions	+
Dilute acids:	
Formic acid, 50 %	+
Acetic acid, 50 %	+
Hydrofluoric acid, 4 %	+
Hydrofluoric acid, 40 %	+
Phosphoric acid, 7 %	+
Phosphoric acid, 50 %	+
Nitric acid, 13 %	+
Nitric acid, 50 %	+
Hydrochloric acid, 7 %	+
Hydrochloric acid, 18 %	+
Sulfuric acid, 10 %	+
Sulfuric acid, 50 %	+
Concentrated acids:	
Formic acid, 99 %	+
Acetic acid, 96 %	–
Propanoic acid, 99 %	–
Nitric acid, 65 %	+
Hydrochloric acid, 36 %	+
Sulfuric acid, 98 %	+
Fuming acids:	
Nitric acid	–
Sulfuric acid	–
Anhydrides:	
Acetic anhydride	–
Carbon dioxide, solid	+
Sulfur trioxide	–
Weak acids:	
Humic acid	+
Carbonic acid	+
Lactic acid	+
Tartaric acid	+
Citric acid	+
Gases:	
a) inorganic	
Ammonia	–
Bromine	–
Chlorine	–
Sulfur dioxide	–
b) organic	
Butadiene	–
Butane	–
Butene	–
Natural gas	+
Ethane	+
Ethene (ethylene)	+
Ethyne (acetylene)	+
Methane	+
Propane	+
Propene (propylene)	+
Propene (propylene) oxide	–

Substance	Styropor P & F foams
Liquefied gases:	
a) inorganic	
Ammonia	+
Inert gases	+
Oxygen (risk of explosion)	+
Sulfur dioxide	–
Nitrogen	+
Hydrogen	+
b) organic	
Methane	+
Ethane	+
Ethene	–
Ethene oxide	–
Ethyne (acetylene)	–
Propane	–
Propene	–
Propene oxide	–
Butane	–
Butene	–
Butadiene	–
Natural gas	+
Aliphatic hydrocarbons:	
Cyclohexane	–
Diesel fuel, Heating oil	–
Heptane	–
Hexane	–
Paraffin oil	+–
White spirit 55 – 95 °C	–
White spirit 155 –185 °C	–
Vaseline	+
Gasoline (regular & super grades)	–
Alcohols:	
Methanol	+–
Ethanol	+–
Ethylene glycol	+
Diethylene glycol	+
Isopropanol	+
Butanol	+–
Cyclohexanol	+
Glycerin	+
Coconut oil alcohol	+
Amines:	
Aniline	–
Diethylamine	–
Ethylamine	+
Triethylamine	–
Miscellaneous organic substances:	
Acetone	–
Acetonitrile	–
Acrylonitrile	–
Dimethylformamide	–
Esters	–
Ethers	–
Halogenated hydrocarbons	–
Ketones	–
Paint thinners	–
Olive oil	+
Tetrahydrofuran	–

Substance	Styropor P & F foams
Inorganic building materials:	
Anhydrite	+
Gypsum	+
Lime	+
Sand	+
Cement	+
Organic building materials:	
Bitumen	+
Water-based rapid-curing cutback and bituminous knife fillers	+
Solvent-based rapid-curing cutback and bituminous knife fillers (free from aromatics)	–
Aromatics:	
Benzene	–
Cumene	–
Ethylbenzene	–
Phenol, 1% aqu. soln.	+
Phenol, 33 % aqu. soln.	–
Styrene	–
Toluene	–
Xylene	–
Vapors of:	
Camphor	–
Naphthalene	–

Styropor VFH 106 can be used to produce expanded foams that have increased resistance to aromatic-free hydrocarbons by comparison with other Styropor grades. The suitability of this product for a particular application must be checked in each case.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Technical Information

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Styropor®

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BASF Plastics

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® = Registered trademark

Resistance of expanded materials to animal pests and noxious plants

Several kinds of insect also appreciate the thermal insulation provided by expanded material made from Styropor for their nesting places. These are primarily food pests in stables and storage sheds, especially moths of the genus Ephestia elutella (e.g. the hay moth and the flour moth). Their larvae penetrate into the expanded foam in order to pupate. Other insects, like digger wasps and termites, burrow into the material in order to deposit their eggs or to store food (aphids, flies, etc.) for their hatched progeny in the expanded foam.

Preventive measures

An effective way to prevent insects boring into the material is to coat vulnerable surfaces with cement slurry (consisting of cement, sand and water) to which a polymer dispersion should be added to give better adhesion.

The most successful method of preventing rodents burrowing into the material is, likewise, an appropriate coating. This can be achieved, e. g. by a layer of fabric-reinforced plaster or the attachment of some suitable cladding. In doing this attention has to be paid to the durable closure of joints.

Since, however, none of these mechanical barriers provide effective long-term protection against attack by insects or rodents, prophylactic measures for pest control, such as fumigation or spraying potential focal points of infection with commercial insecticides should be preferred in every case.

Note

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Regulatory Questions Concerning Food Packaging

In assessing the health hazards of high polymers and their auxiliaries for use in direct food-contact applications, a number of national and international legal provisions must be adhered to and satisfied.

The flavor and odor of a food may not be influenced in any way by the packaging material. The tests required to show this must be performed by the packager.

It has been demonstrated in practice that this requirement does not present any difficulties provided that the Styropor packaging used has been sufficiently, the only cases where difficulties may arise is with the foods have a particularly sensitive aroma and or contain fats, e. g. chocolate, margarine or cakes which contain creme. In cases of this nature, it be necessary to resort to wrappings produced from parchment paper, plastics film or metal foil.

Packaging produced from coloured Styrocolor® G 360 grades can also be used. However, it must be determined that no colour is transferred to the food by contact. In particular, the manufacturer or packager must ascertain that the finished article (packaging) is suitable for the application in question.

Food legislation

Styropor is used in the production of articles for food-contact applications as defined in the German *Lebensmittel- und Bedarfsgegenständegesetz.* Recommendations from the German Federal Institute for Consumer Health Protection and Veterinary Medicine (BgVV), which are published regularly in the *Bundesgesundheitsblatt,* state conditions under which an article consisting of a high polymeric material meets the requirements of Paragraph 3.1.1 of the act dated 15. 08. 1974.

The monomer styrene used in the production of Styropor/Styrocolor is listed and authorized in EU Commission Directive 90/12/EEC relating to plastic materials and articles intended to come into contact with foodstuffs, dated 23. 02. 1990.

The processing and production aids also used in the production of Styropor/Styrocolor are listed in the corresponding recommendations of the German BgVV for polymers containing polystyrene.

Industrial hygiene

Styropor and cellular foams made from Styropor have been produced and processed for decades. Over this period, no reports have ever been received on any harmful effects health which could be shown to have been caused by the use of these materials.

Even external influences, e. g. manure, earth that has been fertilized with phosphates, acid rain, etc. do not have any significant effect. The expanded material does not rot.

In view of the vapour emitted when Styropor foams are cut with hot wires, we recommend the installation of an exhaust fan or fume hood to remove these vapour from the workplace and to ensure that they remain below OEL, TLV and MAK values.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Fire safety when processing Styropor

Plants which manufacture or process flammable materials must take many factors into account when planning fire protection safety measures and putting them into effect. These include for example:

- the building supervisory regulations, the fire protection laws of the Federal German states, the accident prevention rules of the German Professional association of the chemical industry, the German trade and industry code and finally the stipulations of the fire insurer too;
- generally applicable legal provisions and standards;
- special fire protection features in the layout of the buildings;
- special characteristics of the production processes in question and their technical facilities;
- particular properties of the materials used in their different states of matter.

The following recommended safety precautions are not obligatory and do not relieve plant management of the need to observe the requirements imposed by law and agencies.

Transportation and storage of raw materials

Raw Styropor is supplied to the processor in the form of small beads and stored in shipping containers which are either cardboard boxes or corrugated metal drums. Large processing plants store it in on-site silos.

Processing

Preexpansion

The raw material is expanded almost exclusively using steam. This is done in stirred units (preexpanders). Due to the elevated temperature of about 100 °C the raw material softens. The vapor pressure of the blowing agent rises and the beads are inflated to approximately fifty times their original volume. In doing so they lose approximately 30% of the blowing agent. Their bulk density subsequently ranges from 10 to 30 kg/m^3. Used process steam and liberated blowing agent are vented to the open air or drawn off by vacuum.

Intermediate aging

After preexpansion the expanded beads are usually stabilized in a fluidized bed, dried and conveyed pneumatically into ventilated intermediate storage bins composed of textile fabric or of metal.

On cooling, blowing agent and water vapor condense in the beads. This produces a partial vacuum which is equalized by the inward diffusion of air. In this way the beads attain the mechanical stability needed for further processing.

Final expansion

Following preexpansion and intermediate aging the partially expanded beads can be processed further in block molds or automatic molding machines.

Steam is again the energy source for doing this. During final expansion the cellular structure plasticizes once more while the combination of blowing agent, air and steam inflates the beads still further. Under the action of pressure and elevated temperature the beads fuse together to form a mechanically stable block or molded article.

Blockware production

The expanded beads are conveyed by pneumatic means from the intermediate aging area to the working storage hoppers of the usually fully automatic block molds. They then come into the molds by gravity feed or via a blower. Modern block molds are generally provided with steam accumulators and vacuum equipment.

After production, the blocks are stored for drying and subsidence of shrinkage prior to further processing.

Production of moldings

The interior of the mold is filled with partially expanded beads by means of injectors and final expansion is carried out. The molded articles are then packed. In modern production processes equipped with vacuum cooling this is done immediately at the machine. Drying is required only in exceptional cases.

The blowing agent still present escapes during aging except for a residual amount.

Further processing of blockware

Blocks of expanded foam are cut up into panels or boards. This is usually done using vibrating heated wires or with hot knives and saws. At this stage of production the material can also be finished for special applications by elastication or lamination with various coatings or by flock spraying or printing.

Storage of finished product

The shipping store receives the finished articles and if they are not already packed the boards are wrapped in shrink film or banded. Moldings are packed in cardboard boxes or likewise protected by means of film.

Treatment of waste

Waste arising during the production of blockware and moldings can be used within certain limits as raw material for the manufacture of new products. The requirements are that it must be clean, free of dust and be crushed to a particular size.

Ground expanded Styropor foam waste has been used for years under the name of Styromull® for soil improvement in fruit growing, viniculture, landscaping, gardening and sports grounds. More recently it has also been employed as a composting aid. According to the German fertilizer statute, enacted on November 15, 1977, Styromull is treated as a soil improver. It is also suitable for pipe and ditch drainage.

Waste materials can also be converted by sintering and fusion processes into the dense starting material, polystyrene. This can be used to manufacture simple products by injection molding or extrusion.

A different possibility for reuse consists in exploiting the thermal energy of ground expanded foam waste to generate steam in special combustion chambers. In doing this, however, the legally permissible levels for smoke emissions have to be observed.

Expanded Styropor foams do not release harmful substances into the air, soil or groundwater. They can therefore also be deposited without problem in well managed garbage dumps.

Fire characteristics of Styropor

Styropor as a raw material

In chemical terms raw Styropor is composed to the extent of more than 90% of polystyrene or styrene copolymers which contain a mixture of low-boiling hydrocarbons as blowing agent. The F grades additionally contain a flame retardant.

Both the polymer components as well as the blowing agent are flammable substances.

Since 1987, raw Styropor has been classified as a fire hazard in accordance with the ADR and RID, the international regulations for the transportation of hazardous goods. The blowing agent component is a flammable liquid of hazard class A having a flash point in accordance with DIN 51 755 of – 20 °C. As it is dissolved in the polymer, however, the mixture cannot be assigned an exact flash point.

If, however, the temperature at which grades of Styropor evolve flammable vapors in a concentration capable of ignition is determined, the values obtained are considerably higher than the flash point of the blowing agent. Based on DIN 51 755 the value for Styropor P grades is 29.0 °C and for F grades 26.5 °C. The German regulations for the construction and operation of plants for storing, filling and conveying flammable liquids on land do not apply to Styropor because the product remains in the solid state up to the set temperature limit of 35 °C.

Many tests have shown that Styropor does not decompose suddenly when thermal energy is supplied to it in the early stages of a fire. It behaves on the contrary like comparable organic solids. According to the “Handbuch der gefährlichen Güter” (Handbook of hazardous materials) by G. Hommel the material would be categorized in level 2 (of 4) under “risk of ignition when heated”. In the international regulations for the transportation of hazardous materials as set out in ADR and RID, Styropor is ranked as expandable polystyrene in Class 9.

The unpacked raw material in the loose state does not quickly catch fire when discontinuously exposed to flames from matches. If exposure to flame lasts longer, however, 60 seconds say using a touch-paper or 15 to 30 seconds with the flame of a Bunsen burner, the material expands and ignites.

When Styropor P grades are used in such cases the fire spreads over the surface at a rate of about 3 cm/min. This is a value which also applies to other solid materials (e. g. naphthalene).

On the other hand, when F grades are involved, a fire starting up extinguishes by itself after a short time. On longer exposure to intense flames even Styropor F is changed to the molten state in which it carries on burning independently.

The effect of packaging

Packaging affects the behavior of the raw material in a fire

In corrugated metal drums the risk of self-ignition and spread of fire is low. A considerable amount of thermal energy is needed to decompose the contents and set them on fire.

In the case of cardboard containers also, a relatively long fire initiation phase is to be expected even when flames act directly on the packaging. Only when the outer packing is broken through do the contents start burning and then affect the further development of the fire.

The amount of heat evolved by Styropor depends on the extent to which it is involved in a fire. The heat produced on complete combustion is given by the calorific value which for Styropor grades is about 11 kWh/kg.

Intermediate and final products from processing Styropor

The flammable blowing agent present at all stages of processing also has a substantial impact on the fire characteristics of intermediate and final products. For that reason the ignition characteristics when processing Styropor with or without flame-retardant additives have to be assessed as being approximately equal.

Mixtures of blowing agent and air

The shipping containers for Styropor are not absolutely gastight. Even when stored in cool rooms small quantities of blowing agent escape. It is heavier than air. A mixture of it in air is ignitable in the concentration range of 1.3 to 7.8 vol.%.

The ignition point of pentane according to DIN 51 794 is 230 – 290 °C. Naked flames, glowing embers or sparks can thus initiate combustion of the mixture of blowing agent and air. In the flammability limits this occurs as a flash or even as an explosion.

The presence of hazardous mixtures can be determined easily using gas detectors (e. g. from Auergesellschaft in Berlin, Drägerwerk AG, Lübeck or the Gesellschaft für Gerätebau [GfG], Dortmund).

Preexpanded Styropor

The only difference between the raw material and the preexpanded product is that the blowing agent content is up to 30 % lower.

The foamed structure, however, has a substantial effect on fire behavior. Immediately after preexpansion the high specific surface is not yet perceptible for due to its high moisture content it is initially protected effectively against dangerous heat transmission. That changes, however, as drying proceeds. Flammability increases steadily until in the dry state it is more flammable than the raw material.

Blockware and moldings made from Styropor

Immediately after production, expanded materials made from Styropor still contain approximately 50 % of the quantity of blowing agent in the raw material. This value falls relatively rapidly in the course of storage. The blowing agent escapes except for a residue of 10 –15 %.

Viewed in physical terms the expanded material is a closed-cell structure which softens and shrinks in the temperature range 100 –110 °C and finally melts at higher temperatures.

The melt in turn gives off gaseous, combustible decomposition products at temperatures above 200 °C. When they are present in sufficient concentration, these can be ignited by heat sources at more than 450 °C (flames, sparks or glowing embers). The ignition temperature according to DIN 54 836 is 362 °C for expanded foams made from Styropor P grades and 374 °C for those made from F grades.

According to recognized fire protection definitions spontaneous ignition of expanded foam made from Styropor may be ruled out.

The fire properties of freshly produced expanded foam made from Styropor are determined in large measure by the blowing agent still present in it.

After adequate storage, the duration of which depends on the shape and thickness of the molded articles but is at least two weeks, the blowing agent is no longer decisive.

Expanded foam made from Styropor P

In the test for the fire characteristics of building materials and building parts according to DIN 4102, board-shaped samples of expanded Styropor foam are classified as readily flammable. In this test a small ignition flame acts from beneath on a vertically arranged sample. In this case expanded foam made from Styropor exhibits a vertical flame spread of ≥ 15 cm in 20 s. By comparison with this, cellulose materials such as paper, board and thin pieces of wood are likewise classed as readily flammable as defined in these provisions (method of Seekamp and Roeske [3]).

	Thickness (mm)	Speed (cm/s)
Expanded foam made from Styropor P	10	1
Paper	0.05 – 0.16	5.0 – 1.2
Cardboard	0.5	0.5 – 0.7
Corrugated board	3.2	0.7
Walnut veneers	0.6	1.4 – 1.7
Solid woods	2	0.6 – 0.8

Expanded foam made from Styropor F

The flammability and flame-spread of expanded foams made from Styropor F are reduced so markedly that boards made from it can be classified as “flame-resistant” as defined in DIN 4102. After ignition with small flames they do not carry on burning. They go out as soon as the igniting flame is removed.

In a test in accordance with the standard UL 94 (Horizontal Burning Test for Classifying Foamed Materials 94HBF, 94HF-1 of HF-2) they are to be classified as 94HF-1.

Fire tests on a scale of 1 : 1 carried out by the University of Karlsruhe revealed a significantly delayed flame spread in expanded foam made from Styropor F by comparison with foam made from Styropor P without fireproofing additive (molded article test method according to DIN 53 438, Part 3).

Emissions when expanded Styropor foam is involved in fires

The health hazard due to thermal decomposition products arising from expanded foams made from grades of Styropor in the event of a fire were investigated as early as 1976 jointly by the laboratory for plastics engineering at the Technologisches Gewerbemuseum (Industrial technology museum) in Vienna in association with the toxicology laboratory of BASF Aktiengesellschaft. The results were published in Chapter 1 “Brandschutz” (Fire precautions) in Professor E. Neufert’s Styropor Handbuch (Styropor handbook).

In the investigations which were carried out in accordance with DIN 53 436 the concentrations of the individual components of the thermal decomposition products given in the table were found. Apart from rigid Styropor foam, cellulose-based building materials were also included for comparison.

The extensive toxicological tests show that fumes from burning Styropor represent no greater toxic risk than fumes from natural materials, such as wood, cork or wool for example.

Plastics containing hexabromocyclododecane (HBCD) as flame retardant have been checked repeatedly for the possibility of polybrominated dibenzodioxins and dibenzofurans (PBDD, PBDF) being formed in the event of a fire. In 1990 on behalf of the Umweltbundesamt (German Federal Environment Office) **Hutzinger [1]** also checked among other things the combustion fumes from PS granules having a HBCD content of 3 %. He came to the conclusion that the formation of such substances is dependent not only on the conditions of the fire but also on the molecular structure of the flame retardant and found that in the case of HBCD examined, the probability of formation of PBDD and PBDF was negligibly small.

Further independent studies have come to similar results **[2].**

In tests conducted by the Münster office for commercial and industrial supervision when EPS blockware was cut with hot wires no brominated dibenzodioxins were found in the air at the workplace. The concentrations measured for brominated dibenzofurans amounted to less than 1 % of the non-critical daily dose.

The results of these tests also fit with the fire characteristics of stored stacks of boards and are therefore very important for the assessment of fire hazards in processing plants.

Specimen	Constituents of fire fumes	Composition of fumes in ppm at a test temperature of:			
		300 °C	400 °C	500 °C	600 °C
Expanded Styropor P	Carbon monoxide	50*	200*	400*	1000**
	Styrene monomer	200	300	500	50
	Other aromatics	traces	10	30	10
	Hydrogen bromide	0	0	0	0
Expanded Styropor F	Carbon monoxide	10*	50*	500*	1000*
	Styrene monomer	50	100	500	50
	Other aromatics	traces	20	20	10
	Hydrogen bromide	10	15	13	11
Pine	Carbon monoxide	400*	6000*	12 000**	15 000**
	Aromatics	–	–	–	300
Insulating wood fiberboard	Carbon monoxide	14 000**	24 000**	59 000**	69 000**
	Aromatics	traces	300	300	1000
Expanded cork	Carbon monoxide	1000*	3000**	15 000**	29 000**
	Aromatics	traces	200	1000	1000

Note: Test conditions as laid down in DIN 53 436; air admission rate: 100 l/h; specimen size: 300 x 15 x 10 mm

* *slow-burning/smoldering*
** *burning with flames*
– not measured

Fire risks in individual plant areas

The following pointers as to the relative endangerment of individual areas of the plant relate primarily to the fire hazard characteristics of substances stored or processed there.

Raw materials store

The fire hazard arising from stored Styropor raw materials is generally low if the store is cool, adequately ventilated and the accumulation of mixtures of air and blowing agent is prevented.

Ignitable mixtures of air and blowing agent can sometimes form in emptied containers (e. g. corrugated metal drums). A risk of fire also arises from electrostatic charges which can ignite critical gas mixtures.

Such mixtures can form in flammable concentrations in closed, unventilated storage bins for the raw material. It is accordingly necessary to blanket the storage area with an atmosphere of inert gas. Fire safety measures here are directed in the first instance at preventing the action of a primary fire on the stored material.

Preexpansion

At this stage of processing, the material is protected by its moistness. The risk of fire is low. Nevertheless good ventilation is needed here too. In addition careful grounding of the conveyor and loading devices has to be ensured.

Intermediate aging

Intermediate aging is a particular area of risk since the preexpanded material exhibits a large specific surface. The danger of the mixture of air and blowing agent catching fire and of the fire spreading to the intermediate product is higher at this stage.

Here too good ventilation represents the most important precautionary measure. Further measures are: prevention of electrostatic charges, structural isolation from other areas of the plant, installation of a sprinkler system, strict imposition and observance of a ban on smoking.

Final expansion

The risk of fire is lower in this production area than in intermediate aging. The material introduced at this stage now only contains about 70 % of the amount of blowing agent in the raw material. Moreover, the specific surface reduces considerably during final expansion. Nevertheless, the safety measures already described are also necessary here.

Storage of the finished expanded foam

There is an increased risk in the storage area for expanded foam blocks since due to their large volumes they accelerate the spread of flames.

In the moldings store the fire hazard is mainly determined by the height and area occupied by the stack of material. At the same time, although the danger from escaping blowing agent is much less than in the preceding production areas, adequate ventilation is nevertheless still needed.

In all areas of production and storage the installation of sprinkler systems has a quite decisive effect on reducing the risk of fire.

Cutting and making-up

Overheating due to the heated wires of the cutting equipment and also due to high-speed band knives and saws increases the fire hazard in this processing area. There is additionally the danger of ignition due to finely divided waste (dust) on account of its large surface area and tendency to become electrically charged.

A further fire risk arises when using highly flammable adhesives. When applying adhesives to expanded Styropor foams electrostatic charges can result in the formation of igniting sparks from insulated conductors.

Careful grounding of all metallic parts of equipment and instruments is therefore imperative. Measures also have to be taken to carry away mixtures of air and blowing agent spreading out by diffusion. It must be assumed that making-up will also involve expanded foams which have not been aged for long enough.

All expanded foam wastes must be continuously removed from the plant and conveyed to a separate waste depot.

Expanded foam shipping store

The risk of fire in this area should be assessed as similar to that in making-up. However, two further aspects come into play. The expanded foams are in contact with packaging materials which in the event of an external source of fire can possibly set the packaged goods on fire more readily than would be expected from the flammability of the expanded foam alone. In addition it has to be expected that carelessness will be shown by people from outside the company who are not aware of the incendiary properties of the materials stored there.

Waste depot and waste treatment

Due to their variable shapes, sizes, specific surface, composition and loose storage, waste deposits represent a special fire hazard. This also applies to their removal.

The waste depot and treatment area must be set up at a sufficient distance from the processing plant.

It is very important to be able to respond to any particular storage and processing contingency at any time by means of selective fire protection measures.

Disposal and environmental factors

Expanded foam and production wastes

Due to the high level of soot formation it is not permitted to burn expanded Styropor foams in the open air.

Wastes from Styropor P and F products can be burned without residues in garbage incineration plants or in special combustion chambers. In the case of Styropor F, in addition to CO_2 and H_2O small amounts of hydrogen halide are formed which, however, cause no measurable changes in the composition of the flue gases.

Expanded Styropor foams do not decompose into harmful substances, they are insoluble in water and do not release water-soluble substances which could result in contamination of groundwater. They have therefore been classified in water hazard category 0 (generally not posing a risk to water).

In general, the agencies concerned have no reservations about them being deposited in dumps above ground because water cannot leach pollutants in ecologically toxic concentrations out of the residues.

Fire residues

Fire residues have to be collected and disposed of in accordance with the legal provisions applicable to disposal and with the agreement of the competent authorities. According to the German Official Bulletin 1/1990 the Ministry for the Environment recommends the disposal by incineration of any kind of fire debris (to avoid expensive analyses). However, on account of the favorable properties of fire residues from expanded Styropor foams (insoluble in water, immobile, very low migration rate) there are generally no reservations about dumping fire residues – provided the agreement of the authorities has been obtained.

Expanded foams

Retention of water used to extinguish fires is not required by law for products of water hazard category 0.

In a fire, however, different, water-soluble decomposition products are generally formed. As a preventive measure it can therefore be advisable to take precautions to hold back accumulated extinguishing water so that it does not run into open water courses or into the soil.

Tests have shown that spent water from Styropor fires does not cause any disturbance of communal sewer systems, for example due to precipitation of materials or changes in pH. Dissolved organic substances present in it do not impair the activity of the activated sludge of a treatment plant. They are eliminated to an adequate extent.

There are, therefore, generally no reservations on the part of the competent authorities to the channeling of spent fire-fighting water into the treatment plant.

The test results were obtained using water as the extinguishing medium. In the event that the fire department uses additives in the water, the hazard that these additives represent for water has to be taken separately into account.

Preventive fire measures

Preventive fire measures should always be undertaken in agreement with the local building authorities and the fire department. Specifically, it is recommended that the following be done.

- Separation of the individual storage and processing areas by means of fire-resistant (F 90) structural components between the raw materials store, preexpansion area, intermediate aging store, final expansion area and the storage depot. In situ fire installations can act as a partial substitute for these measures.
- Setting up automatic fire alarm and fire-fighting systems in operating areas particularly exposed to danger.
- Installation of smoke and heat extractors which when needed open automatically or can be operated manually from the outside.
- Good ventilation and venting of all sections of the plant (the blowing agent is heavier than air).
- Observance of the specifications of the VDE (Verband deutscher Elektrotechniker = Association of German electrical engineers) or equivalent specifications for installing electrical equipment in factory locations exposed to fire hazards.
- Ban on fires and naked flames.
- Observance of safety regulations in the course of welding work.
- Ban on smoking.
- Avoidance of storage of relatively large quantities of raw materials and finished products at the processing machines.
- Removal of empty packaging materials from the production areas.
- Fork lift trucks must be fitted with conducting tires.
- Persons handling raw material must wear conductive footwear (VDE).
- Floors must have adequate electrical conductivity. Concrete is suitable.
- Signposting escape routes and keeping them clear.

Removal of Styropor from shipping containers

- Do not open corrugated metal drums in the immediate vicinity of the intermediate aging and finished product stores.
- Before the first withdrawal from a drum after lifting off the lid fold the film bag over the edge of the drum and allow the gas to escape for a short time.
- In the case of partially emptied drums flush the space above the product with air, preferably by blowing in compressed air.
- When emptying using lifting gear, ground the drums and other metal parts. When emptying manually do not use metal scoops (insulated conductors).

The relative humidity in the processing areas should be a minimum of 65%. Otherwise the floors should be moistened.

Appoint an experienced fire protection expert, possibly from the fire department, to carry out checks and continual inspection of the plant. Draw up a fire protection code.

Adequate provision of suitable extinguishing materials and extinguishers. Powder extinguishers (P 12, PG 12) have proved to be effective in the early stages of fires. When fires are in an advanced state use a directed jet of water.

Provision of an independent respirator (compressed-air breathing apparatus).

Regular training of staff.

Appendix 1

Special safety specifications for plants producing and processing rigid polystyrene foams

(Drawn up by the Expert Committee on Fire of the German Association of property insurers [Verband der Sachversicherer e.V., VdS] in association with the Insurance Committee of the Federal Association of German Industry [Bundesverband der Deutschen Industrie].)

Preliminary note

The following safety precautions and other safety specifications are based on the current state of the art. In the event that fundamental changes in process and fire-fighting technology emerge the safety precautions and other safety specifications will be rewritten by mutual agreement of the competent committees.

Sphere of application

The following safety precautions and safety specifications apply to plants producing rigid foamed materials from expandable bead-shaped or rod-shaped raw materials the chemical composition of which includes more than 90 % of polystyrene or styrene copolymers with a low-boiling hydrocarbon incorporated as blowing agent. They are also applicable to plants producing rigid expanded foams from the aforesaid raw materials to which a flameproofing agent has been added.

In smaller plants (having a daily output of up to about 300 kg of expanded polystyrene) lesser demands may be imposed with regard to structural fire prevention measures provided local conditions are taken into account.

The following safety precautions and safety specifications do not apply to those plants which store or process rigid polystyrene foams which have been aged and contain substantially no residual amounts of blowing agent. There are special regulations for such plants.

1. It is agreed that the insured party in plants in which rigid polystyrene foams are produced and processed meets the following safety precautions (Part A).

2. This applies with immediate effect to new plants to be built and within a year of notification of these specifications by the insurer in the case of plants already in existence.

3. Insofar as it is not technically feasible for individual measures in the safety precautions to be carried out, equivalent safety precautions adapted to local conditions have to be agreed.

4. Any subsequent elimination or diminution of the safety precautions is treated as an increase in risk (Articles 23-32 of the German Industry Act).

5. The insured party is further under obligation to observe the following safety specifications (Part B).

A. Safety precautions

1. Structural safety precautions

1.1 Isolation of different production activities

The sections of the plant for production of expanded foam have to be separated by fire safety measures from sections of the plant having other production activities. Sections of the plant for production of expanded foam are the store for the expandable polystyrene raw materials, the preexpansion unit, intermediate storage – if required by production circumstances, production of blockware and moldings by means of final expansion – if required by production circumstances, storage of the expanded parts, cutting and making-up and the finished goods depot.

If parts of the plant having different production activities are accommodated in one building, expanded foam production has to be isolated from these other parts of the plant by means of fire walls (DIN 4102) or by means of fire-resistant ceilings (DIN 4102). In the case of buildings having a roof covering made of combustible building materials on a closed supporting base made of combustible building materials (cf. DIN 4102, sheet 3, item 8.3.1.2) the fire wall has to be built up to at least 30 cm above the roof or be completed at the level of the roof covering with a fire-resistant steel-reinforced concrete slab projecting 1 m on either side. Flammable building materials in the roof structure (beams, trusses, laths, boarding) must not be taken through the fire wall. In the case of buildings with low-strength roofing the fire wall has always to be built to 30 cm above the roof. Openings in these structural elements are to be secured with fire-resistant, automatically closing seals (DIN 18 081; DIN 4102).

1.2 Isolation of expanded foam production from systems for the production of thermal energy, workshops and laboratories

If systems for building heating or for the production of steam or workshops or laboratories or individual sections thereof are accommodated in a building together with expanded foam production, they have to be isolated from the relevant parts of expanded foam production by means of fire-resistant walls and ceilings. Openings in these structural elements should be secured with at least fire-retardant, automatically closing seals (DIN 18 082; DIN 4102).

1.3 Structural subdivision within expanded foam production areas

The sections of expanded foam production enumerated in items 1.3.1 to 1.3.3 below, in which expandable raw materials, semifinished expanded foam or finished expanded foam products are stored or processed, have to be isolated from one another and from the preexpansion unit, blockware and moldings production by means of final expansion and from cutting and making-up by the structural measures specified under 1.3.1 to 1.3.3.

1.3.1 Expandable raw materials store

Storage areas for expandable polystyrene raw materials are to be isolated from the other sections of the plant as shown below.

a) Storage exclusively in metal containers

When the amount in storage does not exceed 5000 kg, no structural isolation is needed.

When the amount stored is greater than this and the incendiary load* is not more than 400 kg/m^2, fire-resistant partitioning (F 90) is required.

When the incendiary loading* is more than 400 kg/m^2 fire walls in accordance with DIN 4102 and fire-resistant ceilings are required.

b) Storage wholly or in part in bags

If the amount stored is not greater than 3000 kg, no structural isolation is needed.

When the amount stored is greater than this and the incendiary load* does not exceed 200 kg/m^2, fire-resistant partitioning (F 90) is required.

When the incendiary loading* is more than 200 kg/m^2, fire walls in accordance with DIN 4102 and fire-resistant ceilings are required.

1.3.2 Storage bins of any size for the intermediate aging of preexpanded polystyrene

a) Storage bins standing in the open must be at the following safe distances from the other sections of the plant.

Bins having closed walls not of fire-resistant construction but constructed of incombustible materials: at least 10 m.

Bins made of combustible materials, braided metal or the like: at least 15 m.

Observance of these safe distances is not necessary if a fire wall in accordance with DIN 4102 is placed between the bins and the neighboring sections of the plant.

b) Storage bins of fire-resistant construction standing in the open or in covered spaces need not be isolated from the other sections of the plant producing expanded foam when it is ensured that any fire arising remains limited to the interior of the bin.

c) Storage bins having closed walls not of fire-resistant construction but constructed of incombustible materials standing in covered spaces are to be isolated from the other sections of the plant by means of fire-resistant structural elements (F 90).

d) Storage bins made of combustible materials standing in covered spaces are to be isolated from the other sections of the plant by means of fire walls in accordance with DIN 4102.

e) Item d) applies to storage bins made of braided metal or the like standing in covered spaces.

f) Regardless of its mode of construction, a working hopper associated with an expansion machine does not fall under these isolation provisions as long as the storage capacity of each working hopper does not exceed 500 kg.

1.3.3 Intermediate stores for expanded parts and stores for finished products

Intermediate stores for expanded parts and finished goods are to be isolated from one another and from the other sections of the plant as indicated below.

a) Stores in the open air

The safe distance from the operating sections must be:

- at least 10 m when the stacking height is up to 3 m high;
- at least 15 m when the stacking height is over 3 m high.

Exception

If there is a shortage of space on the plant site and no storage area having the safety separations mentioned above can be provided it is possible with the agreement of the insurer to dispense with these safe distances if the store is isolated from adjoining sections of the plant by means of fire walls (constructed as in 1.1) in accordance with DIN 4102. In this case it must be ensured that the fire wall (fire walls) projects (project) at least 1 m on both sides of the stacks of expanded parts and at least 1 m above them.

b) Intermediate store in the region of a steam expansion unit

If storage lasts for at most four hours after final expansion structural isolation is not necessary.

c) Other stores

If the maximum amount stored is less than 1500 kg structural isolation may be dispensed with.

When the amount is greater than this and the incendiary loading* is not more than 50 kg/m^2 fire-resistant partitioning (F 90) is required.

When the incendiary load* is more than 50 kg/m^2 fire walls in accordance with DIN 4102 and fire-resistant ceilings are needed.

d) Mold stores

Mold stores having an insured value in excess of DM 100,000.– must be isolated from the other sections of the plant in fire-resistant manner in accordance with DIN 4102.

1.3.4 Exceptions

The area of expanded foam production isolated by means of fire walls and protected by suitable, automatic, fixed fire-extinguishing systems installed in accordance with the rules of the German Association of property insurers (Verband der Sachversicherer e.V., VdS) and continually inspected by the technical testing center of VdS does not need to be subdivided by building structures.

1.4 Electrical installations

New electrical systems and extensions of existing ones in the area of the expanded foam production unit (see Section 1.1) have to be installed in accordance with VDE specifications for “production plants exposed to the risk of fire” (VDE 0100, § 50 N) with the exception of § 50 N for electrothermal cutting equipment. In the area for preexpansion and final expansion, for storing the preexpanded material and for storing the expanded foam blockware they additionally have to be installed in accordance with the VDE specifications for “Wet and similar areas” (VDE 0100, § 45 N).

1.5 Heating

a) The areas for expanded foam production (see Section 1.1) must only be heated with steam, hot water or by air warmed by steam or hot water at a temperature which is at most 120 °C on entry into the production areas.

b) Oil-heated or gas-heated hot air generators operating in accordance with the heat exchanger principle are also permissible if the warm air entering the area cannot exceed a temperature of 120 °C. The warm air outlet apertures must be arranged close to the ceilings. The warm air heater must be isolated in fire-resistant manner except for the incoming and outgoing air lines.

2. Fire extinguishing equipment

2.1 Wall-mounted fire hydrants

Wall-mounted fire hydrants with attached hoses and jet nozzles are to be fitted in frostproof manner at the entrances to the plant areas or at otherwise reliably accessible locations in such a way that every point of the plant and storage depots can be reached with hoses connected up to at least two locations and having an effective (directed) jet of water.

Where there is an automatic, fixed fire-extinguishing system installed in accordance with the rules of the German Association of property insurers (Verband der Sachversicherer e.V., VdS) and inspected by the technical testing center of VdS, exemptions from this rule can be agreed.

Fire extinguishers

Suitable fire extinguishers, e.g. powder extinguishers, must be

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** As defined in these safety precautions the incendiary load is to be taken as the amount of material in storage measured in kg per m^2. In determining the incendiary load it should always be assumed that, regardless of the stock in the store at any time, the space provided for storage is fully occupied.*

available in sufficient numbers (see “Merkblatt für die Ausrüstung der Betriebe mit Handfeuerlöschern” [Code of practice for equipping production plants with manually operated fire extinguishers], Section 2, Case C, Production areas exposed to high risk of fire). They must be made available at the entrances and exits of each part of the plant for expanded foam production including associated stores and in immediate proximity to electrothermal cutting equipment.

B. Other safety specifications

1. Storage of flammable materials

Flammable liquids, e.g. solvents, have to be stored in accordance with statutory regulations for this purpose.

Solvents and adhesives exposed to the risk of fire may only be deposited in the expanded foam production sections of the plant in the amount corresponding to up to one day’s consumption.

In the making-up unit other flammable substances have to be stored before processing at an adequate distance from the expanded foams.

2. Expanded foam waste materials

Expanded foam waste materials have to be removed from the production areas at least once a day.

3. Welding and hot-cutting tasks and working with naked flames

Welding, hot-cutting and similar tasks and cutting by grinding outside the workshops designated for this purpose (fitter’s shop, welding shop) may only be carried out with the **written authorization** of the plant manager or his deputy in each individual case and under **expert supervision.** Before authorization is issued there has to be a careful check that there is no fire risk whatsoever at the planned location of work or in its vicinity, arising e.g. from expanded material or wastes thereof, from deposits of dust or the like or from other flammable materials. The location of work and the surrounding area within a large radius have to be thoroughly cleaned (consider the risk of flying sparks, splashes of hot metal and the like). Flammable materials which cannot be removed from the endangered area, e.g. parts fixed in place, have to be covered up in such a way that they cannot catch fire from flames or the arc, from sparks, splashes of hot metal, molten droplets or from thermal radiation or heat conduction. Apart from the welder (welders) and his assistants an adequate number of staff – at least two people experienced in fire fighting – have to be provided at the location of work as a fire watch with suitable extinguishing equipment and attached fire hoses (water and a jet nozzle). The written authorization for carrying out the work must explicitly identify:

1. the expert who will be responsible for supervising the work;

2. the protective measures required in specific cases, e.g. evacuation of the location of work, covering parts fixed in place and type of extinguishers to be provided.

The location of work and the area around it (adjacent rooms and areas above and below the location of work) have to be carefully monitored by the fire watch

a) during the work,
b) immediately after the work has been completed, and in addition
c) repeatedly after the work has terminated

on the lookout for glowing areas, pockets of fire, etc. as well as for suspicious signs of warming and suspicious odors. Suspect locations are to be extinguished immediately or cooled down and if need be floors, claddings and the like are to be broken open. If necessary the fire department should be alerted. Monitoring must only end at the earliest three hours after completion of the welding work if there are no longer any suspicious signs of warming or suspicious odors.

If the fire hazard in the endangered area around the location of work cannot be removed completely then no work should be done at all using a flame or arc. In such cases fastening must be done using screws or flanges for example instead of by means of welding. Alternatively, parts must be detached by sawing or drilling rather than by using the torch.

4. Cutting equipment for expanded foams

The grinding equipment for the blades of cutting machines is to be cleaned regularly, at least once a day, in such a way that any fire hazard is largely precluded. In doing so any dust from grinding and cutting has to be removed.

Electrothermal cutting devices must only be operated at an adequate distance from expanded foam blocks and cut expanded foam boards in storage.

5. Ban on smoking

Smoking has to be forbidden throughout the entire production area and in storage depots. Rest and recreation areas and administrative offices may be exempted from this ban provided that they have no unprotected open passageways to the plant, processing and storage areas.

6. Ventilation of production areas for expanded foam

These areas must be ventilated in such a way that no ignitable mixtures of blowing agent and air can form. In areas in which blowing agent can escape from the raw materials, semifinished foam or the finished parts, checks must be made close above the floor, especially in depressions in it (e.g. drainage gullies, heating conduits), with regard to the formation of dangerous mixtures of blowing agent and air (e.g. using gas detectors from Auergesellschaft mbH, Berlin, Drägerwerk AG, Lübeck, or Gesellschaft für Gerätebau, Dortmund).

7. Cooperation with the fire department

A fire extinguishing code should be drawn up in cooperation with the local fire department. The managers of the fire service should be asked to inspect the operational set-up in order to get to know the prevailing conditions and possible modifications.

8. Training employees

Employees have to be instructed regularly at short intervals on the correct behavior in the event of a fire and the use of the extinguishers. The particular fire risks posed by the production of expanded polystyrene foam should be given especial emphasis.

Appendix 2

Notes and explanations relating to Appendix 1: “Special safety specifications for plants producing and processing rigid polystyrene foam”

1. Development of the safety specifications

The aforementioned safety specifications were developed from 1967 to 1970 by the Standing technical contact committee (StTKA) jointly set up by the Federal Association of German Industry (Bundesverband der Deutschen Industrie, BDI) and the German Association of property insurers (Verband der Sachversicherer e.V., VdS).

2. Significance of the safety specifications

2.1 The VdS originally intended to give the safety specifications the significance in insurance law of “special agreements”.

In January 1970 the BDI was able to arrange that the insurance industry would only apply the results of the work in a legal sense as “safety specifications”. This means that breaches of the adopted safety measures without knowledge of the insured party or of its representatives do not result in the event of damage in exclusion from the services provided by the insurer.

The representatives of the VdS, however, have reserved the right after examination of the subjective conditions in a plant to cancel in individual cases § 7 of the “General fire insurance conditions” (AFB) and the responsibility clause, Item 26, of the “Supplementary conditions for factories and commercial plants” together with the corresponding Item 4, paragraph 2, of the supplementary conditions attaching to the “General insurance conditions for plant outage due to fire” (FBUB).

Following such an amendment of the insurance policy any infringement of the safety specifications tolerated by the insured party even if it occurred without its or its representative’s knowledge and consent is treated as additional risk exposure and fundamentally relieves the insurer of the obligation to provide indemnification for the damage or shares of damage attributable to such breaches and this applies not only when there is deliberate or grossly negligent behavior on the part of the insured party. In addition, when there is also knowledge of breaches of the safety specifications, the insurer is then not bound by any period or obligation of notice of cancellation and despite such knowledge remains free of the obligation to provide indemnification to the extent stated above and without notice of cancellation of the insurance policy.

Such restriction of insurance coverage should, however, only occur in those exceptional cases in which a plant is supervised so deficiently, is frequently modified or otherwise inadequately managed that due implementation of the safety regulations is fundamentally questionable.

In the normal situation the insurance policy should be agreed without the deletions and restrictions referred to above.

2.2 It is pointed out in particular that the safety specifications belong exclusively to civil law and have only been developed as technical suggestions for the protective measures to be taken as a precaution and defense against fire. The fire protection requirements contained in the safety specifications go in part beyond those imposed by the supervisory authorities for safeguarding public safety and order. Regardless of this, however, it is necessary to obtain the approval of the competent authorities for the modifications rendered necessary by the safety regulations.

3. Application of the safety specifications

3.1 The fire insurance companies present the safety specifications to the plants affected by them.

The insured party is allowed at least 1 year commencing with notification by the fire insurer to carry out these measures.

3.2 The safety specifications have been drawn up in such a way that no particular form of construction can be imposed on a plant producing expanded plastic. There are usually several routes available for carrying out the measures. Attention is specifically drawn therefore to Section 1.3.4 and Section (3) of the preliminary remarks.

According to Section 1.3.4, when automatic, fixed fire-extinguishing systems are installed in accordance with the rules of the VdS and continually inspected by its technical testing center no subdivisions at all are required within the expanded foam production area. The effectiveness of sprinkler systems is acknowledged without restriction and the representatives of the VdS in the Expanded Polystyrene Foam Subcommission have never let there be any doubt that when a sprinkler system is used the corresponding extinction rebate, which can amount to 60 % of the premium, is also granted.

Section (3) of the preliminary remarks states that the measures enumerated in the safety specifications are not the only ones and that in special cases further fire protection measures can be agreed with the insurer.

3.3 The safety regulations also make the provision that in plants manufacturing rigid polystyrene foam which process only up to 300 kg of raw material per day, less demanding requirements than those in the safety specifications can be laid down.

In addition the safety precautions have to be planned and implemented in accordance with the peculiarities of the plant. It might be advisable after the plans have been completed to ascertain with the insurer that the measures foreseen are adequate and recognized by it.

4. Special notes

4.1 The safety specifications apply only to plants which produce rigid cellular foams from expandable polystyrene having a flammable blowing agent.

They also apply to those parts of plants producing expanded foam in which incompletely aged expanded foams still containing a considerable amount of blowing agents are stored or processed.

The safety specifications are **not** to be used in plants and isolated parts of plants in which only aged expanded foams having inappreciable amounts of residual blowing agent are stored or processed.

Likewise, the mere **presence** of rigid polystyrene foams, e. g. the presence of packaging material and insulants, does not result in the use of the safety specifications for such plants or parts of plants. The safety specifications declare (page 1, paragraph 4) that special regulations apply to such plants. These specifications are not yet available. It is planned that the Standing technical contact committee (StTKA) will draw them up at a later date.

4.2 With the agreement of the representatives of the insurance industry all fire protection terms in the safety specifications are in keeping with DIN 4102 – Fire characteristics of building materials and structural elements.

Divergent definitions of terms as in the Premium Guidelines for Industry, Fire and Plant Outage Insurance Policies of the VdS are therefore not employed in the present case.

This applies particularly to the construction of fire walls.

If as a result of the construction of a fire wall the expanded foam production area is to be isolated in terms of fire safety from other parts of the plant in such a way that these other manufacturing units represent for insurance purposes a separate "complex" on a separate scale of charges, the wall has to be built in such a way that it fulfills the requirements specified in footnote 2 of DIN 4102, Part 3. It is further recommended that before carrying out the building work information be obtained from the insurer on the effect of the planned measures on the scale of charges for the entire plant.

Summary

The fire risk involved in the processing and storage of Styropor can be clearly defined and kept under control both with respect to the material (raw material, intermediate products and expanded foam) as well as in terms of process engineering. The prerequisite for this is the precise adherence to all regulations and observance of the measures described.

Fire damage in plants which process Styropor has repeatedly shown that the cause of the fire was not attributable to material or processing deficiencies but rather to carelessness which was caused in most cases by non-observance of the rules for carrying out and supervising welding work.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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3 Properties/Tests

Packaging made from Styropor F

Assessment of expanded Styropor F packaging in the Federal Republic of Germany for fire insurance (business premises and consequential loss policies).

A certificate (Gutachten 2.41/14271 dated 9 May, 1969) was issued by the Federal German institute for materials testing (BAM) to confirm that the flame retardant contained in Styropor F remains permanently effective. Panels and moldings produced from Styropor F meet the requirements laid down for Class B 1 poorly combustible (low-flame spread) building materials and structural components as defined in DIN 4102, Part 1.

The same material is also used in the production of molded parts for expanded foam packaging. Fire tests under standardized conditions (see Table 1) and customary storage of molded parts demonstrated the high effectiveness of the flame retardant in Styropor F. Expanded Styropor F foam packaging units stored in latticework crates were stacked to a height of up to 6 m over an area of 3.70 x 4.15 m^2. They were exposed to the flame from a liter of burning hexane. The flame did not spread over the molded parts beyond the primary fire zone. Since the participation of the expanded packaging in the fire was slight, very little smoke was given off.

The effect of shrink film can be seen from the following test.

Expanded foam panels occupying a volume of 10 m^3 were sealed in shrink film. The 2-m high stack was exposed to the blaze from 100 g of wood wool soaked with 100 ml of gasoline. A period of eight minutes elapsed before the expanded plastic ignited spontaneously. After a further five minutes it was possible to put the fire out with manual powder extinguishers.

Consequently, polyethylene shrink film neither detracts from the fire behavior nor does it contribute itself to the spread of flame.

Fire insurance

In the light of the results of these experiments, the German association of property insurers (Verband der Schadenversicherer,VdS) rated Styropor F packaging as Class VP 4, which is the most favorable class of combustible packaging, in their guidelines on fire insurance premiums payable under the conditions of business premises and consequential loss policies. According to the VdS guidelines on sprinklers, the fire risk rating for these molded parts corresponds to the categories V 2 for packaging and L 2 for goods in storage. For expanded Styropor F packaging without outer packaging that is subject to quality assurance and bears the corresponding proofmark this results in a considerable advantage with respect to expanded foam packaging without a flame retardant.

Table 1 Fire performance of expanded foams made from Styropor under standardized conditions

	Moldings made from	
	Styropor F	**Styropor P**
Flammability: ASTM D 3014 Afterburning time	< 0,5 s	> 60 s
Flame spread		
horizontal: UL 94	HF 1	not classifiable
vertical: DIN 53438	F 1	F 3

When using packaging materials made from Styropor F the known advantageous properties of expanded foam, such as high compressive load-bearing capacity, shock absorption capacity and good thermal insulating ability, are retained in full.

However, if the expanded Styropor F packaging is in contact with cellulosic materials, e.g. cardboard outers, the benefits of the flame retardant are lost. In the initial stages of a fire, the behavior of this combination would be determined by the properties of the outer packaging. Once the fire has taken hold the melted expanded plastic would be ignited by the burning cardboard. It is for this reason that German fire insurance companies do not differentiate in this case between packaging materials made from Styropor P and Styropor F.

Emissions from fires involving foam made from Styropor

The concentration of the main products of thermal decomposition that are given off during a fire can be determined at various temperatures by the method described in DIN 53436. Measurements for expanded foams made from Styropor P and Styropor F, as well as for corrugated board and solid-fiber board are reproduced in Table 2. The reference basis is the surface of the packaging materials, i.e. the figures quoted represent the quantity of decomposition products from specimens of the same area.

It is evident from Table 2 that the thermal decomposition of corrugated and solid-fiber board commences at much lower temperatures. The concentration of carbon monoxide in their fumes is many times higher. It reaches or surpasses the threshold value for acute inhalation toxicity (LC_{50}) of 0.55 vol.-% determined in 30-minute exposure tests on rats. By comparison, even following complete combustion (residue 0%), the thermal decomposition fumes from Styropor represent a substantially lower toxic risk.

Prof. E. Neufert published other similarly favorable results for Styropor F relative to cellulosic building materials (wood, wood-fiber insulating boards, expanded cork) in the Styropor Handbuch (handbook), Chapter 1 “Brandschutz” (fire protection). The thermal decomposition products from samples of the same volume were investigated jointly in 1967 by the plastics technology laboratory of the Technologisches Gewerbemuseum in Vienna and the toxicology laboratory of BASF Aktiengesellschaft (see TI 0/1-130, Table 2).

Expanded foams made from Styropor F contain less than 1 percent by weight of hexabromocyclododecane (HBCD) as fire retardant. The German Ministry of the Environment has published two reports inter alia dealing with the question of the formation of halogenated dibenzodioxins and dibenzofurans from such compounds in a fire (Report No. 10409222, 1991 and Report No. 10403363, 1990). They quote experiments with polystyrene granules containing HBCD (3 wt.-%) in a tube in accordance with DIN 53436. The tendency for HBCD to form brominated dibenzodioxins and dibenzofurans in the event of a fire is described as negligible and explained by the special structure of this molecule.

This finding was confirmed in a further investigation. In 1990, the Münster office for commercial and industrial supervision found only small amounts of brominated furans in the air at the place of work when polystyrene foam is cut with hot wires. Their concentration amounted to less than 1% of the tolerable daily dose.

Fire residues and extinguishing water

a) Solid fire residues

The residues left behind by a fire involving Styropor and foam made from Styropor contain no significant amounts of substances which can be eluted by water.

In 1990 the German Federal Health Office published measures on how to deal with fire residues (Bundesgesundheitsblatt 1/1990). It recommended that burnt and charred plastic should be disposed of in a suitable incinerator, provided that an analysis of the residue shows that no better alternative utilization exists.

b) Extinguishing water

In Germany there is a fundamental prohibition against putting contaminated water into natural water courses. This regulation therefore applies to fire-fighting water also. It contains dissolved components from the fumes and extracts from the fire residue, and possibly also

Table 2 Gases emitted during the combustion of packaging materials
(determined by DIN 53436 method on samples of the same area; rate of thermal decomposition: 2 cm^2/min)

Specimen	**Temperature °C**	**Mass g**	**Air volume[1)] l/h**	**CO$_2$[2)] (%)**	**CO[2)] (%)**	**Residue[3)] (%)**	**Ignition**
Styropor F d = 20 mm	300	2,2	100	< 0,025	< 0,0025	95,3	none
	400	2,2	100	< 0,025	0,01	15,3	none
	500	2,2	100	< 0,025	0,01	5,2	none
	600	2,2	100	< 0,025	0,02	0	none
Styropor P d = 20 mm	300	1,75	100	< 0,025	< 0,0025	91,0	none
	400	1,75	100	< 0,025	0,01	10,5	none
	500	1,75	100	< 0,025	0,01	0,5	none
	600	1,75	100	< 0,025	0,025	0	none
Corrugated board d = 6,8 mm	300	2,0	100	1,7	0,40	6,2	glows
	400	2,0	100	1,7	0,45	4,6	glows
	500	2,0	100	1,7	0,34	2,6	glows
	600	2,0	100	1,7	0,35	4,6	glows
Solid fiber board d = 3 mm	300	4,0	100	2,2	0,60	18,7	glows
	400	4,0	100	2,3	0,66	16,8	glows
	500	4,0	100	2,5	0,64	16,5	glows
	600	4,0	100	2,5	0,50	15,5	glows

[1)] *The primary air rate for Styropor is diluted from 50 l/h to 100 l/h*
[2)] *Percent by volume*
[3)] *Percent with respect to mass used*

auxiliary fire-fighting aids which the Fire Department adds to the water.

Plastics are assigned to water hazard category 0 and thus are generally not a hazard to water. For plants which produce or store expanded foams made from polystyrene there is therefore no legal requirement to have a retaining pond for fire-fighting water. It can, however, be advisable if other circumstances are not favorable. Fire tests were carried out with expanded foam blocks made from Styropor P and F and the accumulated fire-fighting water analyzed. In tests on Daphnia and fish this spent extinguishing water provided no evidence of ecologically harmful effects. Matter contained in the fire-fighting water did not interfere with the operation of a mechanical and biological treatment plant and dissolved organic matter is adequately eliminated.

If for fire-fighting purposes the Fire Department should add foaming agents to the water, the spent extinguishing water should only be released to the public drainage system following agreement with the staff at the treatment plant.

Conclusions

The products arising when expanded foams made from Styropor burn do not represent any particular hazards to the environment.

Expanded foam packaging made from Styropor F contributes to fire safety:

- when it used without a cardboard outer,
- when the packaging components are kept in storage.

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Fire Research Center, University of Karlsruhe (1975)

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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3 Properties/Tests

The aging of expanded foams

Aging of a plastic is defined as the change in its properties in the course of time. Its cause may lie in the plastic itself, e.g. internal stresses, crystallization processes, etc. However, it can also be attributed to the external influences to which the plastic is exposed during use. Whether and to what extent various factors have an effect on the aging of expanded foams made from Styropor will be discussed below.

Effect of temperature

Expanded Styropor foams of normal bulk density consist of 1 – 5% by volume of polystyrene, a thermoplastic. Below its softening point, which is 90 – 100 °C, it is amorphous. Even at extremely low temperatures, it does not undergo any changes in structure, e.g. crystallization. For this reason, there are no lower temperature limits to the application of expanded Styropor foam unless a boundary is set by structural circumstances connected with the contraction in volume (linear coefficient of expansion 6×10^{-5} /K) associated with cooling.

If expanded Styropor foams are exposed to elevated temperatures, the upper temperature limit for application depends on the duration of exposure and on the mechanical load on the expanded plastic. When there is no mechanical load, expanded Styropor foams can be exposed to temperatures of up to approximately 90 °C. In the course of time, a slight linear shrinkage of up to about 0.5% can occur. When the expanded plastic is exposed to temperatures above 100 °C, pronounced shrinkage is observed initially. If the temperature rises above 300 °C, the polystyrene melt depolymerizes again to yield styrene. Long-term tests on low-flammability expanded foam panels made from Styropor F have revealed that there is no risk of a change in properties, even for the flame retardant, under normal temperature conditions. This observation, confirmed by an official test certificate, was made on specimens 7 1/2 years old.

Effect of water and steam

The base material of expanded Styropor foam i.e. polystyrene, absorbs only 0.05% by weight of water. Since polystyrene is a pure hydrocarbon, water can effect no change such as hydrolysis or swelling. Nor does Styropor have constituents that can be extracted by water and whose extraction would affect the properties of the expanded plastic.

Expanded Styropor foam with well fused beads absorbs only very small amounts of water in immersion tests. This has a negligible effect on buoyancy. The amounts of water normally absorbed by expanded Styropor foams of various bulk densities in the course of time are presented in Fig. 1.

If there is a continuous water vapor pressure gradient in one direction and the temperature in the expanded plastic falls below the dew point, water vapor may condense and result in accumulation of water in the expanded foam to up to 30% by volume. This can occur when expanded foam is incorrectly laid or in the case of expanded plastic bodies floating on water. In such cases the thermal conductivity of the expanded plastic is increased. The following rule of thumb applies: for each 1% of water content, the thermal insulation properties deteriorate by 3.8%. However, the original thermal insulation capacity of the expanded plastic is regained as soon as it has dried.

The effect of light

Owing to the high proportion of ultraviolet radiation in sunlight, direct exposure to it results after a few weeks in yellowing of the surface of the expanded foam.

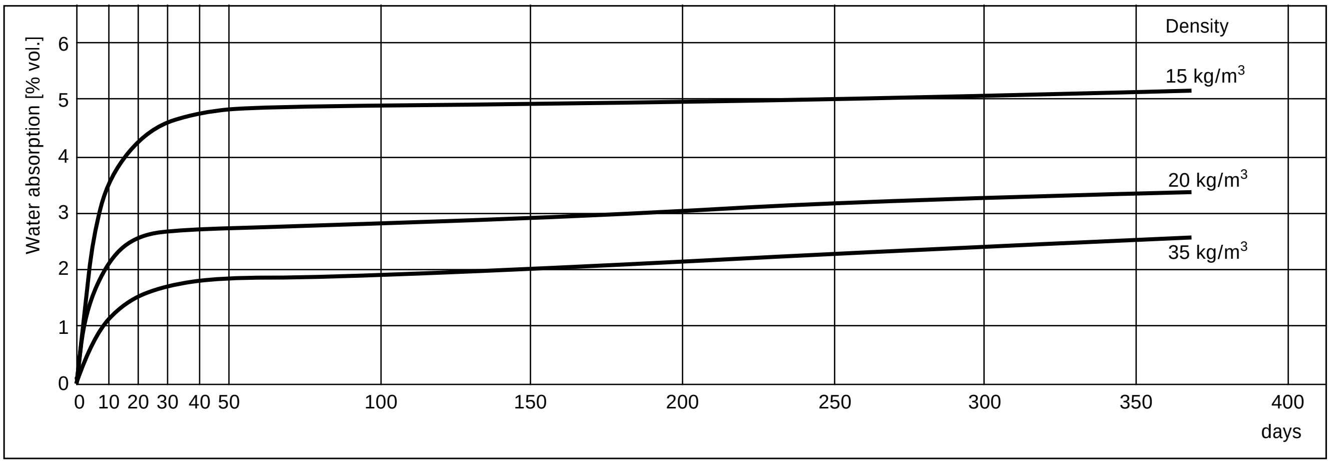

Fig. 1 Water absorbed by expanded Styropor on immersion in water

within a few weeks. The yellowing may be accompanied by a slight embrittlement of the uppermost layer of expanded plastic. This yellowing is of no significance for the mechanical strength of an insulation, because of the low depth of penetration.

The effect of radiation

Prolonged exposure to high-energy radiation, i.e. short-wave ultraviolet, X-rays and gamma-rays, causes embrittlement of the expanded foam structure. The degree of embrittlement depends on the radiation dose and the duration of exposure. The adverse effects of various sources of radiation on the compressive strain and the flexural strength of expanded foams (expressed as percentage deterioration with respect to the untreated foam) are set out in the following table.

Effects of weather

The joint action of sun, rain and wind, as opposed to each of these influences on its own, causes erosion of the expanded foam. On exposure to direct sunshine, the uppermost layers of cells become brittle. They can then be readily carried away by rain, hail, and wind. This mechanism depends markedly on the bulk density of the expanded foam. Thus expanded foams having a bulk density of 60 kg/m^3 displayed no signs of erosion after outdoor weathering for a period of four years, whereas these signs were already visible after only a few months' exposure in the case of foam having a bulk density of 15 kg/m^3. The skin formed during the manufacture of moldings protects the expanded foam to some extent. It can be observed that the erosion of expanded plastics formed from fine-grained material proceeds more slowly than that of coarse material.

Microorganisms

Microorganisms have no effect whatever on expanded Styropor foams. The material does not offer them a nutrient medium; it does not decay, become moldy or rot. Even if microorganisms settle on the foam when it is greatly soiled and under special conditions, it acts merely as a support and takes no part whatsoever in the biological process.

Mechanical effects

Expanded Styropor foams undergo deformation when subjected to continuous mechanical loading, the extent depending on the amount and nature of the applied stress. In each case, tests should be run to determine whether the material is strong enough for the intended application. Results obtained in long-term trials are available for compressive loading, which is the most important form of loading in practice (Fig. 2).

The loads per unit area that expanded foams can withstand for prolonged periods are, of course, lower than the values found in short-term compressive tests according to DIN 53421.

Type of expanded plastic	Source of radiation	Radiation dose kGy	Rate of radiation Gy/s	Decrease in strength in %	
				Compressive stress (10% strain)	Flexural strength DIN 53423
Styropor P	Röntgen	340	1.17	10	20
	Co 60	2000	0.55	30	40
	van de Graaf	2000	41.7	30	40
Styropor F	Röntgen	340	1.17	0	30
	Co 60	2000	0.55	30	60
	van de Graaf	2000	41.7	50	70
Styropor FH	Röntgen	340	1.17	0	0
	Co 60	2000	0.55	0	15
	van de Graaf	–	–	–	–

Table 1 Effect of exposure to radiation on mechanical strength (measured on expanded foams having densities of 15 to 25 kg/m^3). The unit of energy dose is the Gray (Gy). 1 Gy = 1 J/kg

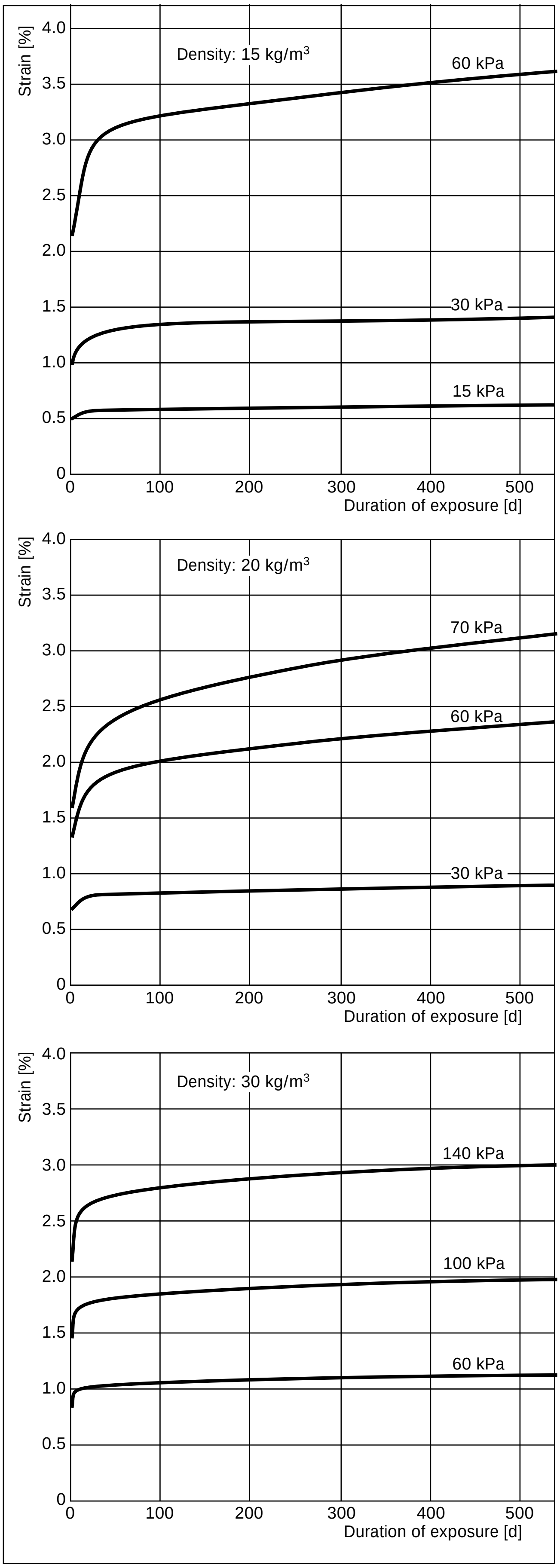

Fig. 2 Compressive creep diagram showing the compression undergone by expanded Styropor foams having densities of 15, 20 and 30 kg/m^3 under various loads

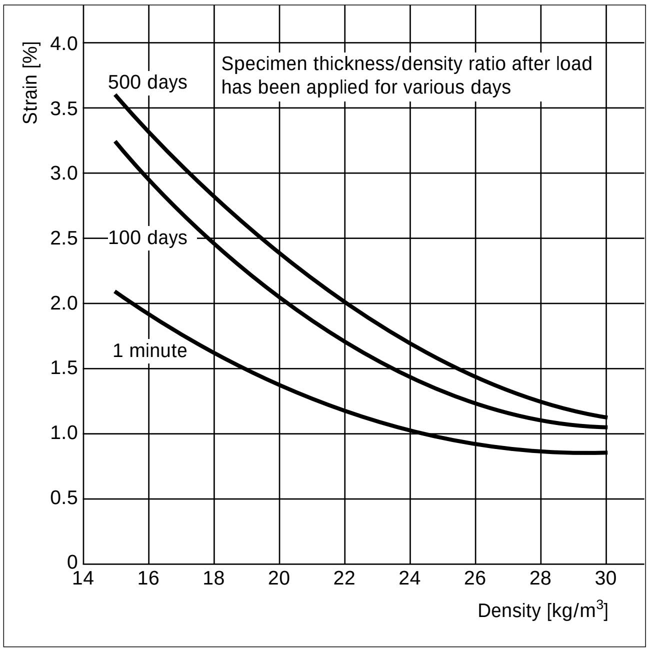

Fig. 3 Dependence of compression on bulk density after different numbers of days

Summary

This compilation demonstrates that expanded foams made from Styropor are resistant to aging. Practically the only threat is when they are stored for long periods without protection or when they are installed uncovered. We therefore recommend that expanded Styropor foams be stored and installed in such a manner that they are protected against weathering and mechanical damage.

Note

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3 Properties/Tests

Thermal conductivity of expanded materials

Apart from a vacuum, air is the simplest and lowest cost thermal insulator. Thin layers of air (up to about 6 mm) have a very low thermal conductivity (λ = approx. 0.026 W/[m·K]). More commonly, however, thermal insulation effects sought in practice require the use of much larger air gaps; generally 20 – 250 mm is customary. The problem with large air gaps is that convection currents occur, which markedly increase the overall thermal conductivity. To avoid this unwanted effect it makes sense to divide the volume of air into small volumes. Expanded foams made from Styropor meet this condition in ideal fashion.

Heat transfer in expanded foams is made up of the following components.

1 Heat conduction in solids

Because the amount of solid material in the foam plastic is relatively small, it contributes very little to the overall thermal conductivity of the foam. Styropor foam with a density of 20 kg/m^3 only contributes λ_{solid} = 0.002 W/(m·K)

2 Heat conduction in gases

Here heat energy is transmitted by collisions of the faster moving gas molecules in the warmer regions of the foam. Because most of the volume of Styropor foam consists of air, this form of heat conduction contributes by far the most towards the overall thermal conductivity. As a first approximation, the contribution of low-density foam is equal to the volume fraction of the gas multiplied by the thermal conductivity of the gas at the temperature in question.

3 Heat transmission through convection

Convection makes a negligible contribution in foams having cell sizes of less than 3 mm.

4 Radiation

The contribution made by radiation to the overall thermal conductivity is difficult to calculate beforehand. The main determining variable, however, is the bulk density.

A good approximation to the overall thermal conductivity λ is obtained by adding the components for the gas, the solid structure and radiation:

$$\lambda = \lambda_{solid} + \lambda_{gas} + \lambda_{convection} + \lambda_{radiation}$$

Permeability to radiation increases particularly markedly in the range of small bulk densities. This is the main cause of the steep rise in thermal conductivity, λ, in the low-density region of the graph in Fig. 1.

It is therefore not possible to predict the exact value of thermal conductivity; it can only be determined with sufficient accuracy by measurement (see next section on measurement methods). DIN 18164, Part 1, classifies polystyrene foams into groups according to their thermal conductivity λ.

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Measurement methods

When measuring thermal conductivity a distinction is made between non-steady state and steady state methods, as well as between relative and absolute methods. In the non-steady state measurement method, very accurate measurements of the temperature at the surfaces of the test specimen are taken simultaneously. The result of this measurement is the thermal diffusivity a. Given the density of the material r and its specific heat capacity c, which may require further measurements, the thermal conductivity can be calculated from:

$\lambda = a \cdot c \cdot r$

The advantage of non-steady state methods is that they are relatively quick to perform; however, this method is not sufficiently accurate for testing expanded foams having low thermal conductivity.

Steady state methods are more accurate, but take longer to perform – a few hours to several days depending on the thickness of the test specimens. The dimensions of test specimens (e.g. panels, cylinders and cylindrical hollow bodies), the heat flow through them and the temperature difference between two surfaces a known distance apart are measured.

In the relative method, a test specimen is compared with a specimen of the same shape and known thermal conductivity. To obtain accurate results the thermal conductivity of the comparison standard must previously have been measured by an absolute method.

One very important absolute method for determining thermal conductivity under steady state heat flow conditions is that due to Poensgen for materials of low conductivity. Being the most frequently used of the various state steady methods – and the most reliable – it is used as the standard device for classifying materials according to their thermal conductivity as set out in DIN 18164.

Test procedure and evaluation

The standard laid down for this is DIN 52612 “Determination of thermal conductivity with the plate apparatus”. The test is carried out on two square specimens with sides measuring 500 mm (two-plate method). The two specimens are placed symmetrically on either side of a heated plate. Heat is conducted away by cooling plates placed on the opposite outer surfaces of the specimens. The heater plate is thermally shielded by surrounding it with a heating ring.

DIN 52612 does not specify a thickness for the test specimen. However, the relationship between specimen thickness and thermal conductivity has been determined in extensive tests conducted in association with the German thermal insulation research institute. As Fig. 2 shows, the thermal conductivity increases with increasing specimen thickness. The dependence on thickness becomes more pronounced the lower the bulk density. In general, however, this effect diminishes as the thickness of the specimen increases. For bulk densities ≥ 20 kg/m^3 and specimen thicknesses ≥ 50 mm there is no further significant increase.

Because thickness is an influencing factor, it should always be stated when thermal conductivity values are being quoted. To best simulate practical conditions, thermal conductivity should be measured on specimens at least 30 mm thick. The reason why specimen thickness affects the thermal conductivity value is to do with the contribution that radiation makes to the flow of heat, which is temperature-dependent. For foams with densities greater than 25 kg/m^3, thermal conductivity increases linearly with temperature, whereas for less dense foams, the thermal conductivity rises disproportionately due to the higher contribution from radiation. For building applications, DIN 52612, Part 2, specifies the determination of thermal conductivity at an average temperature of 10 °C ($\lambda_{10,\, tr}$). This value is determined by plotting a straight line joining values of thermal conductivity measured at different temperatures.

In Germany, DIN 18164, Part 1, is the definitive standard for classifying expanded foam insulating materials used for building applications. The standard groups materials according to their thermal conductivity. For this purpose the thermal conductivity including a supplement (λ_Z) must attain at least the numerical value for the group (e.g. 040 and 035). λ_Z is determined from the observed value $\lambda_{10,\, tr}$ and a supplementary value Z in accordance with DIN 52612, Part 2:

$\lambda_Z = \lambda_{10,\, tr} (1 + Z).$

For Styropor foam this supplement amounts to 0.05. It takes into account the effects of the small amounts of moisture found in practice, variations in the properties of the material and other indeterminate factors arising on installation.

In Germany the theoretical verification of structural thermal insulation is defined by the calculated value λ_R (according to DIN 4108, Part 4) is used for calculations relating to heat insulation in buildings. This calculated value is determined on the basis of the aforementioned thermal conductivity class.

The two-plate measurement method is standardized in the USA in ASTM C 177-63 and in the UK in BS 874: 1956 respectively.

The determination of thermal conductivity by steady-state heat flow using the two-plate method is expensive and time consuming. The of measurement can only be carried out successfully by specially trained personnel in properly equipped laboratories. Data that does not originate from recognized laboratories should be viewed with some skepticism.

The determination of thermal conductivity using the plate device for heat flow measurement according to DIN 52616 is primarily suitable for series measurements and production control. These measurements must not be used as the basis for classifying materials into groups according to their thermal conductivity; DIN 18164 must be used instead.

Other factors affecting thermal conductivity

The bulk density of the Styropor foam exerts a dominant influence on thermal conductivity. Fig. 1 shows the thermal conductivity of expanded foams made from Styropor F grades as a function of bulk density based on a mean value curve. At very low densities the thermal conductivity is determined primarily by thermal radiation. The thermal conductivity reaches a minimum at around 30 – 40 kg/m^3 and then rises approximately linearly with increasing density to a value of 0.13 W/(m·K) at 1050 kg/m^3 (compact polystyrene).

In general, the addition of reground foam waste causes the thermal conductivity to increase slightly. Depending on where it came from or how it has been handled, the foam waste shrinks to a greater or lesser extent when molded. As a consequence, the beads of fresh preexpanded Styropor expand to a greater extent and partially fill the volume freed by the shrinking ground material. This results in the formation of regions of lower density than the average for the block or panel.

Note, however, that for amounts of waste of less than 10 % by weight, this effect should be so small as to produce no noticeable increase in thermal conductivity.

The effect of thickness on thermal conductivity is more marked for lower density material.

Styropor foam can absorb moisture on direct contact with water or if there is a large partial pressure difference in water vapor. Fig. 3 shows the relationship between the thermal conductivity of Styropor foam (density 19 kg/m^3) and its water content (according to Achtiziger, “Measurement of the thermal conductivity of foam plastics with various moisture contents”, KIB, Themenheft 23).

In practice the expanded foam is protected against heavy moisture penetration by the correct application of suitably sized vapor barriers, a film covering or by providing some means of drainage.
DIN 52612, Part 2, adds 5 % to the thermal conductivity value to take account of the effect of the low moisture content found in practice.

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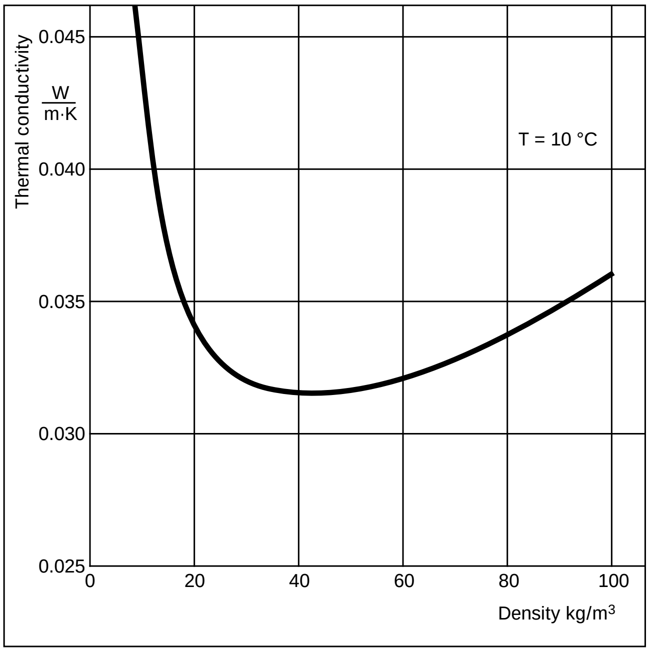

Fig. 1

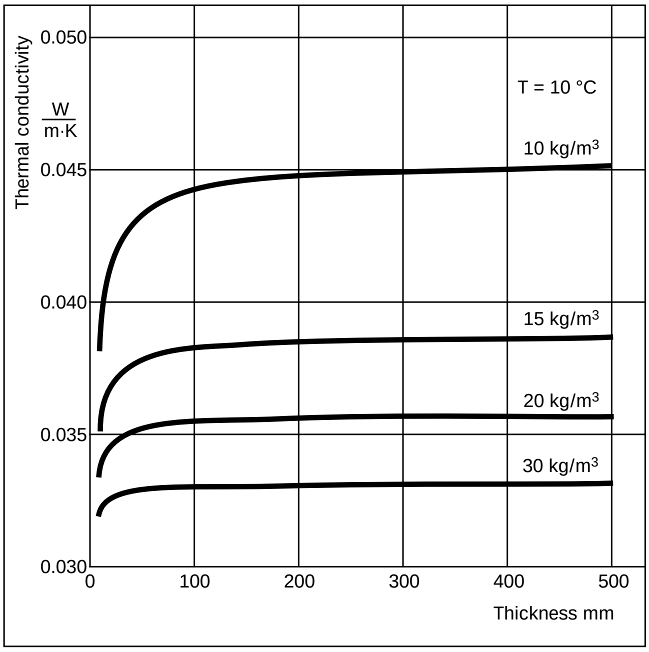

Fig. 2

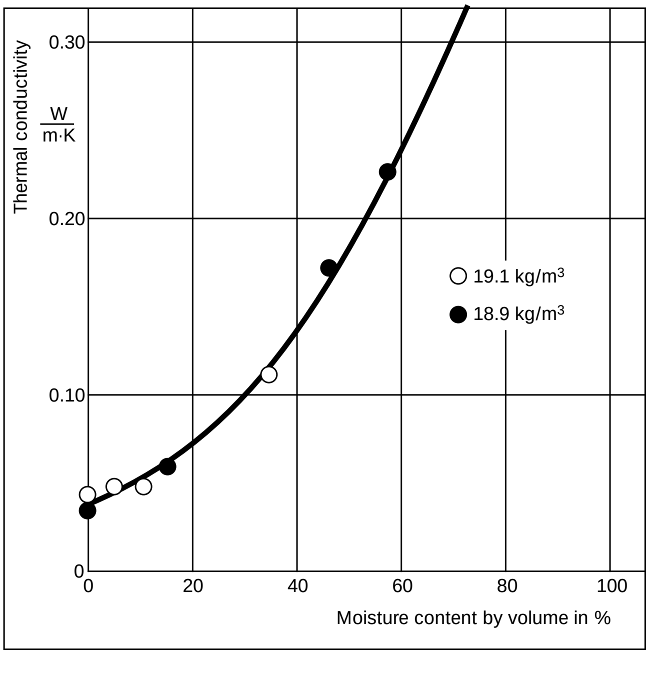

Fig. 3

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3 Properties/Tests

Expanded Styropor and the Environment

This Technical Information Bulletin has been compiled in response to a number of ecological questions that have arisen in connection with the production and processing of Styropor and applications of foams made from Styropor.

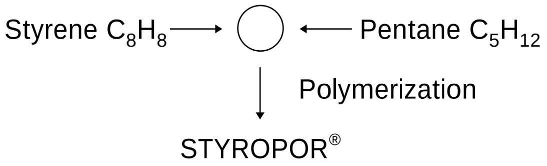
Raw materials and production

Expandable polystyrene (EPS) is obtained by polymerizing styrene and introducing small amounts of a blowing agent, viz. pentane.

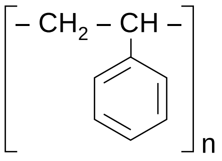
Both pentane, which is contained in petroleum, and styrene, which is a petroleum derivative, are pure hydrocarbons, i. e. they consist solely of carbon and hydrogen.

Components

Styropor is manufactured in general-purpose, flame-retarded and specialty grades. The general-purpose grades of the “P” series do not contain a flame retardant. Those of the “F” series contain hexabromocyclododecane (HBCD, CAS No. 25637-99-4), a brominated cycloaliphatic hydrocarbon. In many European countries, cellular materials for applications in the building trade must meet the requirements for non-readily ignitable materials. Specialty grades, e. g. for colored expanded plastics, contain pigments.



the expandable polystyrene (EPS) containing a blowing agent



Styropor is BASF Aktiengesellschaft’s registered trademark for expandable polystyrene and is also the registered trademark of *Industrieverband Hartschaum e.V.* for thermal insulation materials produced from it.

Styropor is supplied in the form of small spherical beads or cylindrical pellets. The expanded material is formed by fusion of the individual particles.

Specialty grades, e. g. for coloured expanded plastics, contain pigments.

Styropor products contain small amounts of coating agents necessary for processing the beads. These coatings conform to worldwide food-contact regulations.

Blowing agents

n-Pentane and iso-pentane, the pneumatogen used in Styropor, are members of the alkane family of hydrocarbons as are compounds like methane, ethane, propane and butane.

Pentane is present in petroleum. It is also continuously formed and decomposed in nature. Pentane is decomposed more rapidly in the atmosphere than lower alkanes such as methane. Pentane is also a product of anaerobic biochemical degradation in humans and animals and finds its way into the atmosphere via respiration.

In the atmosphere, pentane is rapidly degraded by hydroxyl radicals in a photochemical reaction. The half-life, (i.e. the time during which its concentration is reduced to half the original value) is between 10 and 15 hours. Various factors are responsible for these differences in time, one of them being the intensity of solar radiation. Consequently, pentane is decomposed more rapidly in summer than in winter and more quickly in daylight than at night.

Pentane decomposition products are absorbed by water and in soil, where they are metabolised to carbon dioxide and water by plants, bacteria, and microorganisms.

Chlorofluorocarbons (CFCs) and hydrogenated chlorofluorocarbon (HCFCs) are not released to the environment during the production and processing of Styropor and the cellular materials obtained from it, simply because they are not used to manufacture Styropor.

Emissions

Factories and installations concerned with the transportation, storage and processing of Styropor and cellular materials made from Styropor are not directly subject to the provisions of the German Clean Air Act (BImSchG). Therefore, these factories and installations may be built and operated without official authorization under the German legislation for the prevention of air pollution (TA Luft). However, they are to be designed and operated so as to prevent harmful effects to the environment that could be avoided considering the current state of the art.

Handling the raw materials

Information on the safe handling of Styropor is given in the Safety Data Sheet.

Production of expanded foam

Styropor is processed in four stages, i.e.

preexpansion,

intermediate aging of the preexpanded particles,

moulding, and

foam storage.

During these stages, pentane and traces of styrene are liberated. Their concentrations depend on the technical equipment and facilities used, storage conditions and product properties. Thus technical advice is essential to obtain accurate data.

Handling cellular material

Residual blowing agent and traces of styrene can still be emitted from freshly prepared block and moulded parts, although these emissions diminish quickly with time. A study made on Styropor insulation board installed in rooms has demonstrated that the emission of styrene into indoor air can no longer be detected after an adequate storage period. Likewise, the emission of residual blowing agents practically ceases after this period. (See expert study by Prof. Dr. med. H. G. Sonntag, Hygiene Institut der Universität Heidelberg, 05.09.85; Dr. H. Voss, **Kunststoffe,** 77, p. 1–2, 1987.)

Cutting cellular material with hot wires

Vapour and gases are given off when expanded Styropor is cut with heated wires. They are formed by degradation and cleavage of the polymer chains into segments that become progressively smaller until volatile organic compounds are released.

Heat from the wire melts the polystyrene and causes degradation products and the blowing agent to vapourise. The vapours emitted consist essentially of low-molecular weight clearage products, like styrene and pentane. Traces of hydrogen bromide may also be emitted from flame-retarded cellular materials (cf. “Industrial health”).

Radioactivity

Neither alpha, beta, or gamma radiation nor radon were detected in studies on expanded Styropor, and none are expected. (Expert study by R. Reiter, Garmisch-Partenkirchen, 07.03.1987.)

Fire behavior and combustion

Styropor and cellular foams made from Styropor are combustible. The gaseous products of combustion formed in the event of a fire do not differ very much from the fumes given off by other organic materials. The combustion products consist predominantly of carbon dioxide and water. Other constituents, the concentrations of which depend on the conditions under which the fire occurs, are carbon monoxide and soot. Traces of hydrogen bromide are also given off during combustion.

Styropor and cellular materials produced from it, including these containing a flame retardant, may be burned completely in incinerators at temperatures of ca. 1000 °C, if adequate air is supplied.

In the event of a fire involving Styropor, no additional risks to the environment due to toxic fumes or water contamination are to be expected. The gaseous decomposition products are comparable to those that are given off by wood-based materials. The traces of hydrogen bromide, which may dissolve in the water used to extinguish a fire and thus reach natural waters, also do not present additional hazards beyond those from other organic building materials like wood (see TI 810 and TI 130).

Brominated dibenzodioxins were not detected either in the gas phase or in the fire residues in experiments with Styropor F grades conducted according DIN 53436. All that was detected were negligible amounts of brominated benzofurans, all of which do not fall under the German chemical prohibition ordinance of 1994.

Industrial hygiene

Styropor and cellular foams made from Styropor have been produced and processed for decades. Over this period, no reports have ever been received on any harmful health effects which could be shown to have been caused by the use of these materials.

Pentane and traces of styrene are liberated during the production and processing of expanded Styropor. Thus there is a slight risk of workplace exposure to these substances. Pentane and styrene (as with ethanol), are classified as industrial chemicals that may be harmful to health or constitute a health hazard if expose limits are not observed. Therefore, steps must be taken to protect all personnel exposed to them. The criterion adopted by industrial hygienists in Germany for assessing the health hazards inherent in a chemical substance is the maximum allowable concentration in the workplace (MAK value). MAK values are taken as a basis to decide whether or not a given concentration of a given substance may be harmful to health*.

MAK values are reviewed annually by the MAK commission and either confirmed or revised. The commission also arranges for additional studies on substances that have already been listed and on others that have not. The MAK values for pentane and styrene are:

Pentane	1000 ml/m^3	(ppm vol.)
	≙ 2950 mg/m^3	
Styrene	20 ml/m^3	(ppm vol.)
	≙ 85 mg/m^3	

(1998 MAK List)

These values must never be exceeded. Normally, the concentrations in workplaces where Styropor is processed lie 1 to 3 orders of magnitude below these limits. However, we recommend that fume hoods or exhaust fans be installed in areas where Styropor is cut with hot wires (see above) in order to ensure that the workplace concentrations remain below the MAK values.

Physiological aspects

Styropor and cellular foams produced from it are chemically neutral, insoluble in water and do not give off any water-soluble substances that could lead to contamination of the ground water. They are not decomposed by microorganisms. Likewise, Styropor and expanded Styropor do not provide nutrient value for human beings and animal.

Even external influences, e.g. manure, earth that has been fertilized with phosphates, acid rain, etc., do not have any significant effect. The expanded material does not rot.

A number of studies have been conducted by K. H. Sirtl at the Institut Bio-Bauforschung in Karlsruhe and reported on 29 June 1982. The effects of cellular EPS foam made from Styropor on living organisms are summarised below.

Experiments on seeds and mealworms

Seeds were allowed to germinate on EPS foam and wooden boards. No differences were observed during germination, in the shape and color of the embryos, or during further growth. Similar experiments were performed with mealworms on EPS foam and wooden boards. Again no differences were observed. Holes that were drilled into the EPS boards were also used for pupation.

Although foams made from Styropor do not provide animals with nutrient value, pests such as insects and rodents can burrow into EPS foam and build nests.

Experiments on microorganisms

Since microorganisms have exceptionally sensitive reactions to toxins, even in extremely small amounts, a number of microbiological tests were performed.

Expanded Styropor foam was placed on a substrate together with ubiquitous moulds. Both these and the reference cultures showed no signs whatsoever of harm in any phase of growth. Furthermore, no changes were observed in the subsequent generations.

Expanded EPS foams from Styropor were also placed in a liquid nutrient, which was inoculated with mixed apathogenic species of aerobic and anaerobic bacteria. The cultures were compared with a control. In a number of experiments of this nature, neither a microbiocidal nor a microbiostatic effect was observed. Likewise, no microbiocidal or microbiostatic effects were observed in yeast and vegetable cell cultures in liquid nutrients when applied to foams made from Styropor. There were also no signs of hypertrophy.

In all these experiments, no evidence was obtained of morbid or degenerative mutation.

Experiments on algae and lichens

Experiments on colonies of green and blue algae and lichen that had been established on foam made from Styropor were found to be exclusively on the surface. They did not penetrate into the cellular material itself. The surface was accepted for colonization, and the colonies grew in the same way as they do on stones, plants, wood, bricks, etc. Over a period of one year, no changes whatsoever were observed in the cultures. Only when the necessities for their life (light, moisture, etc.) were withdrawn, did the algae and lichens die out.

Questions concerning Food-contact applications

Detailed information relating to food packaging regulations can be found in Technical Information sheet TI 125: “Legal Questions Concerning Food”.

Recycling and disposal

After use, foams made from Styropor can be recycled in a variety of ways. They can be re-used in the production of cellular material; they can be converted into Styromull® (cellular flakes), they can be melted and pelleted to yield compact polystyrene for injection molding; or they can be converted back to raw material feed stocks. If none of these routes are possible, then foams made from Styropor can be landfilled on incinerated. These subjects are dealt with in detail in Technical Information Bulletin TI 810 (Recycling and disposal of used expanded Styropor).

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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** “The MAK value (maximum concentration in the workplace) is defined as the maximum permissible concentration of an industrial substance present in the air within a working area (in the form of a gas, vapor, or suspended matter) which, in the light of current state of knowledge, generally does not impair the health of persons employed nor cause undue inconvenience. MAK values are based as a rule on work schedules involving shifts of 8 hours’ duration in an average working week of 40 hours. The main factors taken into account in the compilation of MAK values are the characteristic effects of the substances and (as far as possible) the practical circumstances of the work processes or the exposure pattern determined by the latter. In doing this the decisive issue is well-founded scientific criteria for the protection of health and not the technical and scientific means for their implementation in practice.” (translation of a direct quotation from, Maximale Arbeitsplatzkonzentration und Biologische Arbeitsstofftoleranzwerte 1987 (Maximum allowable concentration at the workplace and tolerance values for biological industrial substances), VCH Verlagsgesellschaft mbH, D-69469 Weinheim, 1987).*

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3 Properties/Tests

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Expanded Styropor; Environmental Questions that Arise from Building Applications

Questions on the environmental compatibility of foams made from Styropor.

Raw materials and manufacture

Expandable polystyrene (EPS) is predominantly manufactured by polymerization of styrene with the simultaneous addition of a blowing agent, a mixture of n-pentane and iso-pentane.

Styropor is BASF Aktiengesellschaft's registered trademark for expandable polystyrene, and is also registered for use by the *Industrieverband Hartschaum e.V.* for EPS thermal insulation board produced from it.

Styropor and the cellular materials produced from it consist of carbon (C) and hydrogen (H). Neither during its production nor during its application are chlorofluorocarbons (CFCs) or hydrogenated chlorofluorocarbons (HCFCs) used.

Components

Styropor is manufactured in regular and in specialty grades. The regular grades of the "P" series do not contain a flame retardant. Those of the "F" series contain small amounts of a brominated cycloaliphatic hydrocarbon flame retardant. In many European countries, cellular materials for applications in the building trades must be difficultly inflammable. Specialty grades, e.g. for coloured expanded plastics, contain pigments.

Blowing agents

The blowing agent, pentane, is a component of crude oil and is derived from it.

Pentane is decomposed very rapidly in the atmosphere. Ultimately carbon dioxide and water are formed when pentane is degraded in the atmosphere.

Handling expanded plastics

Freshly prepared foam materials (in the form of blocks and moulded parts) still emit residual blowing agent and traces of styrene. After an adequate period of ageing, emission of styrene into the atmosphere can no longer be detected, as a study on insulated Styropor panels installed in dwellings has revealed. (Expert study by Prof. Dr. med. H. G. Sonntag, Hygiene-Institut der Universität Heidelberg, 05.09.85; and Dr. H. Voss, Kunststoffe, 77 [1987] 1). The emission of residual blowing agent is also practically ended.

Radioactivity

Neither alpha, beta or gamma radiation nor radon were detected in studies on expanded Styropor. (Expert study by R. Reiter, Garmisch-Partenkirchen dated 07.03.1987).

Fire behaviour and combustion

Styropor and expanded Styropor are combustible. The gaseous products of combustion formed in the event of a fire do not differ very much from the fumes given off by other organic materials. The combustion products consist predominately of carbon dioxide and water. They also contain carbon monoxide and soot to an extent which depends on the conditions of the fire. In addition, traces of hydrogen bromide are present in the fumes given off by flame-retarded foams made from expanded Styropor.

Styropor and expanded plastic foams produced from it, including those that contain a flame retardant, may be burnt completely at temperatures of ca. 1000 °C in incinerators, if adequate air is supplied.

In the event of a fire, no risk or hazard to the environment from toxic fumes and no risk of water contamination are to be expected. The toxicity of the gaseous decomposition products is comparable to that of wood-based materials. The traces of hydrogen bromide, which may dissolve in the water used to extinguish a fire and thus find their way into surface waters do not present additional hazards. (See TI 810, TI 130.)

Brominated dibenzodioxins were not detected either in the gas phase or in the fire residues in experiments with Styropor F conducted according to DIN 53436. All that was detected were negligible amounts of lesser brominated dibenzofurans, all of which, are not listed in chemical prohibition ordinance of 1994. (See expert report by Dr. J. Hossein pour and Dr. K. Ficht, Ökometric GmbH, Bayreuth, dated 06.06.94.)

Hygienic aspects

Styropor and foams made from Styropor have been manufactured and processed for decades. Over this period, no reports have ever been received on any harmful health effects which could be shown to have been caused by the use of these materials.

Styropor and foams made from Styropor are chemically neutral. They are insoluble in water and do not give off any water-soluble substances that could lead to contamination of the ground water. Likewise, Styropor and expanded Styropor do not provide nutrient value for human beings and animals.

Even external influences, e.g. manure, earth that has been fertilized with phosphates, acid rain, etc., do not have any significant effect. The expanded material does not rot.

For decades Styropor have been is also used for the manufacture of food packaging and, to a small extent, for toys. Detailed information concerning food-packaging regulations can be found in Technical Foration sheet TI 125: “Legal Questions Concerning Food”.

Biological aspects

A series of studies have been carried out to determine the effects of foam made from Styropor on biological organisms. These experiments were carried out by the Institut Bio-Bauforschung K.H. Sirtl, Karlsfeld, and reported on 29.06.82.

In germination tests on seeds and pupation tests with meal worms, foam or similarly untreated wooden boards caused no changes to seedlings or meal worms.

These experiments also failed to reveal any morbid or degenerative mutations in microorganisms, algae, and lichen.

Although foams made from Styropor do not provide food value for pests such as insects and rodents, they can burrow into such foams and build nests.

Recycling and waste disposal

After use, foams made from Styropor can be recycled in a variety of ways. They can be re-used in the production of cellular material; they can be converted to Styromull® (cellular flakes); they can be melted and pelletized to yield compact polystyrene for injection moulding; or they can be converted back to raw material feed stocks.

If none these routes are possible, then foams made from Styropor can be landfilled on incinerated. These subjects are dealt with in detail in Technical Information Bulletin TI 810: “Utilization and Disposal of Scrap Expanded Styropor”.

Note

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3 Properties/Tests

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Goods-inward and production control in Styropor processing plants

To be able to produce expanded foam products from Styropor economically and to a consistently high level of quality, the producer of the finished goods needs an unbroken and continuous system for monitoring quality. The application for which the finished foam part is destined determines the control measures for the required properties.

For example, the important quality characteristics for thermal insulation panels are different from those for packaging items.

This Technical Information leaflet provides information about the types of controls to be carried out and their implementation from the delivery of the raw material through to the finished part.

1 Inspecting the raw material

Visual inspection:

Immediately following delivery the containers must be checked to see whether their contents correspond to the goods ordered. The containers must display not only the exact product description, but also a 6-digit delivery number (this is not the same as the 6-digit “Package No.” that is recorded on every order).

If, exceptionally, a container should be found defective at the time of delivery, please contact your supplier or shipper regarding claims.

2 Production inspection

Preexpansion

In order to maintain the required bulk density of the continuously or batchwise preexpanded material, it is necessary to perform a permanent check on the weight of the material coming out of the preexpander. Too high a bulk density means uneconomic processing, too low a bulk density may result in a reduction in quality; and with it the risk of complaints from the purchaser of the finished goods. The bulk density can be checked by weighing a fixed volume of the preexpanded Styropor (e. g. in a 10-liter measuring vessel). Special automated density measuring and control devices have also proved worthwhile.

Intermediate aging

Adherence to the proper aging times is decisive for the subsequent processing and properties of the foam. This is especially important for short aging times of less than 8 hours for blocks and 4 hours for material used for molded parts. Before expanding the aged material further, the bulk density must be checked again.

Production of foam blocks:

Quality control during the production of foam blocks can be confined to a visual inspection of corners, edges and surfaces, as well as checking for possible depressions and warpage. A weight check immediately after demolding and before further processing (after 24 hours at the earliest) provides information about the block's density and water content. In the further processing of the blocks foam panels cut from them should be sampled and their bonding tested – especially those that come from the middle of the block.

In Germany, the Güteschutzgemeinschaft Hartschaum e.V. (Quality assurance association for rigid foam) prescribes in-house checking of quality characteristics (e. g. size, shape, squareness and density) for rigid foam panels made from Styropor that are to be used in building construction. It specifies that a daily sample of at least 5 panels (preferably taken from the middle of the block) is to be dried and tested. EPS foams for use in building construction must be of low flammability in accordance with DIN 4102.

Molding

Piece numbers and quantity

Production control systems (today predominantly computer-based) are of great importance for obtaining a precise overview of numbers of molded parts produced per unit of time and of their quality. The number of parts produced (less rejects) is readily determined by means of a counter on the molding machine. The causes of rejects have to be ascertained. Defective parts are separated out either immediately after rejection or in the packing room.

3 Final inspection

(or goods-inward inspection by the user)

Visual inspection:

The molded parts must be checked for defects (e. g. damage to surfaces, corners and edges) either straight after their manufacture or before use.

Dimensional stability

A check on dimensional stability is to be carried out on samples of foam parts, such as ceiling tiles and packaging items, for which certain tolerances have to be adhered to.

Particle fusion

Information about how well the particles of Styropor have fused together is provided by the fracture pattern. A piece of the foam is broken open and the proportion of ruptured as opposed to undamaged particles is estimated and specified as a percentage. Expanded foam packaging or moldings that have to be impermeable to liquid are tested by taking samples and filling them with colored liquids. If the test is carried out on freshly manufactured foam parts, these are observed to leak more frequently than those that have been aged for at least 24 hours.

Bulk density

The constancy of the bulk density is suitably checked by determining the weight of the molded parts. These are weighed after drying. Statistical quality control with the aid of control charts makes it easier to gain an overview of production quality.

Water content/degree of drying

The water content of material used to pack goods that are corrodible or sensitive to moisture must not exceed certain limits. As an indicative test of water content a freshly manufactured molding is dried for about 3 hours at 70 °C and then stored for 24 hours in a normal environment (23 °C, 65 % rel. humidity). The weight of the molding is determined before and after drying. The requirements and tests for EPS foam to be used for packaging, such as designation, bulk density, nature of the material, physical characteristics (compressive stress, flexural strength), degree of drying, dimensional stability, combustion behavior and fracture behavior are to be found in DIN 55471, part 1.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

Examples of a quality control sheet for raw material receiving and pre-expansion

Raw material				First Preexpansion					Second Preexpansion			Silo	
Product and date	Del. No.	Wt. metric t	Condition, (OK, contamination moisture etc.)	Date	Time Start – Finish	Bulk density (kg/m^3)	Special occurrences (e. g., pourability, caking)	Silo No.	Transport from silo Date/time	Bulk density (kg/m^3)	Silo No.	Transport from silo Date/time	Bulk density (kg/m^3) before expansion
Styropor P	42-8164	6	OK	28.3.	6.30 – 12.00	15 – 16	none	3 + 8	–	–	–	29.3. 6.30 – 20.00	15
Styropor P 27.3.	45-8173	3	OK	29.3.	14.00 – 16.25	15.5						30.3. 20.00 – 4.00	
Styropor P 4.4.	67-8245	9	OK	4.4.	6.30 – 16.40	21	none	2 + 4	5.4. 6.30 – 12.00	14	5 + 9	6.4./7.4. 12.00 – 16.00	14

Example of a quality control sheet for manufacturing blocks and panels

Product	Delivery date	Del. No.	Bulk density (kg/m^3)	Mold No.	Wt. of block after demolding	External appearance of the block after 24 hrs	Assessment of the cut panels			
							Surface	Density (kg/m^3)	Fusion in samples	Dimensions
Styropor F	4.4.	42-8562	16	5	16.5	excellent	smooth	15.5 – 17.3	adequate	within tolerance

Example of a quality control sheet for the manufacture of moldings

Product: Styropor **Delivery No.:** **Bulk density:** 24 kg/m^3 **Intermediate storage:** 9 h

Molding	**Transistor packaging**		**Telephone packaging**			**Saw blade packaging**	**Light bulk packaging**	
Machine No.	3 4-cavity	4 6-cavity	1	2	9	5	6	7
Date	6.4.	6.4.	6.4.	6.4.	6.4.	7.4.	6.–7.4.	6.–7.4.
No. of cycles per shift	203	182						
No. of good parts per shift	806	970						
No. of reject parts	6	122						
Damage (or cause)	–	breakage (ejector)						
Surface fusion	good	good						
Dimensions	OK	OK						
Weight after demolding, g/pce.	34	37						
Dry weight dried g/pce.	28	28						
Moisture content % (by wt) before dispatch	2,1	2,8						
Fusion after 24 hrs	satisfactory	good						
Miscellaneous								

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3 Properties/Tests

Compressive strength of expanded material

Compressive strength is the most important mechanical property of expanded foams made from Styropor. It depends primarily on the bulk density, i. e. the lower the density, the less the compressive strength. Other factors are the shape of the cells, the temperature and the age of the expanded material. In contrast, the grade of Styropor and the particle size do not exert a significant effect on the compressive strength of samples cut from cellular material.

Since the values measured depend on the geometry of the specimen, the rate at which stress is applied and the temperature, the test conditions must be standardized.

Test in accordance with DIN 53421

The compression test specified in DIN 53421 for rigid cellular materials is preferably performed on specimen cubes having sides measuring 50 mm. If specimens of this geometry cannot be prepared, other dimensions can be agreed. The compression die moves at a constant speed (5 mm/min. or 10% of the original height of the specimen per minute). The force thus applied is plotted against the compression.

Fig. 1 shows the curve of compressive stress versus deformation obtained in compression tests on cubes with 50-mm sides produced from expanded Styropor foams having densities of 15, 20 and 30 kg/m^3. Initially, the curves obey Hooke’s law, i. e. the stress is proportional to the strain. The elastic limit is reached at 1.0 – 2.0% deformation, after which the specimens undergo irreversible deformation. The steep gradient passes over into a flatter curve. Expanded foams made from Styropor are classified as a rigid closed-cell foams (see DIN 7726 for definition). This means that the cellular structure does not suddenly collapse above the elastic limit, but rather that the cells are steadily – and for the most part irreversibly – deformed. In order to characterize the behavior of expanded Styropor foams under compressive loads the “compressive stress at 10% compression”, i. e. the resistance to deformation offered by the 50-mm cube when it is compressed to a thickness of 45 mm is specified.

It is evident from Fig. 1 that due to their thicker cell walls heavy foams (e. g. 30 kg/m^3) exhibit greater compressive strength, i. e. offer higher resistance to deformation. At the same time it can be also seen is that the elastic characteristics alter with bulk density. The cellular material with the lowest density is softer than that with the highest and has a flatter curve. Within the elastic range, the modulus of elasticity, i. e. the quotient of the compressive stress and the corresponding strain, also increases with the density. It is 1.6 – 5.2 MPa for the material having a density of 15 kg/m^3 and 3.4 – 7.0 MPa for foam of density 20 kg/m^3. The compressive stress at 10 % compression for expanded foams made from Styropor is shown as a function of bulk density in Fig. 2.

ASTM and British Standard tests

There are two ASTM standards for determining the compressive strength of cellular materials. The preferred sample dimensions laid down in ASTM C 165-83 for thermal insulation panels are 6 in. x 6 in. (minimum 2 in. x 2 in.); and the thickness of the specimens must be at least 0.5 in. The rate of compression is 5% of the thickness of the specimen per minute. ASTM D 1621-73/79 recommends circular or square specimens having an area of 4 – 36 sq. in. and 1 in. thick (the maximum thickness is equal to the width of the specimen) and the rate of compression is 10% of the sample thickness per minute. The compressive stress at 10% compression is quoted. The values for the compressive stress at 10% compression

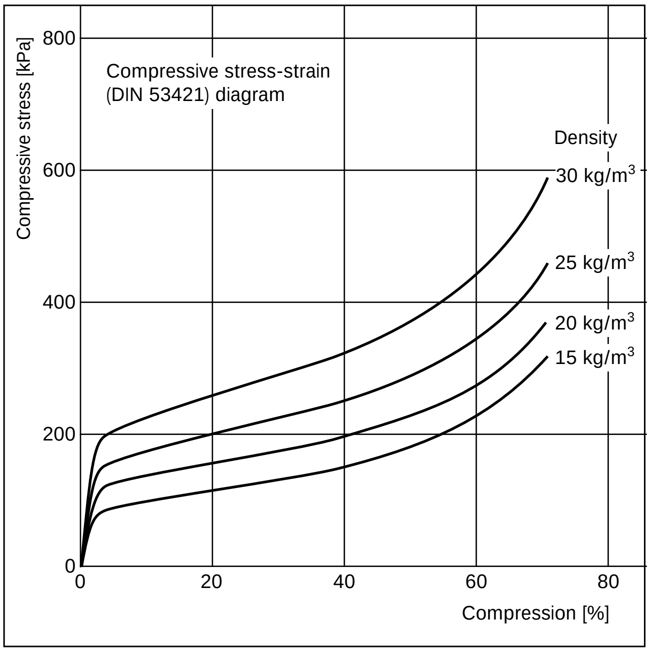

Fig. 1 *Compressive stress versus deformation for expanded foams made from Styropor*

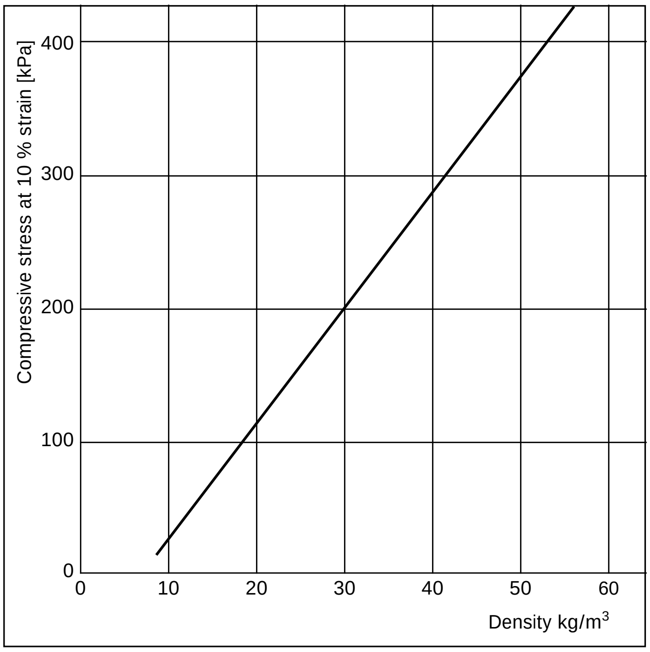

Fig. 2 *Compressive stress at 10% compression as a function of bulk density*

measured in the ASTM C 165-83 and D 1621-73/79 tests cannot therefore be compared with those determined by the DIN 53421 method.

On the other hand, the test method described in British Standard 4370/1988 corresponds to the DIN 53421 method.

Factors that influence the measured values

Geometry of specimen

The values of compressive stress for a given strain determined on cubes with sides measuring 50 mm side are about 10–15% higher than those determined using the rectangular specimens (127 mm x 127 mm x 40 mm) laid down in ASTM C 165-83. They decrease with increasing area of the specimens, but the thickness has hardly any effect.

Rate of compression

DIN 53421 lays down that the rate of advance of the die should be set to give a compression of 10% within about one minute. Thus a specimen of 50 mm thickness would be compressed at a rate of 5 mm/min.

Temperature

The compressive strength decreases with rising temperature. As a rule of thumb, in the range of –5 °C to 60 °C, the compressive stress at 10% compression decreases by about 7% of the value at 20 °C for each 10 °C rise in temperature. The cellular materials have a correspondingly higher compressive strength at temperatures below 20 °C, but the increase is less than 7% at temperatures below –5 °C. However, the cellular material does not become brittle even at –196 °C.

Age of specimen (cellular material)

In the first few hours after production, cellular material has a considerably lower compressive strength owing to the partial vacuum in the cells. As air is absorbed through the walls of the cells, the vacuum is gradually replaced. For this reason, particular care must be taken when demolding freshly expanded parts due to their sensitivity to pressure.

Even after sufficient air for pressure equilibrium has been absorbed through the cell walls, the compressive strength increases by a further 10% in the course of the next 4 – 8 weeks. This increase is brought about by the release of residual blowing agent, which has a certain softening effect. Allowance must be made for this slow build-up to maximum strength in order that the compressive strength of the expanded foams can be exploited to the full, e.g. in stackable packaging. The moisture content of expanded Styropor foams is of no significance for the compressive strength.

Cell orientation

The shape of the cells has a significant effect on the compressibility of cellular plastics, but the size of the cells is of secondary importance. As a consequence of the change in density during the expansion phase in the mold, the cells close to the mold wall are flattened. This can be readily recognized from a microtome section. This “orientation” entails considerable mechanical anisotropy. In other words, the values determined for the compressive strength may exhibit a marked dependency on the direction of testing. Thus if a compressive load is applied in the same direction as that in which the cells are stretched, high values will be obtained for the compressive strength. If the load is applied at right angles to the direction of stretching, the flattened cells will be flattened even more, and lower values will be found.

Anisotropy must be taken into account in testing, i.e. the surface to be loaded must be marked. The cubes are suitably tested in such a way that the compressive load is applied in accordance with conditions encountered in practice, i.e. normal to the plane of the panel.

The values plotted in Figs. 1 and 2 were measured on cut specimens that were largely isotropic. In directly expanded specimens conditions are more complicated. The compressive stress in the edge zone measured normal to the wall of the mold is less than that corresponding to the average bulk density of the specimen. In the center of the molding, it is higher. Since the variation in bulk density and cell orientation occurring during expansion is heavily dependent on the expansion conditions, it is clear that the compressive strength is greatly influenced by the production conditions. The lower the expansion pressure during molding, the more closely the compressive strength of moldings (with skin) approaches that of cut isotropic specimens of the same bulk density.

Long-term compressive loads (creep)

Creep curves (change in thickness v. log time) are presented in Fig. 3 for expanded Styropor specimens of three different densities subjected to various constant loads over a long period. The greatest compressive strain occurs in the first few days; and, as the compaction becomes greater the strain per unit time becomes less. If the initial compression is less than 1.5%, it can be expected that the thickness of the cellular material will not change much more over long loading periods.

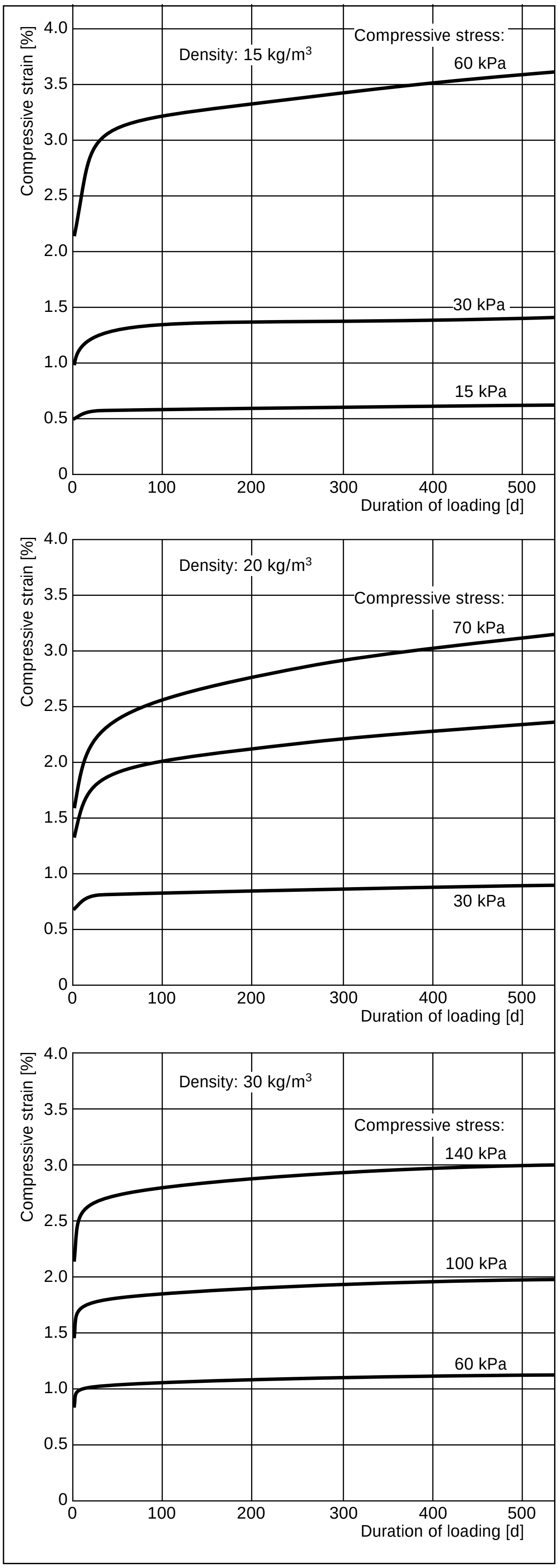

Fig. 3 Compression as a function of time at different compressive stresses for expanded foams having bulk densities of 15, 20 and 30 kg/m³.

The maximum load-bearing capacity of expanded foam panels made from Styropor is plotted against bulk density in Fig. 4. The total compression is limited to 2%, and the initial compression is ≤ 1.5%. If the duration of loading is comparatively short, e.g. one week, higher loads may be selected than for longer periods, e.g. 60 weeks.

A special form of creep test, dimensional stability under the action of heat, is described in DIN 18164. The properties of expanded foams made from Styropor are described in TI 100.

Impact loading

The compressive behavior of expanded Styropor foams subjected to very short loading cannot be determined by tests analogous to those described in DIN 53421, ASTM C 165-83, and ASTM D 1621-73/79. The data required for designing packaging are obtained from special time lag measurements in the drop test (see TI 510).

Compressive strength of expanded beads

In conclusion we provide some information on the compressive strength of expanded Styropor beads. This is of interest in underwater applications involving buoyancy, e.g. raising sunken ships. In the test, the particles are subjected to hydrostatic pressure on all sides and the change in volume in each case is recorded. For beads of different bulk densities a family of curves of compressive stress versus deformation (similar to Fig. 1) is obtained. In Fig. 5 the compressive stress at the elastic limit is plotted against bulk density. The curve applies solely to short-term loading, and lower values must be assumed for sustained loading.

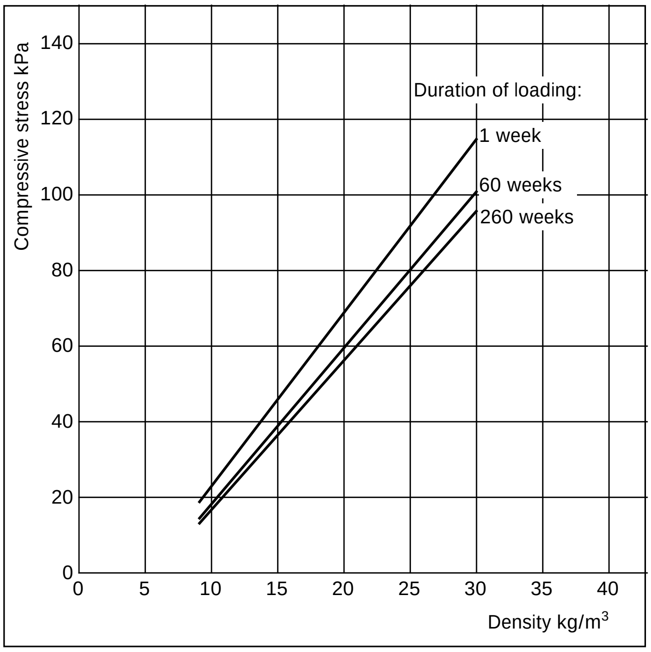

Fig. 4 Compressive strength versus density at 2% total compression.

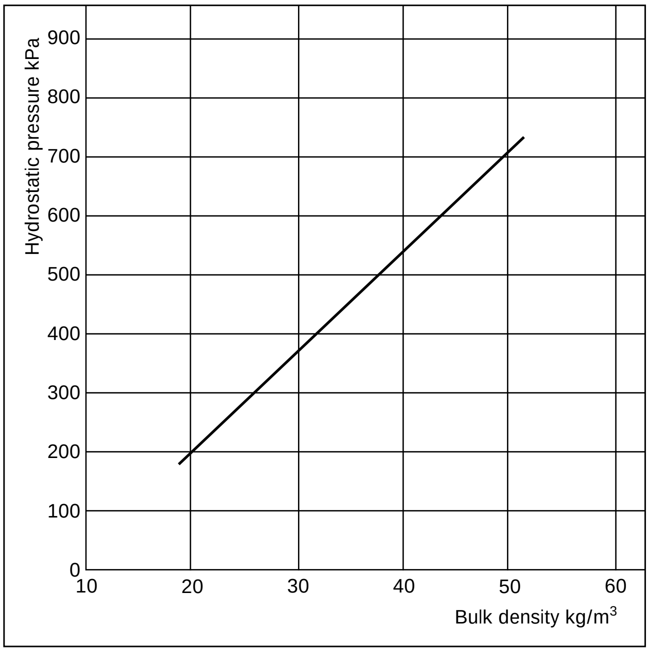

Fig. 5 Short-term hydrostatic load-bearing capacity at the elastic limit of preexpanded Styropor.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Foam pressure measuring devices

Introduction

The economics of making expanded foams from Styropor depends greatly on how close the mold opening time is to the optimum. The essential criterion is the pressure the expanded foam exerts on the inner walls of the mold. If the mold is opened too early (i.e. while the residual foam preessure is still too high), there is a risk of the expanded foam continuing to swell.

Initiating mold opening at a specific residual pressure in the foam, minimizes the risk of post-expansion and allows consistest adherence to the shortest possible mold residence time.

The maximum foam pressure reached during steaming can be used as a criterion for checking for a certain degree of fusion. By this means additional safety margins (time and/or pressure) in steaming caused by fluctuations in bulk density, intermediate aging time and steam inlet pressure can be dispensed with.

The pressure gage should be installed as far as possible at a position where the molding is thickest.

The foarn pressure decay curve then has a flatter shape. Thus on reaching a specified residual foam pressure mold opening can begin directly without allowing additional safety time. Evacuation during the pressure drop phase has no effect on the measurement.

Both pneumatic and electronic systems have proved useful as foam pressure sensors. To avoid false readings the sensor must be fitted flush with the mold wall.

Pressure sensors

1. Pneumatic devices

Pneumatic sensors convert the foam pressure into a signal by means of:

a) a nozzle-baffle system, or

b) a double miter valve

Both kinds of device translate the material pressure into a pressure signal in the ratio 1:1. Automatic control can be effected by connecting a P/E transducer.

2. Electronic devices

The material pressure is transferred via a membrane to a liquid cushion and from there on to a piezoelectric element. An electrical signal is produced. This can be conveyed directly to a display device and/or used for automatic control.

Form of the devices

All the devices are constructed in the shape of a rod. The measuring surface is at the front end and the pneumatic or electrical connection is at the rear end.

Fitting

Devices with a thread at the measuring surfaces are screwed into the wall of the mold and sealed rear wall of the steam chamber by means of a flange with an O-ring.

Devices consisting of a continuous smooth tube are inserted into the mold wall through a bore and fastened and sealed at the rear wall of the steam chamber using a locking ring with an O-ring.

It is important that the wall of the mold is connected to the rear wall of the steam chamber. Movable surfaces distort the measurements.

Suppliers of foam pressure sensors

Supplier	Type	How fitted	Diameter/mm			Cylinder length/mm
			pressure pad	bore in mold	cylinder	
Pneumatic sensors						
Allo-Werk Postfach 2265 41564 Kaarst, Germany Tel. +49-2131-68081 Fax +49-2131-68085	nozzle & baffle	to steam-chamber wall via flanged collar	18 – 40	26 – 48	28 – 50 28 M, 1	100 – 250 350
Erlenbach GmbH & Co. KG Am Rödchen 1 56355 Lautert, Germany Tel. +49-6772-8010 Fax +49-6772-8220	nozzle & baffle	to steam-chamber wall via flanged collar	15.8 6	22 30	22 30	300 or 500 120 + pneumatic adjustment 0 – 90
H. Prokosch Mechanische Werkstätte Raiffeisenstraße 1 76684 Östringen-Tiefenbach, Germany Tel. +49-7259-411 Fax +49-7259-8978	double miter	screwed into mold, collar + O-ring at steam-chamber wall	10 20 20 30	16 M, 1.5 min. 26 M, 1.5 min. 28 M, 1.5 min. 36 M, 1.5 min.	16 28 28 38	to order, as required
Electronic sensors						
Dynisko Geräte GmbH Postfach 1547 74005 Heilbronn, Germany Tel. +49-7131-2970 Fax +49-7131-23260	piezo-electric element	to steam-chamber wall via flanged collar; in some cases screwed into mold	23.6	23.6	33.3	up to 500
Juchheim M.K. GmbH + Co. Moltkestraße 13 36039 Fulda, Germany Tel. +49-661-60030 Fax +49-661-6003500	piezo-electric element	to steam-chamber wall via flanged collar	18	18	18	300

Note

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81995 January 1998

3 Properties/Tests

® = Registered trademark

Determination of pneumatogen content in air

Flammable mixtures with air may be formed when the blowing agent (pentane) diffuses from Styropor* and expanded foams made from it during storage and processing. There is a danger of the mixture exploding when the concentration of pentane in the air lies between 1.3% and 7.8% by volume, i.e. the lower and upper explosion limits. This corresponds to a concentration of blowing agent of 40 to 260 g/m^3 of air.

In order to preclude any possibility of explosive pneumatogen/air mixtures accumulating, warehouses and workrooms in which Styropor is stored or processed must be continuously ventilated in such a way that the concentration of pentane in the air is always sufficiently far below the lower explosion limit.

Human senses do not suffice for detecting the presence of these ignitable and dangerous mixtures in the air; rather some form of warning device must be installed.

Suitable portable and fixed gas warning instruments, which must be calibrated for pentane, are supplied for example by the following companies:

Auergesellschaft mbH,
Thiemannstraße 1,
D-12055 Berlin

Drägerwerk AG,
Moislinger Allee 53/56,
D-23558 Lübeck

Gesellschaft für Gerätebau,
Hannöversche Straße 72,
D-44143 Dortmund.

It is absolutely essential to ensure that the instruments used function safely and reliably and are approved by the relevant testing agencies.

Principle of measurement

The explosion sampling chamber normally operates on the principle of the heat of reaction. As a rule the gas/air mixture is drawn by a built-in pump or hand pump through diffusion chambers into the sampling chamber where it is burnt catalytically at heated detector elements. The rise in temperature produced by combustion (oxidation) is proportional to the concentration of the components being measured. The resultant change in resistance at the detector element causes an imbalance in a Wheatstone bridge. The associated signal flows to the alarm unit and indicator unit at which the lower explosion limit is displayed in percent by volume. Depending on the make of instrument, an acoustic and/or optical signal is given long before the lower explosion limit is reached in order to draw attention to the danger of a high pneumatogen concentration.

The instrument manufacturer’s instructions must be observed.

Important notes

Since pentane vapor is denser than air, the samples must always be taken at the lowest point in a room. Particular attention should be paid to cable shafts, trenches and drainage channels. Measurements need to be made at several points in large rooms, and the instrument should be rezeroed at frequent intervals in long series of measurements. The instrument must never be opened in rooms or areas threatened by explosion.

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* *Also applies to all other expandable types of polystyrene, e.g. Styrolit®, Styrofill®, Styrocolor®, Ultrafill®.*

Note

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Styropor®

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4 Processing

® = Registered trademark

Steam as energy source for producing expanded foams

The most important source of energy for converting Styropor to cellular materials is live steam. Its proper condition is of great importance for both the ease of processing and the quality of the expanded foam produced. Since very many of the problems encountered in processing are attributable to defects in the steam system, apart from the core topic of the steam plant itself, details are also given here of the theoretical principles which are necessary for understanding the thermodynamic processes involved in steaming.

Contents

1 Theoretical principles

Changes of state in water vapor

The following example is intended to illustrate the transition of water from the liquid to the vapor phase and to clarify the terms wet steam, saturated steam and superheated steam.

Consider a vessel filled with one liter of water at 0 °C (Time 1), to which a certain amount of heat is continuously fed (Fig. 1).

Each 4.18 kJ of heat supplied to 1 kg of water raises its temperature by 1 K. Thus 251 kJ are required to raise the temperature of 1 kg of water from 0 to 60 °C (Time 2).

On supplying 418 kJ at normal atmospheric pressure (about 1 bar), the boiling point of the water is reached (Time 3).

At normal atmospheric pressure, 2260 kJ (heat of vaporization r) are required to convert 1 kg of water at the boiling point (Time 3) into saturated steam (Time 6).

The amount of heat required to reach Time 5 for example which lies in the transition region (wet steam), is calculated as follows:

Heating 1 kg of water to the boiling point = 418 kJ
Evaporation of 0.7 kg of water (x = 0.7)
0.7 r = 0.7 x 2260 = <u>1582 kJ</u>
Thus enthalpy i in each kg of the mixture of water vapor and steam = 2000 kJ.

During the conversion of water at the boiling point (Times 4 and 5) into steam, the temperature remains constant despite the continuing supply of heat until the last drop of water has evaporated. The steam in this dry state is said to be saturated (Time 6). The saturated steam phase is an unstable state because the addition or withdrawal of even a small amount of heat suffices to convert it into superheated (Time 7) or wet steam (Time 5) respectively.

The phase transitions at various pressures are shown in Fig. 2. The boiling point of water rises with increasing pressure. This is the principle underlying the pressure cooker, which allows temperatures higher than 100 °C to be attained depending on the pressure. On the other hand at pressures below normal atmospheric pressure, e. g. in high mountainous regions, water boils at temperatures below 100 °C. As will be explained in detail in Sections 3 and 4, this behavior is exploited for storing steam in large-capacity boilers or differential-pressure accumulators.

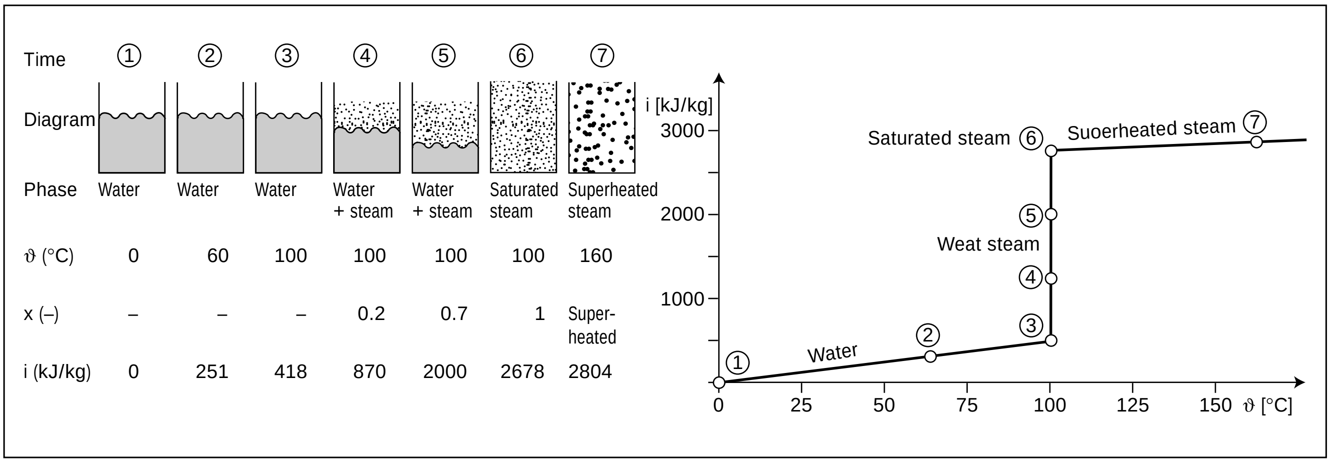
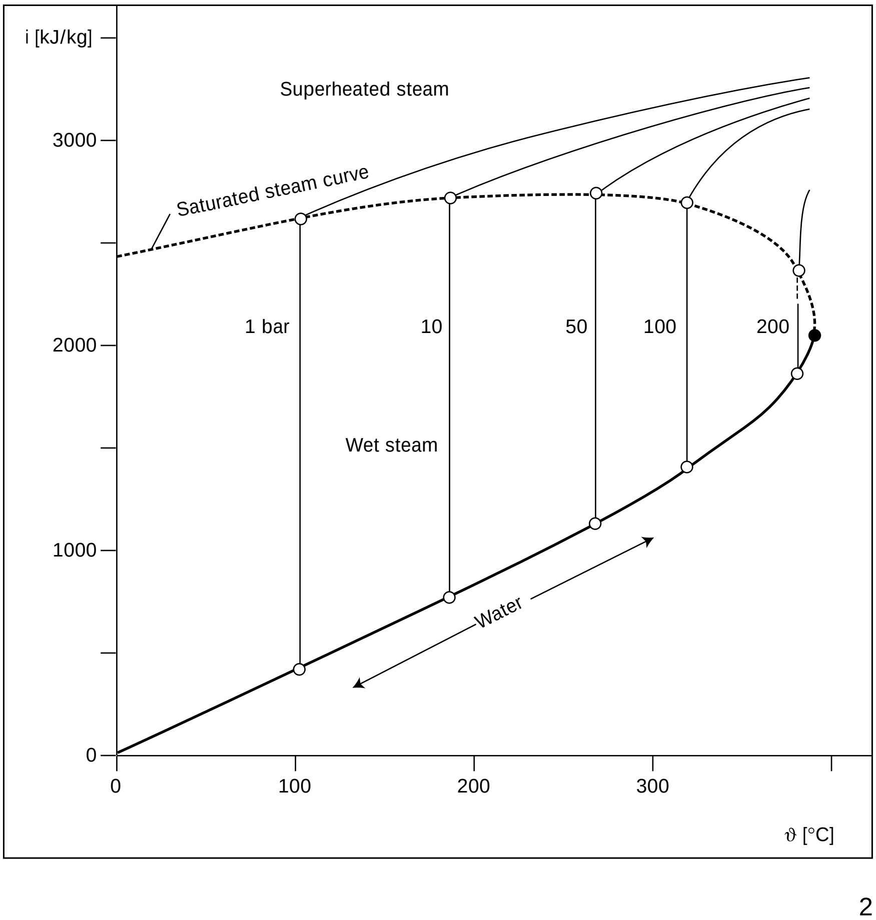


Fig. 1

Key to symbols and units used in this text

Temperature*	ϑ (K or °C)
Pressure (absolute)	p (bar)
Volume	V (m^3)
Specific volume	v (m^3/kg)
Amount of heat	Q (kJ)
Enthalpy	i (kJ/kg)
Heat of vaporization	r (kJ/kg)
Water vapor fraction of wet steam	x (–)
Steam throughput	D (kg/h)
Valve characteristic	Kv (m^3/h)
Entropy	s (kJ/kg K)
Boiler output	N (metric t/h)
Mass (usually form or mold weight)	m (kg)
Specific heat	c (kJ/kg K)
Time	t (h, s)
No. of cycles/hour	n (l/h)
Velocity	v (m/s)



* *Temperature differences are quoted in kelvins (K), e.g. the temperature difference between ϑ_2 = 30 °C and ϑ_1 = 20 °C amounts to 10 K.*

The amount of heat required for the complete evaporation of water at the boiling point, i. e. to convert it into dry saturated steam at the same temperature, is 5.4 times greater than that required for heating the water from 0 °C to the boiling point. This heat is released again when the steam condenses. Even small amounts of energy supplied to saturated steam suffice to achieve a comparatively high degree of superheating.

The boiling or saturated steam temperature prevailing throughout the entire wet steam zone depends solely on the pressure. Hence citing the pressure and temperature does not suffice to define the state of the steam (except for the case of superheated steam) because all mixtures of steam and water at a given pressure have the same temperature.

Superheated steam is a colorless, i.e. invisible, vapor. Visible “steam” according to normal linguistic usage is in fact made up of extremely small water droplets; in other words, it is a mixture of steam, water, and air.

Saturated steam would be desirable for converting Styropor to expanded foams. From the thermodynamic point of view, however, this is merely a theoretical, unstable state that is represented by only one point on the enthalpy-temperature curve. In practice, it can at best be passed through only briefly when the state of the steam changes from wet to superheated or vice versa.

Accordingly, all efforts in the planning and construction of steaming installations can only be directed at the compromise of preexpanding and molding Styropor using wet steam having as low a moisture content as possible.

The water content must be as low as possible because moisture that enters the preexpander with the steam impairs heat transfer to the beads, and thus expansion behavior and the pourability of the material discharged. The moisture has an even more detrimental effect in the subsequent expansion in closed molds and this in fact emerges in several respects.

In the first place, the film of water that wets the beads impedes the desired rapid transfer of heat and also keeps the beads apart. Both effects make fusion more difficult. In the second place, the water condensing in the interstices and microchannels on cooling prevents the escape of gases (steam, air and pentane). As a result, longer times are required for the pressure to fall. To this is added the heat of the water entrapped in the expanded foam which also has to be removed with an attendant lengthening of the cycle time.

Improvements achieved by the application of a vacuum do not alleviate in any way the fundamental disadvantage of a high water content in the expanded foam.

However, even superheated steam can cause problems in processing. It is produced by a reduction in the pressure of dry live steam. However, superheating is prevented by just small amounts of entrained water that become turbulent and reevaporate spontaneously on passing through the seat of the valve. Thus only 3% of moisture is enough to prevent the formation of superheated steam when the pressure is reduced from 11 bar to 3 bar.

Thermal damage very rarely occurs in the production of moldings or blockware, because intermittent withdrawal of steam causes more boiler water to be entrained which reevaporates when the pressure is reduced. In addition, the relatively small amount of superheating energy would be given up to the steam chambers or molds to be heated. This does not apply to preexpanders or to automatic molding machines, which operate with little or no water cooling (energy-saving machines), i.e. with very hot molds. During preexpansion, relatively small amounts of steam are continuously withdrawn from the boiler and thus scarcely any boiler water is entrained. As a result, the steam can become superheated and the beads can agglomerate. There is also a risk of superheating in energy-saving automatic molding machines, because in the first place little and thus comparatively dry steam is withdrawn from the boiler. Secondly, the superheating energy cannot be given up to cooled mold surfaces and this can finally result in scorching of the moldings, particularly in the vicinity of the steam nozzles.

This can be remedied in both cases by:

– locating the pressure-reducing station at some distance from the steam consuming devices;

– providing for the minimum feasible reduction in pressure (boiler pressure);

– partially removing the insulation on the steam line downstream from the pressure-reducing station;

– using steam nozzles with slot widths ≥ 0.5 mm.

Only in the case of continuously operating belt systems is superheated steam deliberately produced in the presteaming chamber in order to heat the upper belt with as little condensation as possible and at the same time to expel air from the bead interstices.

2 Treatment of feed water

Naturally occurring water contains highly variable amounts of inorganic salts, especially hydrogen carbonates, sulfates and chlorides of calcium, magnesium, sodium and potassium. Organic substances and gases are also present.

The equipment needed for chemical treatment must therefore be determined separately for each source of natural water. As a rule, manufacturers of water treatment plants carry out the analysis of a water sample and advise on the appropriate processing.

If untreated water were supplied to the boiler, the calcium hydrogen carbonate most commonly present in natural water would on heating give rise to chalk deposits and carbon dioxide. The scale thus formed on the flues and fire tubes impedes heat transfer and can result in severe damage to the boiler.

For this reason, in the most widely adopted method for the treatment of feed water, base exchange, calcium ions are replaced by sodium ions.

Usually, only the calcium hydrogen carbonate is converted into sodium hydrogen carbonate using ion exchangers, and this decomposes subsequently in the boiler to form carbon dioxide and soda. The unstable soda in turn undergoes cleavage to form in part carbon dioxide and sodium hydroxide.

Thus, even if the feed water has previously been degassed, carbon dioxide is continously formed in the boiler together with sodium hydroxide.

The carbon dioxide gets into the processing machinery together with the steam and may there give rise to signs of corrosion on unsuitable alloys. Much the same applies to the sodium hydroxide dissolved in the feed water. As will be described later, droplets of the solution are entrained in the steam and under unfavorable circumstances primarily destroy molds made from aluminum containing copper.

In this type of process constant replenishment and evaporation of feed water gives rise to an increase in the concentration of salts in the boiler water which is counteracted by periodic or continuous “sludge removal”. This expression is misleading, for it is scarcely sludge which is discharged but rather saline water. On average, 10 % of the feed water is run off. This measure also affects the pH which can fluctuate between 9 and 13 under operating conditions. Hence the water in the boiler is always alkaline and tends to foam, especially when steam is withdrawn intermittently and the pH is rising, thus promoting entrainment of water droplets. As far as foaming of the boiler water is concerned neutral water with a pH of 7 would be best but then the boiler shell would be attacked. A pH of 9 to10 is regarded as optimum because then a good protective layer of magnetite is formed on the boiler steel. This value is a compromise between protection of the boiler and the water content of the steam.

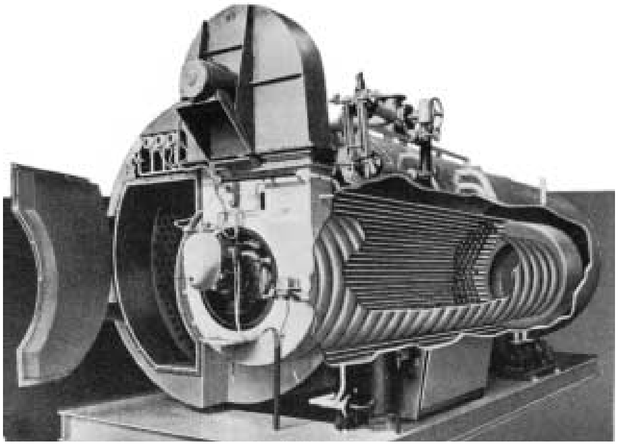


Fig. 3
Three-flue fire-tube boiler

If the feedwater is completely deionized (e. g. by reverse osmosis), sludge removal can be dispensed with (cf. Section 6).

Further details on water treatment are given in TI 360.

3 Boilers

The choice of boiler depends on the method of steam withdrawal. For plants processing Styropor in which the steam is withdrawn intermittently high-capacity boilers, for example fire-tube boilers (Fig. 3) are the most suitable. Because of their large boiler capacity they can „store“ the steam between withdrawal periods with an attendant rise in pressure. The steam thus stored can be released again, very rapidly if necessary, and the pressure drops. The steam storage capacity of a large-capacity boiler can be calculated (as in the case of a Ruths accumulator also) from the product of the boiler water volume and the specific storage capability which can be read off from the diagram in Fig. 4. The nominal output (N in metric t/h) of a boiler is mainly governed by the performance of the burner. A caculable peak demand can be met by interposing an accumulator (Figs. 4 and 5).

Boilers in which a relatively small amount of water is pumped through a tube system (flash boilers) or is conveyed in natural circulation (radiant-type boilers), although less expensive, have smaller dimensions and usually allow higher steam pressures are nevertheless unsuitable for Styropor processing plants. In the case of intermittent steam withdrawal the drop in pressure associated with this would cause pronounced ebullition. The steam bubbles thus formed would impair the heat transfer from the tubes to the water to such an extent that the tubes could be excessively overheated and finally rupture. Their use in conjunction with accumulators is also inadvisable, because they deliver comparatively wet steam even under conditions of steady withdrawal. In addition the feed water must be very carefully prepared in order to avoid scale inside the tubes.

The moisture content of the steam produced by the large-capacity boilers recommended essentially depends on the pH, the rate of withdrawal of steam, the boiler pressure, the area of the water surface, and the distance between this surface and the steam outlet. The drop in pressure brought about by a brief increase in the steam withdrawal rate causes the formation of steam bubles in the hot water which quickly rise to the surface and entrain boiler water. For instance, when steaming a block mold of average size, depending on the boiler pressure a volume of steam is produced varying between 7 m^3 (10 bar) and 15 m^3 (5 bar) which passes a water surface only about 4 – 5 m^2 area in a matter of seconds. Fig. 6 gives an idea of how the water surface changes under the action of the rising steam bubbles at a load of 80 –100 %.

The water level is raised non-uniformly so that differences in level of

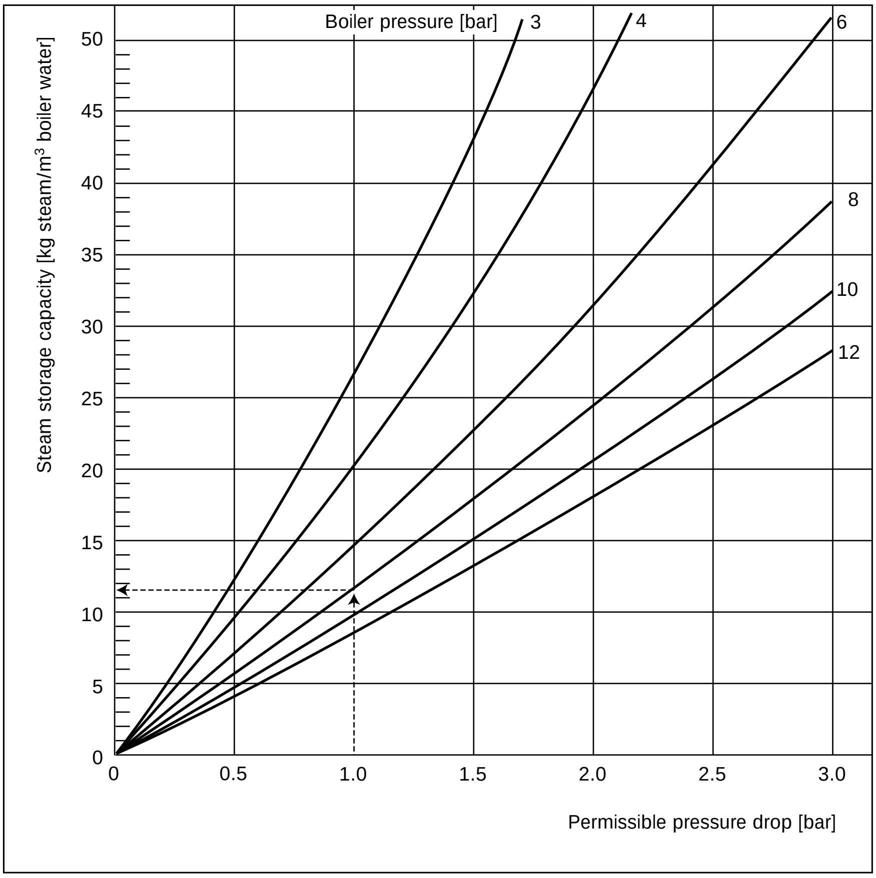


Fig. 4 Steam storage capacity of a Ruths (variable-pressure) steam accumulator as a function of the pressure drop

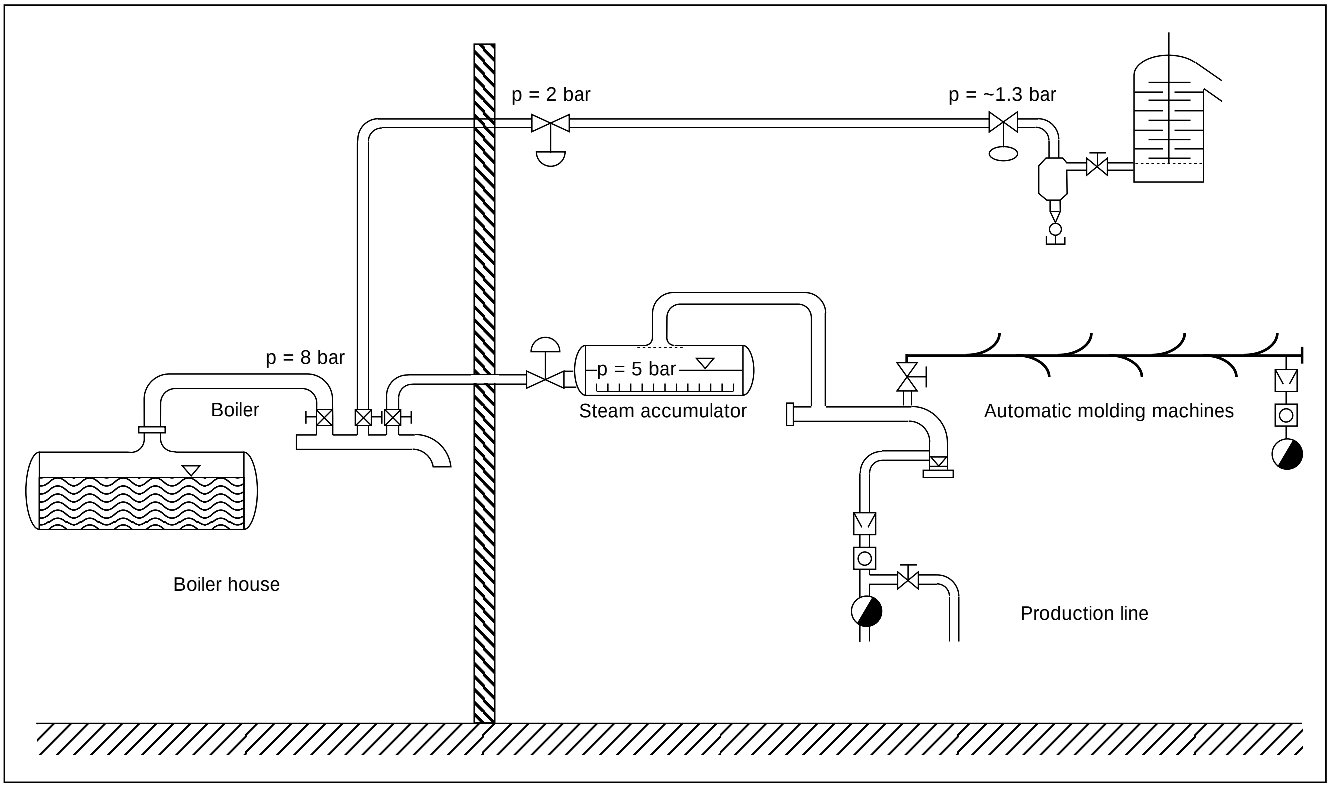


Fig. 5 Suggested layout for operating with a boiler and steam accumulator

180 to 200 mm are produced. (For this reason, it must never be assumed that the reading on a level indicator applies to the entire surface of the water.) Immediately below the steam outlet nozzle, the boiling water bubbles particularly vigorously and numerous droplets are flung into the steam space. Although most of these droplets fall back into the water, some of them are caught by the flow and entrained with the steam, especially at the outlet.

It is evident that in intermittent withdrawal the smaller the distance between the surface of the water and the outlet, the more water is entrained. In boilers of normal size, the distance is only about 0.3 m. Hence, when buying a boiler it is recommended for a little extra outlay to order a steam dome fitted with a water separator. This recommendation also applies if an accumulator is to be installed in tandem with the boiler, because the dome greatly reduces the quantity of alkaline boiler water that reaches the accumulator and increases in concentration there. Nevertheless the accumulator should also have sludge removed (i. e. be bled off) from time to time.

4 Accumulators

Steam accumulators are horizontal, cylindrical pressure vessels that are usually half-filled with boiling water (Fig. 7).

The accumulator is charged from the boiler via a feed line (Fig. 5) which terminates in the accumulator as a perforated charging tube. A reducing valve in the feed line allows the pressure in the accumulator to be adjusted. Despite the customary 100 mm thick insulation, enough condensate is usually formed to obviate the need for feed water pumps once the system is in operation. All that is required to limit the water level is an overflow pipe connected to a steam trap. The condensate can also be run off manually for this purpose.

When choosing the accumulator dimensions a large diameter should be borne in mind so that when it is half full, there is sufficient space between the steam outlet and the surface of the water. Accumulator diameters of 1.6 to 2 m have proved satisfactory in practice. If for reasons of cost, preference is given to an accumulator of smaller diameter, a compromise is essential in the form of an adequately sized steam dome fitted with a water separator.

The condensate run off from the water separators is valuable as boiler feed water and should be reused as such. Regardless of the accumulator's dimensions, baffles and demisters are usually fitted in them to retain water droplets suspended in the steam.

An installation that has become firmly established in the last few years consists of a combination of

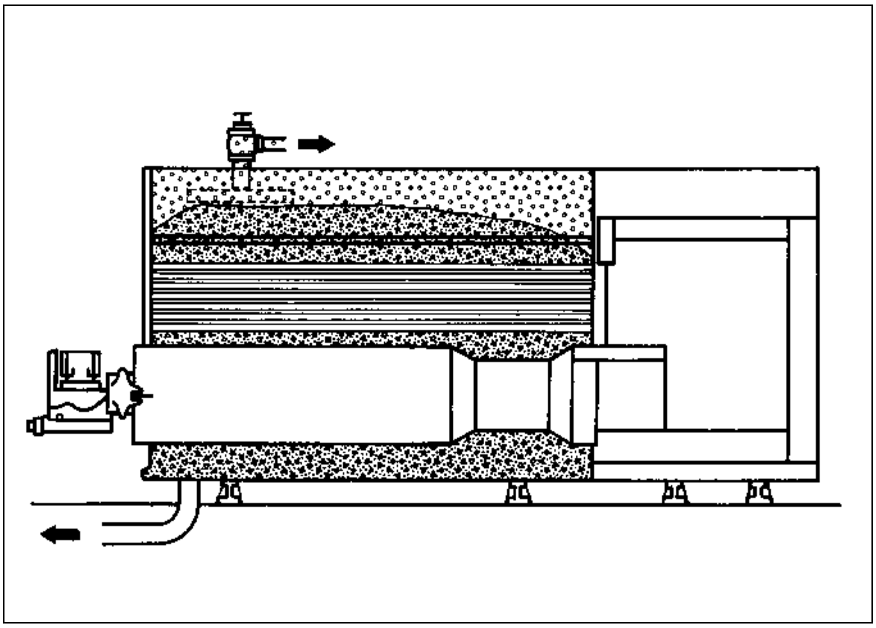


Fig. 6 Change in water level when steam is withdrawn intermittently

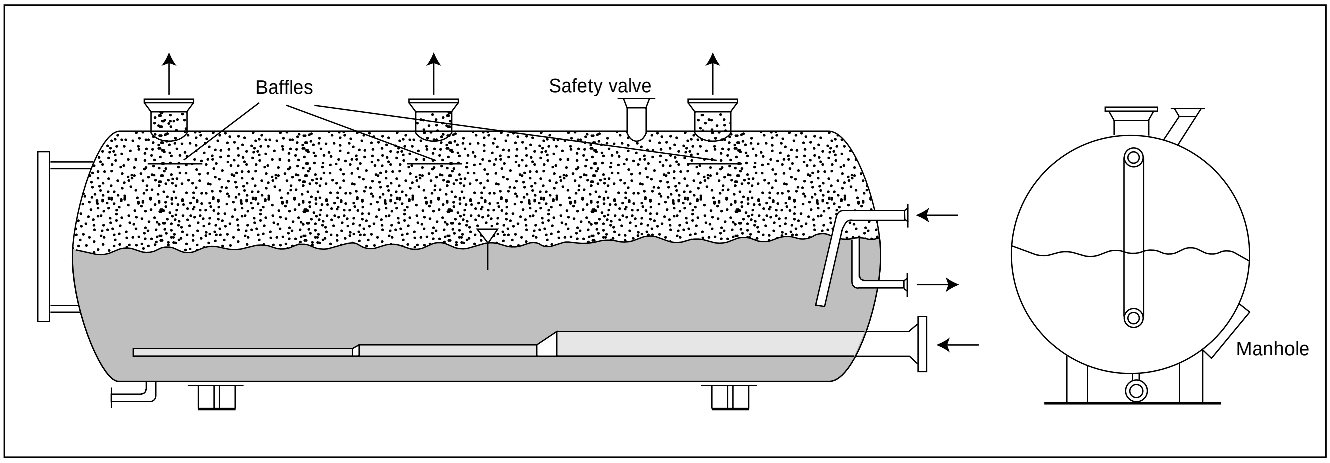


Fig. 7 Steam accumulator

large capacity boilers (in a boiler house) and steam accumulators close to the processing machinery (see Fig. 5). The reasons in favor of this are as follows.

- By virtue of the large water content of the accumulator and its proximity to the steam consumers, the requisite quantities of steam for optimum production are immediately available at the desired pressure.
- Since the entire network of steam lines can be insulated without the risk of overheating, heat losses are reduced.
- Steam that is withdrawn intermittently from well-designed accumulators is much drier than that from conventional large capacity boilers.

To explain the latter point attention may be drawn to the fact that in the recommended large-capacity, horizontal accumulators the area of free water surface through which the steam bubbles pass is much greater and therefore less stressed than in conventional boilers. The large distance between the surface of the water and the steam outlet, which in the case of the accumulator diameter recommended above is at least 0.8 m, also has a very favorable effect. Withdrawal of the steam through two to three outlets is also advantageous.

5 Steam lines

When the temperature fluctuates, the length of the steam tubes varies by about 0.011 mm per meter and kelvin.

On the basis of the two extreme temperatures of

+ 183 °C (operating state at 11 bar) and
+ 5 °C (during shutdowns in winter),

the increase in length expected for a 50-m section of steam pipe would be about 100 mm.

If steam lines are prevented from free thermal expansion or contraction as a result of incorrect mounting, fractures will appear at the welded joints or the anchors will be broken loose. The steam line should therefore always be installed by a specialist contractor so that (through the fitting of expansion joints and the correct number and positioning of fixed supports and pipe slide bearings) such damage is avoided.

Very great importance is attached to good piping installation: in the first place, to save energy (even if the insulation is of average quality, no-load losses in a steam plant still amount to about 10%); and, in the second place, to reduce unwanted condensation. It is recommended that all parts of the steam installation that give off heat should be insulated as well as possible, with the following exceptions.

(a) The condensate runoffs leading into thermal traps are not insulated.

(b) In the case of preexpanders, depending on pressure conditions and the condition of the steam, steam pipes should be insulated only over part of their length (risk of superheating).

(c) According to recent experience the same also applies to automatic molding machines that operate without water cooling and little steam.

When an installation is started up from cold, a period of between 5 and 20 minutes must be allowed for parts with thick walls, e. g. valves and flanges, to heat up, as otherwise pronounced stresses may be induced and lead to leakages at joints or even more severe damage.

The pipe diameter depends on the steam pressure, the permissible pressure loss, and the mass flow rate of steam. Calculations of the steam flow rate should be based on the most adverse circumstances, e. g. more than adequate amounts of steam for each machine and very short steaming periods.

Since in Styropor processing plants, steam is mainly required intermittently and can reach velocities of up to 50 m/s it must be ensured by appropriate installation that as much condensate as possible can run off during the intervening, non-withdrawal periods. Otherwise any condensate still remaining would be swirled up and entrained at these high flow velocities. Due to the feared “water hammer”, in which very high localized pressures can occur, flow regulation fittings are subjected to high stresses and the pipe network (especially the pipe bends) is prone to increased wear. For process reasons all measures resulting in condensate-free saturated steam are to be taken (see Section 1).

For this reason the pipes should be arranged to slope downwards in the direction of flow at a gradient of at least 1 : 100 (the greater, the better). Drainage points are to be arranged at 25 to 40 m intervals. A recommended design is shown in Fig. 8. The nominal diameter of the condensate outlet pipe is the same as that of the steam line. In the case of pipes having a diameter of more than 200 mm a nominal width of 200 mm for the outlet suffices. A large sized outlet having a length between 0.5 and 1 m accommodates the condensate formed when the cold installation is started up. A frequent error is to weld a drainage pipe that is far too small into the steam line (in the worst case there is even a projection into the steam line). Complete drainage cannot be achieved by this means because the flow goes round or over the drainage opening (Fig. 9).

If there is a change in the direction of the steam line, the arrangement shown in Fig. 10 should be adopted. Any condensate entrained in the

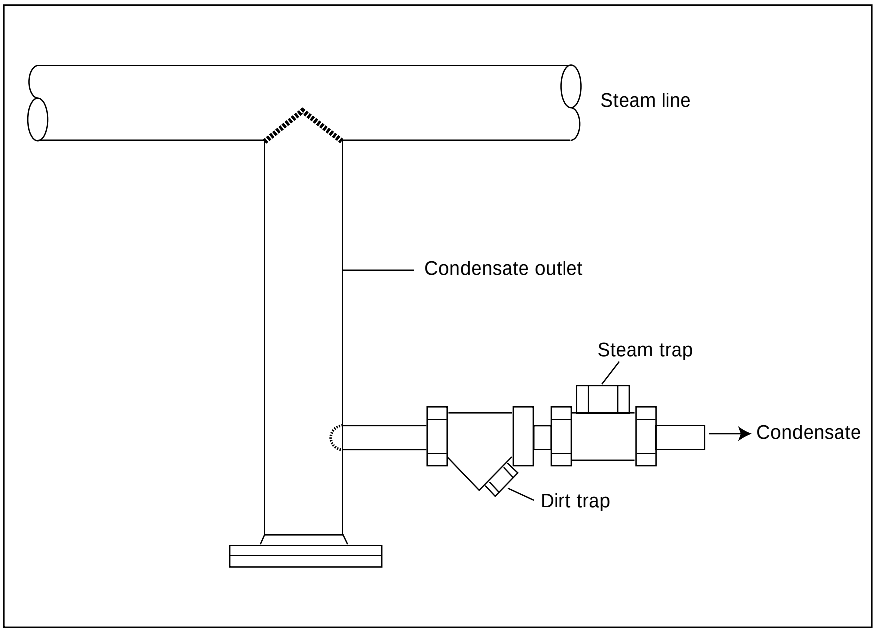


Fig. 8 Condensate discharge pipe

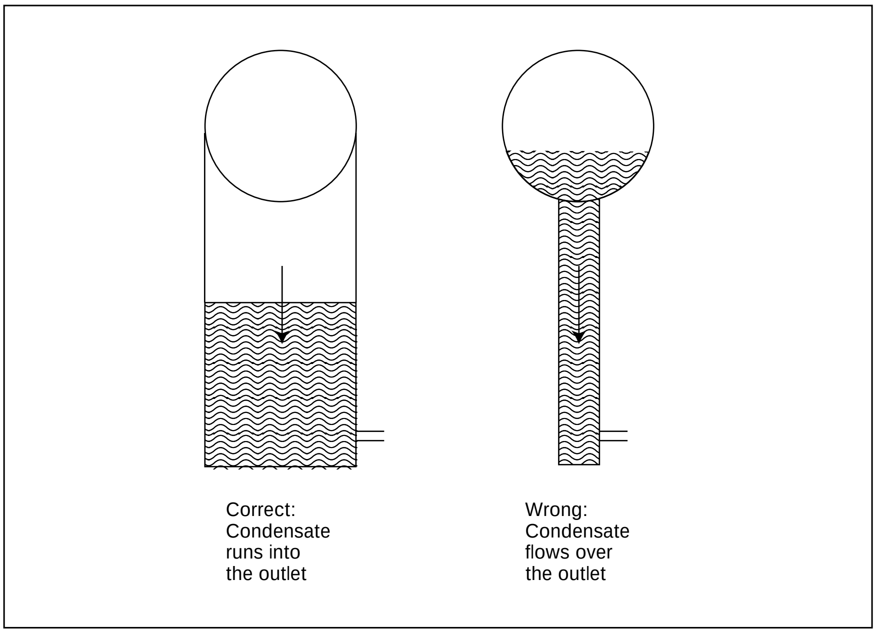


Fig. 9 Effect of the condensate outlet diameter

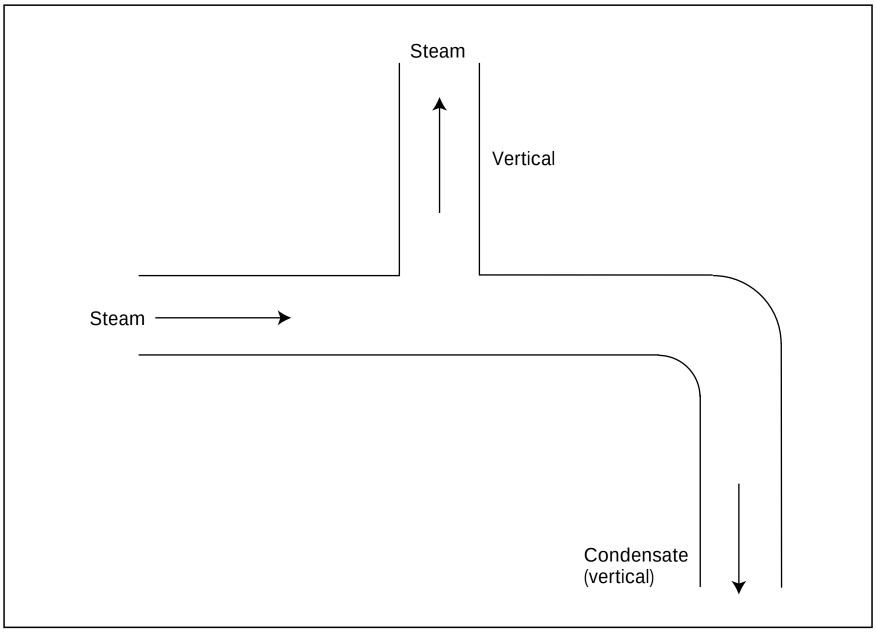


Fig. 10 Drainage on change of direction

steam cannot change direction owing to its inertia. It thus accumulates – shielded from turbulence – in the drainage outlet pipe, which in this case is constructed as a pipe bend.

The inertia of the water can also be exploited in supplying processing machines with steam which is as dry as possible from an overhead horizontal steam distributor main. In installing the branching lines it has to be borne in mind that the water separation effect is all the better the sharper the change in direction (Fig. 11).

Water separators are important components of the steam installation. Their function is to remove the freely suspended condensate droplets from the steam and to lead them into a condensate drain. In most of the designs, separation is achieved by changing the steam's direction of flow. When choosing the separators it has to be borne in mind that each separator is only able to separate off a particular range of particle sizes – wide or narrow depending on design. In addition separation efficiency depends on the operating state, i. e. the velocity of flow. Obviously the smallest droplets (< 0.005 mm) are the most difficult to remove from the steam.

The lowest demands on separation efficiency are made by steam installations for preexpanders, because in this case relatively low steam velocities are required and the steam is withdrawn continuously. As a rule, simple baffle plate or cyclone separators (even of in-house construction) suffice to remove the condensate from the continuous current of steam. The water collected should not be led to thermal traps, because they are regarded as sluggish and not very reliable at low pressures. Good results have been obtained by separators with float valves and thermodynamic separators. In the latter case the pipe between separator and trap must be at least one meter long and uninsulated.

Removal of water from steam is more critical in the production of molded parts and blocks in which intermittent dry steam is required (with pronounced fluctuations in the velocity of flow). Separators of simpler design could not cope with the rapid changes in operating conditions. An example of a separator that is highly efficient under these conditions is the centrifugal separator of Prof. Barth (Fig. 12), in which a spiral flow path is produced by means of guide vanes.

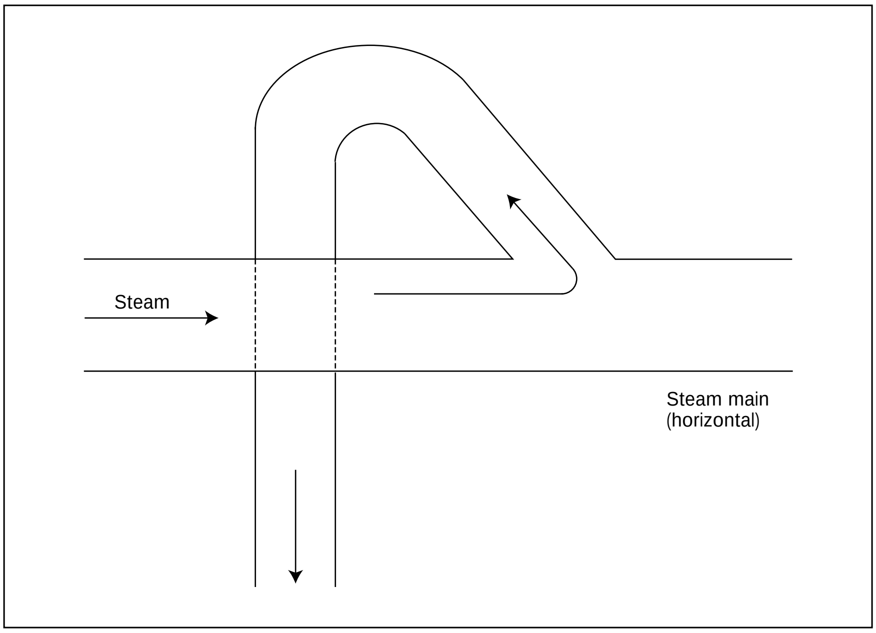


Fig. 11 Downward branch line

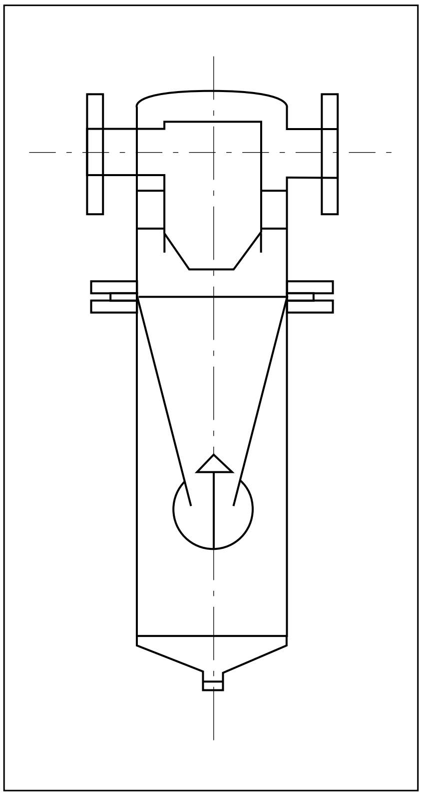


Fig. 12 Barth separator

Lamellar separators (Fig. 13) even guarantee residual condensate fractions of less than 0.1%. This also applies for pronounced steam surges and operating conditions fluctuating between 15 and 100 % of the rated steam capacity. The principle of separation is based on multiple zigzag changes in direction in a bundle of lamellae with vertical trapping pockets which drain the separated condensate into the collecting chamber (Fig. 14). In principle, all kinds of condensate traps are suitable in view of the higher operating pressures.

A schematic diagram of the system of steam lines for the production of blockware is presented in Fig. 15, and for the production of molded parts in Fig. 16.

6 Reduction of steam generation costs

Complete deionization

In Section 2, it was pointed out that in feed water treatment using ion exchangers about 10 % of the water in a boiler has to be removed as “sludge” to prevent the salt content rising too much and to maintain the pH. This measure entails the loss of large amounts of energy.

Automatic full deionization plants have rarely been installed so far in Styropor processing plants. Their technical advantages were always evident, but now the rising costs of steam generation have made them increasingly desirable from the economic point of view for feed water treatment because then the amount of boiler water to be removed is almost negligible. Furthermore, in fully deionized feed water the so-called soda cleavage (see Section 2), in which sodium hydroxide and CO_2 are liberated in the boiler, does not arise. The pH can also be maintained constant at the optimum value and thus foaming can be largely suppressed with advantageous consequences for steam quality.

Finally, no scale is formed in the boiler.

These benefits justify the higher capital investment costs for an automatic deionization plant (for instance around DM 40 000 for 6 m^3/hour of water as compared to about DM 10 000 for a simple water softening plant). This is evident from the following specimen calculation.

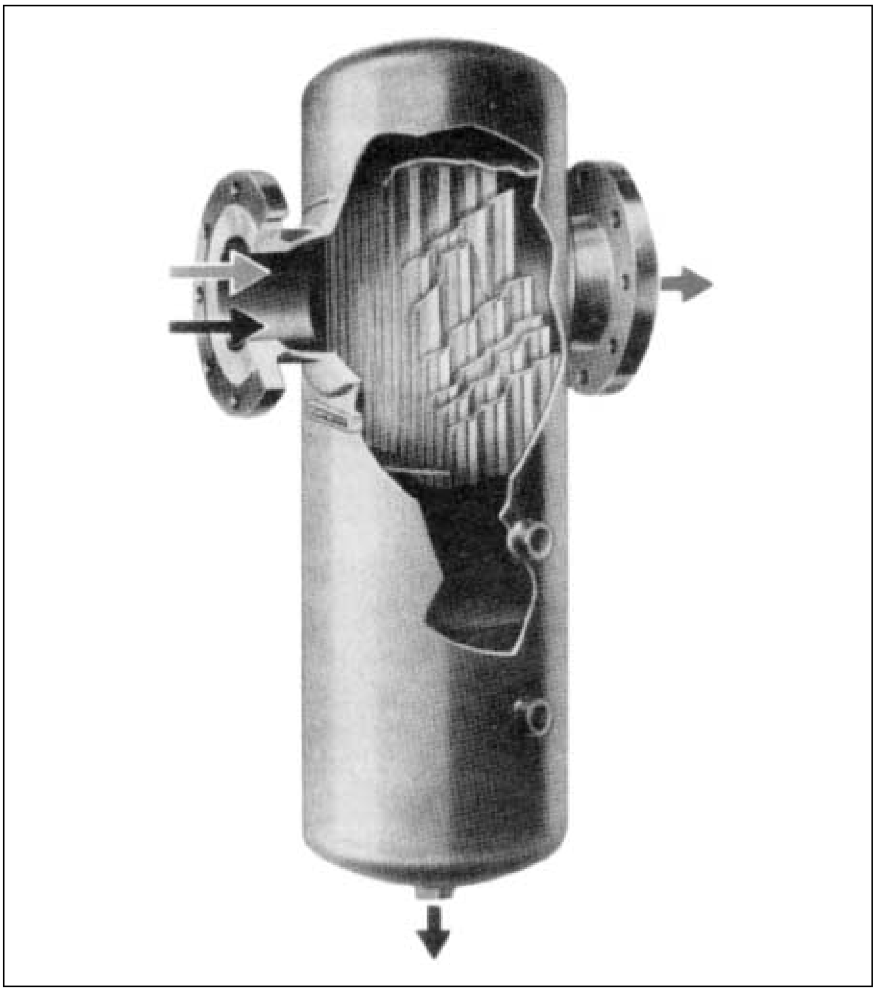


Fig. 13 Lamellar separator

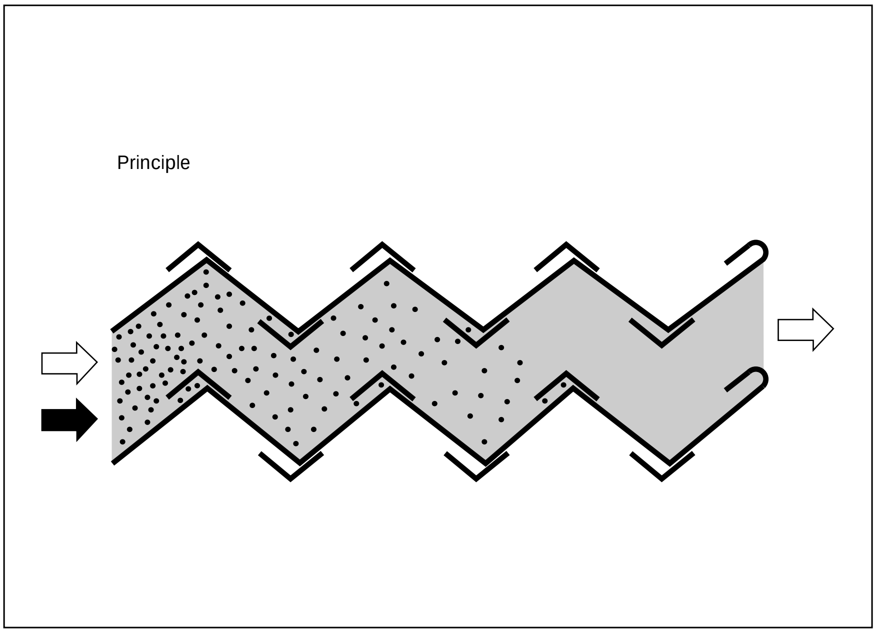


Fig. 14 Principle of water removal in a multi-baffle separator

Key to Fig. 15

1 *Feed water deionization*
2 *Feed water pump*
3 *Economizer (flue gas heat exchanger)*
4 *Boiler*
5 *Pressure-reducing valve*
6 *Steam accumulator*
7 *Perforated steam inlet pipe*
8 *Steam main for preexpanders*
9 *Pressure-reducing valve (preexpanders)*
10 *Branch pipe leading to preexpander*
11 *Preexpander*
12 *Branch pipe leading to second preexpansion stage*
13 *Second preexpansion stage*
14 *Cyclone steam separator*
15 *Assembly consisting of dirt trap, condensate trap, and bypass control*
16 *Steam main for block molds*
17 *Condensate separator, e.g. lamellar type*
18 *Main valve for block mold*
19 *Steam manifold for block mold (both sides)*
20 *Block mold*

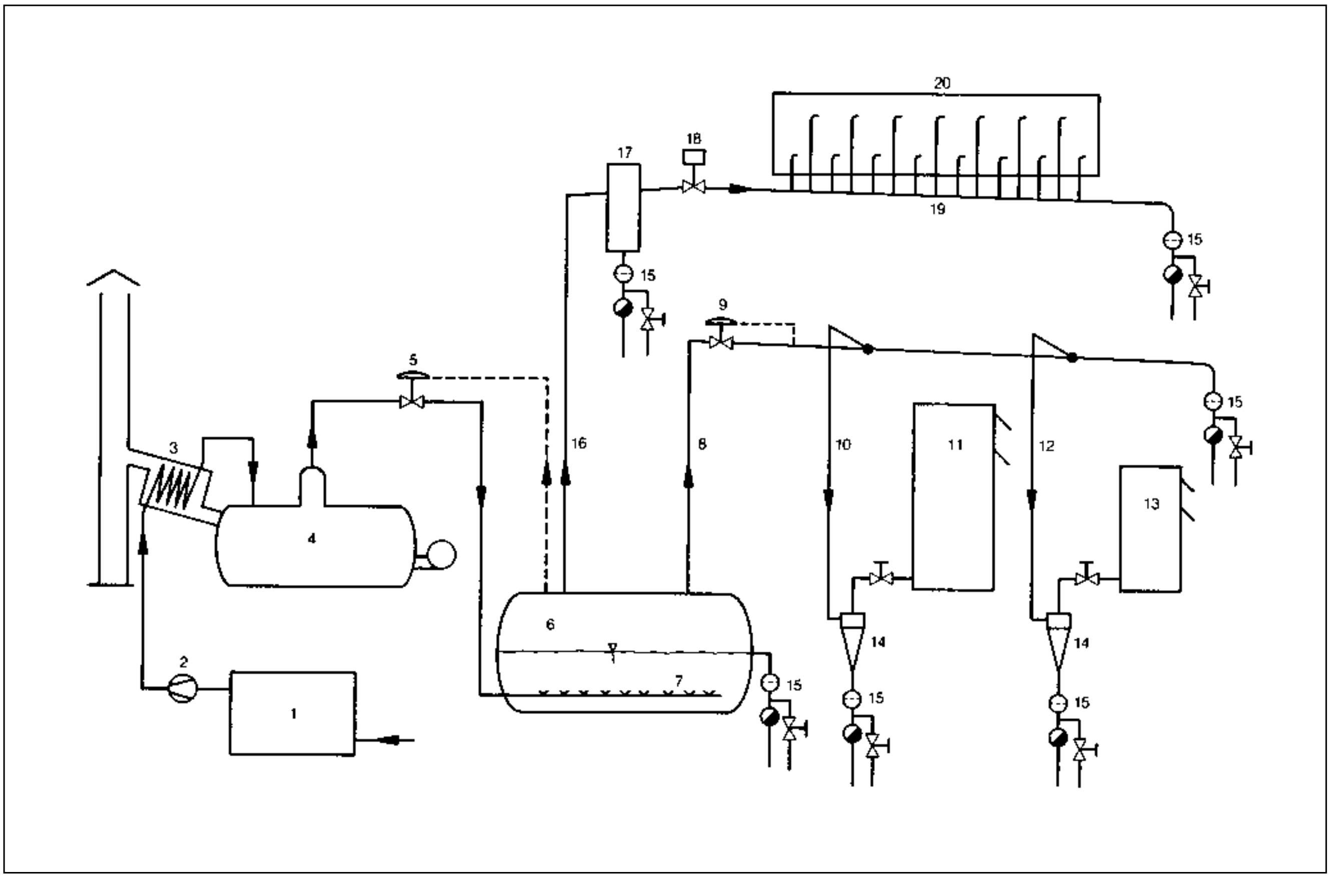


Fig. 15 Layout of steam installation in a block production plant

Given:

- steam consumption 6 metric tons/hour
- two shifts (4000 hours pa)
- 10% boiler water sludge removal
- the costs of hot water and steam behave to a first approximation in the same way as their enthalpies
  - steam costs DM 75 metric ton
  - other sources of waste heat are available for heating the boiler feed water.

Under these conditions, the annual sludge removal losses amount to 2400 metric tons of hot water. Since the enthalpy of hot water is approximately a quarter of that of steam, the annual losses amount to about DM 45 000. Hence the extra capital investment costs for an automatic deionization plant would already be amortized after about one year.

Lowering the boiler pressure

Styropor is expanded by steam of less than 2 bar pressure, and it is customery to run boilers at about 11 bar pressure. An obvious question that thus arises is whether the boiler pressure should be reduced to that of the steam main, i. e. about 6 bar.

One of the reasons is the effect of boiler pressure on the amount of water spray at the surface. The lower the pressure the higher is the moisture content of the steam. This is the main reason why boiler manufacturers recommend that compact boilers be operated at high pressure. In addition extra costs arise for the larger steam lines including insulation and pressure-reducing valves. The objection of greater entrainment of water can be ruled out if

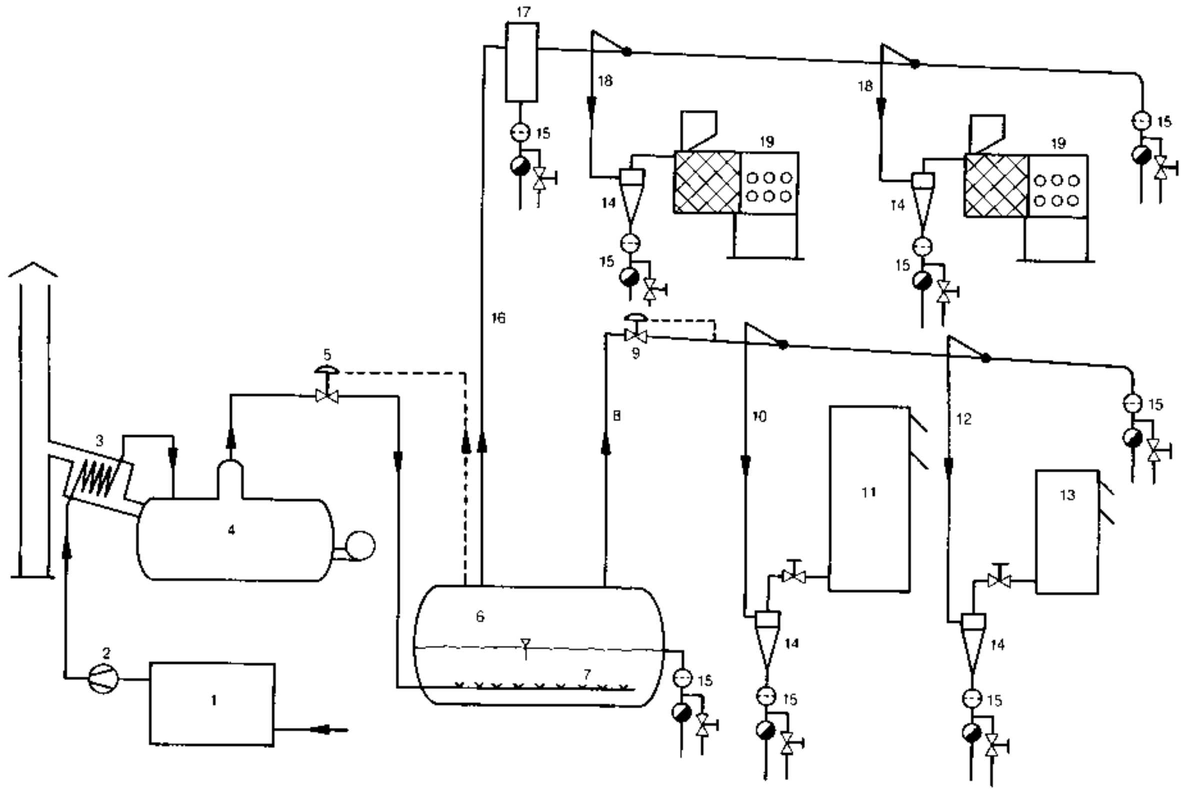


Fig. 16 Steam installation for automatic molding machines

the boiler without withdrawal peaks supplies a steam accumulator.

On the other hand a lower boiler pressure of about 6 bar affords the following benefits.

- The capital investment costs are roughly 10 % lower.
- A greater mass of steam can be stored in unit volume of boiler water. This is particularly advantageous when the boiler has to supply automatic molding machines direct as well as the accumulator for the block molding machines.
- The boiler efficiency is greater at low pressures. The flue gas temperature in boilers of conventional design is about 40 K higher than that of the saturated steam. Thus for a boiler running at 11 bar the flue gases have a temperature for example of about 225 °C, while at 6 bar it is about 200 °C.
- The heat losses by convection are also less.
- Less pressure reduction is required, and the risk of superheating is thus reduced (relates to preexpanders).
- No pressure-reducing valve is required in the steam main supplying the automatic molding machines.

Key to Fig. 16

1 Feed water deionization
2 Feed water pump
3 Economizer (flue gas heat exchanger)
4 Boiler
5 Pressure-reducing valve
6 Steam accumulator
7 Perforated steam inlet pipe
8 Steam main for preexpanders
9 Pressure-reducing valve (preexpanders)
10 Branch pipe leading to preexpander
11 Preexpander
12 Branch pipe leading to second preexpansion stage
13 Second preexpansion stage
14 Cyclone steam separator
15 Assembly consisting of dirt trap, steam trap, and bypass control
16 Steam main for block molds
17 Separator, e.g. lamellar type
18 Branch line for automatic molding machines
19 Automatic molding machines

In most Styropor processing plants these benefits clearly outweigh the extra costs for pipes of greater diameter, which do not relate to the entire pipe installation but only to the connecting length between the boiler and the pressure-reducing valve in the steam accumulator feed line.

If additional automatic molding machines have to be supplied direct from the boiler, all that would be required is to install a length of pipe of greater diameter between the boiler and the point where the reducing valve would have been (at the lower pressure no valve is required). It would also be advisable to install more efficient separators, because wetter steam can be expected if the boiler pressure is reduced.

Choice of fuel – heat losses in flue gas

The heat losses in the flue gas depend on the burner settings and the flue gas temperature at the boiler outlet. The latter temperature should be as low as possible, and the carbon dioxide content, which is a measure of the combustion efficiency, should be as high as possible (see Fig. 17).

For economic reasons efforts are increasingly being made to keep energy losses from flue gases, i. e. the flue gas temperature, as low as possible by using heat exchangers to withdraw from the gas a part of its heat and using the latter as the last stage for heating the feed water. The minimum flue gas temperatures at the end of the chimney, below which they must not be allowed to fall, depend on the fuel (sulfur content). The limit for heavy fuel oil is 160 °C, for light fuel oil 130 °C; and for natural gas 110 °C.

Natural gas exhaust gases are thus better suited for the recovery of heat. In addition natural gas is regarded as the more environmentally friendly and cleaner fuel. It does not form soot on heated surfaces and therefore does not gradually impede heat transfer and impair boiler efficiency.

If possible, a changeover to natural gas is recommended. However, it requires official approval in many

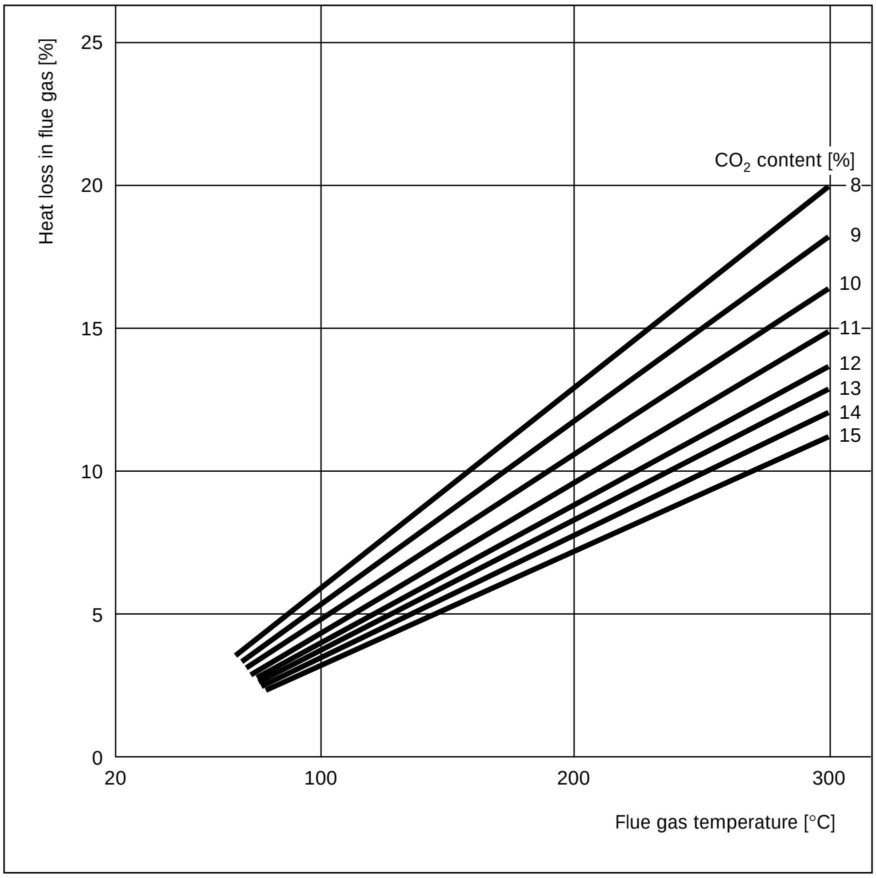


Fig. 17 Heat loss in flue gas as a function of flue gas temperature and carbon dioxide content

countries and involves work by specialists. The same applies to the retrofitting of an economizer (a heat exchanger around which the flue gases flow).

If the temperature of the flue gas falls below the limits quoted above, which may be regarded as dew points, especially in the case of heavy and light fuel fuel oils sulfurous acid will be formed which will rapidly attack the steel flue (sooting). Thus at a recommended boiler pressure of 5 bar and using the most common fuel (light fuel oil) the temperature difference available for heat recovery is only 200 – 130 °C = 70 K. In the event that the economizer consists of steel the feed water must first be heated to 130 °C with live steam after it has been degassed since at lower temperatures the pipe walls would be below the acid dew point. The temperature of the feed water would then rise by approximately 10 – 20 K in the economizer, the actual value depending on the area available for heat transfer. Much higher heat recovery efficiencies, even at low boiler pressures, can be achieved with a stainless steel economizer and a steel chimney with VA lining because in this case the temperature may fall with impunity below the dew point of the acid (to be taken into account in planning a new factory). However, the accumulating sulfurous acid must be collected and disposed of. This is a point that must be taken into account in plant design.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Technical Information

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4 Processing

Vacuum technology in expanded foam production

I General

The use of saturated steam to supply energy in the conversion of Styropor to expanded foams was an important discovery. Just as important, however, is the use of vacuum in the subsequent cooling stage, i. e. in the dissipation of energy. Both processes are similar, but one is the reverse of the other (see also TI 340).

- Rapid cooling by evaporation.

  A lot of heat energy can be removed from the mold by the evaporation of small quantities of water.

  The lower the absolute pressure, the greater the heat of vaporization and therefore the greater the amount of heat (kJ/kg) that can be extracted (see Fig. 4 overleaf).
- Efficient heat transfer by avoiding steam/air mixtures.

The advantages in detail are set out below.

A Application of vacuum after the mold is filled (immediately before steaming)

This method is state of the art in the manufacture of blocks.

Advantages are: Approximately 50 % less steam is needed and the foam particles are fused homogeneously even inside 1 m thick blocks. This technique is rarely used, however, for molded parts because the lack of an adequate vacuum buffer would result in longer cycle times.

B Vacuum applied after steaming

This technique is applied in both block molds and automatic molding machines for bulk densities up to a maximum of 30 kg/m^3 and has the following advantages:

a) considerable reduction in the time for foam pressure to fall off;

b) reduction of the foam’s initial water content;

c) acceleration of the escape of residual pentane from the expanded foam.

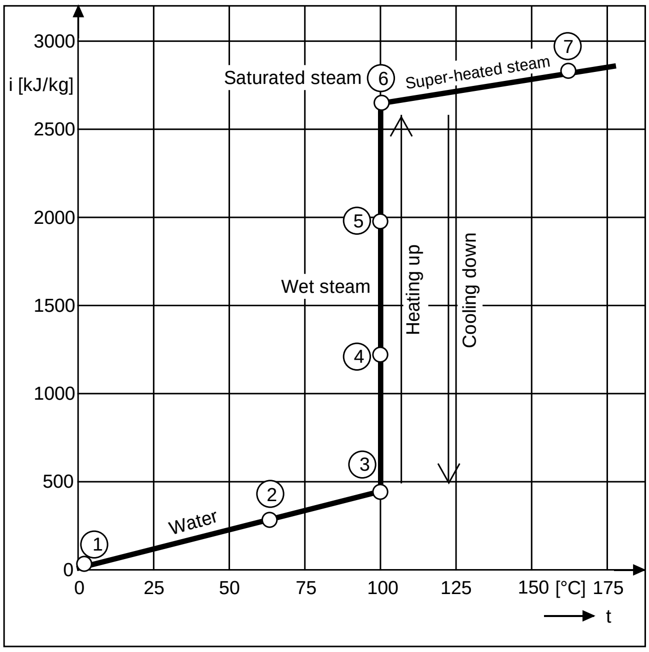

*Fig. 1 Change of state of water from the liquid to the gaseous phase by provision of energy (p_e = 0 bar)**.

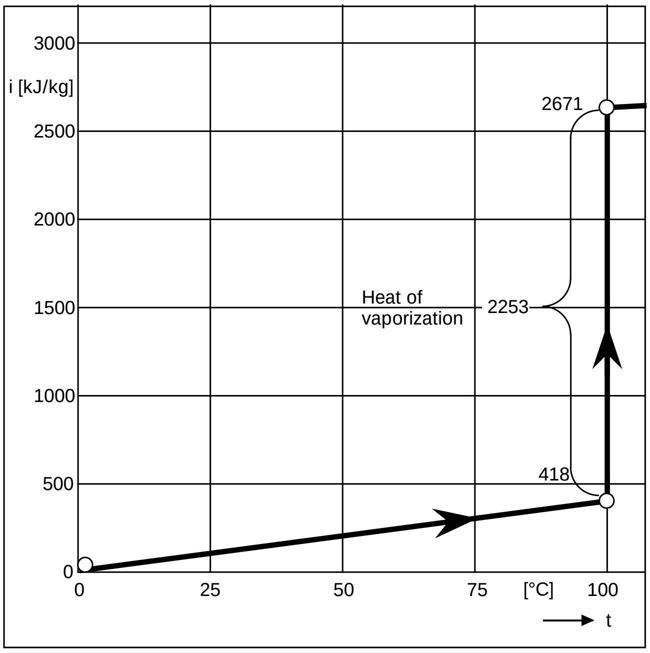

Fig. 2 Energy required to heat and vaporize water at p_e = 0 bar (see also TI 340).

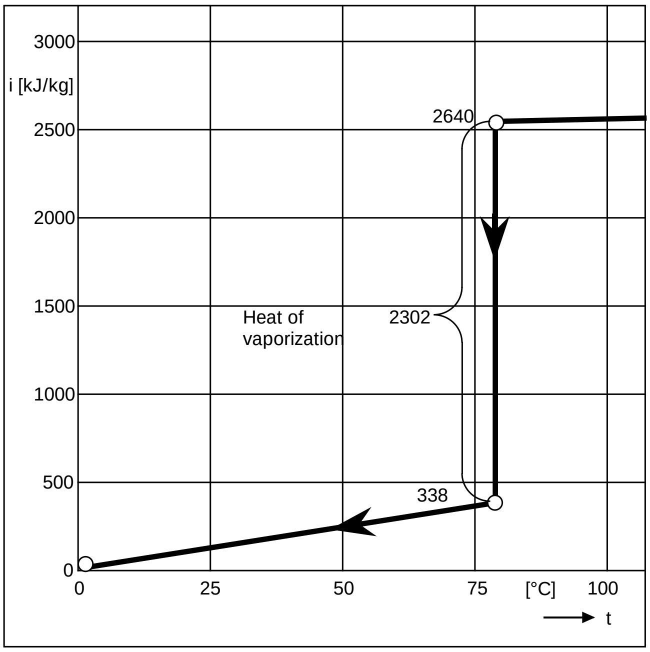

Fig. 3 Energy required to vaporize water at p_e = –0.5 bar.

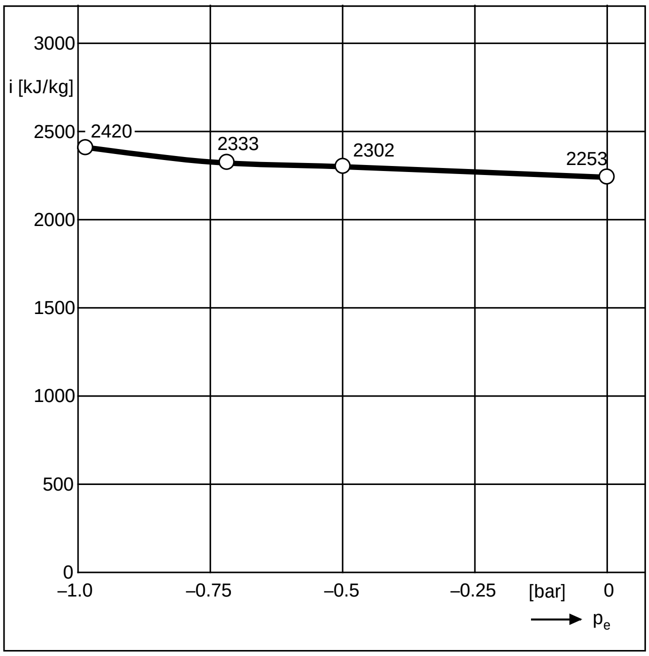

Fig. 4 Heat of vaporization as a function of pressure.

* p_e 0 bar ≙ p_{abs} 1 bar

II Requirements for achieving the described advantages

a) The mold should be heavily and uniformly perforated to provide an effective channel between the steam chest and the foam so that the vacuum can act uniformly at as many positions as possible.

b) The vacuum should be applied as quickly as possible immediately after the end of the steaming phase and should at least be of the order of $p_e = -0.5$ bar. For this purpose a duration of 1 s to 3 s (max.) is particularly advantageous. A rapid reduction in pressure, which also means shorter foam-pressure reduction times, is achieved by using

- a sufficiently large vacuum buffer volume (central vacuum system),
- fast and efficient condensers,
- a vacuum pump with adequate capacity, and
- an airtight system.

III Equipment used – arrangement and operation

A Vacuum pump

Since the application of vacuum to the steam chests results mainly in the extraction of a mixture of steam and water, water-ring pumps, which use water both as operating and sealing medium, have been used exclusively for producing the vacuum.

One characteristic of this type of pump is that the service water is heated by friction on the inner wall of the pump body. As the water gets hotter, the suction performance drops. The pumps are therefore designed to continuously discharge part of the heated water on the discharge side of the pump and to replace that lost with fresh water from an inlet on the pump body. The fresh water should be clean, softened and as cool as possible (5 °C to 25 °C max.).

There are single-stage and two-stage water-ring pumps. Single-stage pumps are totally adequate for the range of pressure needed when expanding foam (0.2 –1.0 bar). In this pressure range they are also more efficient than two-stage pumps.

Cavitation and vacuum regulation

If the demand for vacuum drops to zero (caused by machine stoppage for instance), the vacuum pump quickly reaches the lower end of the vacuum it can produce (approx. pe = – 0.1 – 0.15 bar, depending on the temperature of the service water). When this situation arises cavitation occurs inside the pump, which is characterized externally by the pump emitting whining, rattling noises. Cavitation can damage the pump, including the impeller. It can be easily prevented by fitting a vacuum limiter valve in the vicinity of the pump’s intake pipe.

Sensitivity to solid particles

Water-ring vacuum pumps are basically subject to damage by solid particles. Damage to the impeller and plate cams can be such as to reduce the suction power to zero. Expensive repairs can be avoided by protecting the pump through the arrangement of a filter or suitable condenser on its intake side (where it can have a filtering effect).

B Condenser

General

If the vacuum pump is connected directly to a steam chest, the steam referred to under IIIA is carried straight to the vacuum pump where it condenses. The disadvantage here is that the volume of steam reduces the pump suction power. In addition, the steam heats the pump’s service water thus contributing to a further reduction in performance. Seen in this way, the vacuum pump is being misused as a condenser, which is an uneconomic mode of operation. It is therefore unusual to find systems today without condensers.

The aforesaid misuse can be avoided by positioning a condenser between the steam chest and vacuum pump. The size of the vacuum pump can then be kept much smaller, its purpose being to produce and maintain a vacuum for the sake of economy solely by extracting air. Only air dissolved in the water and air entering the system through leaks is to be conveyed. The required size and performance of the condenser largely depends inter alia on whether at the end of the steaming phase the steam in the steam chests

- is fed directly to the condenser or
- is led off briefly (1 – 2 s) via a bypass to the condensate collector pipe (direct connection of steam chests to the consensate collector pipe for reduction of excess pressure) or
- is first of all condensed in the steam chests by injecting water until a certain reduction in pressure is achieved, and then opening the valves connecting the steam chests to the condenser.

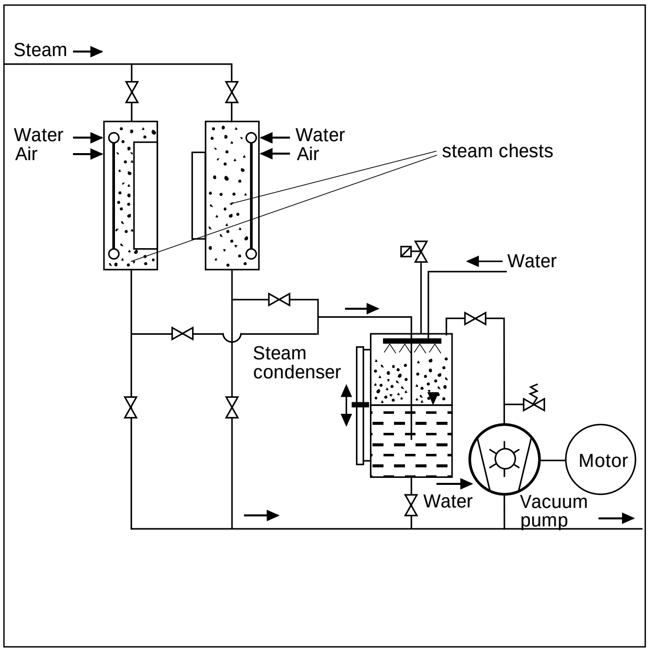

Fig. 5 Vacuum system, incorporating steam condenser, connected to the outlet side of the steam chests

The warm water in the condenser must be replaced periodically by cold water.

Proven designs and empirical values

- Immersion condenser
- Partial vacuum of $p_e = -0.5$ bar is achieved in 2 – 4 s.
- Spray condenser
  Partial vacuum of $p_e = -0.5$ bar is achieved in 3 – 8 s.

A combination of both systems is also used.

Multi-tube surface condensers are seldom used (partial vacuum of $p_e = -0.5$ bar in 11 – 14 s).

C Centralized vacuum plant

In this mode of operation the vacuum pump can be used much more economically than when dedicated to one device. The advantages are that vacuum is available more quickly and there are fewer rotating parts subject to wear.

The centralized vacuum plant consists of three main elements:

- Buffer vessel
- Manifold line
- Vacuum pump (see also Fig. 6).

For the condensate to be able to drain away properly, it is important to observe the relative positions of the elements shown in Fig. 6. By use of modular design, a centralized vacuum plant can be expanded in every respect.

For trouble-free and economic operation of the plant, it is essential to locate a condenser between the manifold line and each consuming device. If this is not done, too much hot vapor is fed to the vacuum pump, reducing its efficiency. The system must also be air-tight.

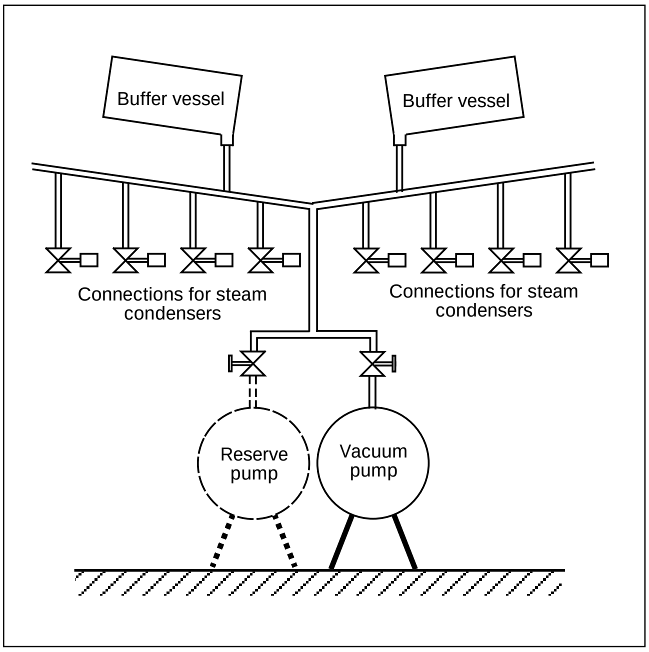

Fig. 6 Centralized vacuum plant

IV Layout criteria, empirical values, examples (see also Tables 1 and 2)

A Pumps

Dedicated provision for automatic machines

Depending on the efficiency of the condensers used vacuum pump powers of between 3.8 kW and 11 kW per square meter of clamping surface are common.

Dedicated provision for block molds

a) A vacuum pump power of 18.5 kW has proved adequate for a 2 m^2 block mold when 10 m^3 of vacuum buffer and a condenser volume of 0.5 m^3 are available.

b) for a 7.5 m^3 block mold, a vacuum pump power of 45 kW and simultaneous availability of 20 m^3 of vacuum buffer space and a condenser volume of 1 m^3 are needed.

Machine	No.	Size	Type of vacuum supply	Pump capacity m^3/h	Power required kW	Condenser	Buffer volume m^3
Part molder	1	clamp. surface 1 m^2	local	390	11	no	–
	1	clamp. surface 1 m^2	local	130	4	yes	–
	10	clamp. surface 10 x 1 m^2	central	250	7.5	yes	6
Block molder	1	volume 2.5 m^3	local	1230	35	no	–
	1	volume 2.5 m^3	local	645	18.5	yes	10
	2	volume 2 x 2.5 m^3	central	645	18.5	yes	20
	1	volume 7.5 m^3	local	1800	45	yes	20
	2	volume 2 x 7.5 m^3	central	1800	45	yes	30

Table 1 Pump performance (empirical values)

B Centralized vacuum plants

Pump power for automatic machines

When the system is sufficiently airtight a 7.5 kW vacuum pump is adequate to supply 10 automatic machines each with a clamping surface of 1 m^2.

Pump power for block molds

The installations described under D below are able to provide adequate vacuum for two block molds of the described size simultaneously.

C Vacuum surge vessel

As with other services – steam, water and compressed air – the peak demands for vacuum must be covered by means of a storage vessel. The vessel volume required depends on the maximum amount of air to be accommodated, as well as the allowable rise in pressure. So that the foam pressure can be reduced uniformly and quickly, the vacuum pressure in the vessel should not be allowed to increase above $p_e = -0.5$ bar. The required volume of the vacuum surge vessel V_K is given by

$V_K = V_{nK} \cdot p_a/(p_o - p_u)$, where

V_K [m^3] = volume of vacuum vessel

p_a [bar] = intake pressure = 1 bar

p_u [bar] = lower pressure limit

p_o [bar] = upper pressure limit

V_{nK} [m^3] = the volume of air (converted to intake pressure) stored between pressures p_o and p_u. For example, values of $p_a = 1$ and $p_o - p_u = 0.5 - 0.2 = 0.3$ can be used.

D Vacuum manifold line, practical values

Part molding machines

A manifold line of diameter 200 mm is adequate for a system consisting of 5 – 6 machines and a 2 m^3 vacuum surge vessel.

Block molds

A manifold line of diameter 300 mm is recommended for each block mold with volume of up to 5 m^3, together with a vacuum buffer volume of 10 – 20 m^3.

E Cooling water circuits for automatic machines

To achieve steady cooling of the hot mold walls after steaming, cooling water with a relatively high temperature (50 – 70 °C) should be used. It is then possible to spray the back wall of the mold with a thin film of water which is evaporated when vacuum is applied. The mold is cooled in the desired manner by the withdrawal from it of the heat of vaporization needed to evaporate the water (see Figs. 1 – 4).

A cooling water temperature of 50 – 70 °C is however unacceptably high for the operation of vacuum pumps and condensers. These require temperatures of 5 °C up to a maximum of 25 °C. For this reason, modern molding plants have two separate cooling water systems with different temperatures.

Process water requirement m^3	Vacuum pump performance at 15°C water-ring temperature m^3/h	at intake pressure of mbar abs.	Motor power kW	Recommended nominal diameter of the vacuum pipe ND
0.55	130	200	4.0	50
0.70	180	200	5.5	65
1.20	250	200	7.5	80
1.50	390	200	11.0	100
1.80	500	200	15.0	125
2.0	645	200	18.5	125
2.5	940	200	28.0	150
3.0	1230	200	35.0	150
4.0	1800	200	45.0	200

Table 2 Technical data for vacuum pumps

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4 Processing

Cooling-water problems in plants processing Styropor

Contents

1 General considerations

The molding machines used for the manufacture of shaped parts from Styropor must be supplied with cooling water. The temperature of this cooling water depends on the grade of Styropor used and the design of the molding machine (with or without vacuum cooling – see Table 1).

A fundamental distinction is made between once-through cooling and closed-circuit cooling. Once-through cooling is generally uneconomic. It is therefore recommended to use recirculated cooling water. After being heated this must be cooled again and be freed of solids.

2 Types of cooling-water circuit

Wet cooling tower (open circuit)

Wet cooling towers are usually used for recooling the water. Since in doing so the water comes into contact with the air, this is called an "open" circuit.

About 2 % of the water is lost by evaporation in the cooling tower alone. Further losses arise through leakage and deliberate bleed-off so that total losses of 5 % must be made good with treated fresh water.

The cooling performance of the wet cooling tower depends on the humidity and temperature of the outside air (moist air temperature).

It occasionally happens that the ambient air in the vicinity of the cooling tower contains undesirable constituents. These substances can get into the cooling water circuit and separate out resulting in faults due to deposits. Any problems arising in this way can be avoided by means of timely water treatment measures and/or suitable additives in the cooling water.

Air cooler (closed circuit)

For various reasons (e. g. avoidance of clouds of water vapor or constituents of the air) it can be necessary to use air coolers instead of wet cooling towers.

The cooling performance of an air cooler is dependent on its surface area and also very much on the temperature of the outside air (dry air temperature).

The warm air accumulating can be used for space heating (silo chambers, storage rooms) or also for preheating tunnel drier air.

Table 1 Recommended cooling-water temperatures

Styropor type	Molding machine	Cooling-water temperature
Slow-cooling	vacuum-cooled machine no vacuum cooling	30 – 50 °C 20 – 25 °C
Fast-cooling, energy-saving	vacuum-cooled machine no vacuum cooling	40 – 70 °C 30 – 40 °C

3 Heat recovery using heat exchangers and heat pumps

Much of the energy in warmed cooling-water and exhaust steam (from preexpanders, molding machines and block molds) can be recovered and used elsewhere. For each molding shop it is worthwhile carrying out a thermal audit based on the conditions in that particular shop. Some of the possibilities to be considered are indicated in Table 2.

In very many shops it can be sensible to employ plate heat exchangers which are particularly economical. Moreover, by calculating through the prevailing conditions it may turn out that it is more economical to install a heat pump rather than a cooling tower.

4 Construction, description and sizing of a cooling-water system with a cooling tower

Introductory remarks

When using fast-cooling, energy-saving grades of Styropor in association with vacuum cooling, it is particularly advantageous to work with two cooling-water circuits at different temperatures as follows.

– Cooling-water circuit 1 (warm-water circuit) serves only to wet the backs of the machine mold walls and is drawn from the warm-water pond (cf. Fig. 1). The temperature of this water is usually between T = 50 – 70 °C.

– Cooling-water circuit 2 (cold-water circuit) supplies the vacuum pumps and machine condensers with replaceable process water.) The temperatures should be as low as possible (T = 10 – 20 °C).

Since demand for cold cooling water when processing Styropor in automatic molding machines is intermittent, the circuit also includes a large cold-water pressure tank as a buffer connected in the water circuit ahead of the machines. The same applies to the warm-water circuit, though in this case the pressure tank can be fed from the cold-water pond as well as the warm-water pond. The temperature of the water can be adjusted, e.g. by a mixing valve controlled thermostatically.

The water which warms up on spraying the part molds is fed via a collecting pipe to the lower-lying warm-water pond. If the molding machines with vacuum cooling are in use then, apart from the cooling water coming from the molds, the process water from the vacuum pump(s) and possibly water from condensation tanks is also led into the warm-water pond for cooling. From here, if necessary, the water is pumped to the cooling tower where it trickles down over the fill cooling as it does so and flows without pressure into the cold-water pond.

When the pressure in the cold-water pressure tank falls below a certain limit, a second pump controlled by a pressure switch conveys recooled water from the cold-water pond to the pressure tank.

A thermostat in the cold-water pond regulates the cold-water temperature. If the temperature of the water is too high the thermostat actuates the warm-water pump and the fan motor in the cooling tower.

To prevent possible flooding of the plant due to volumes of water arriving at irregular intervals, water overflows from the cold-water pond to the warm-water pond and then on into the gully.

The system loses water in various ways, in particular through evaporation, overflows into the gully, water spray, etc. Losses are made up automatically with fresh water by means of a float valve.

To allow manual bleed-off and sludge removal and manual addition of water, hand-operated valves have to be installed at the bottom of the water ponds or in a separate fresh-water line.

Dimensions of the warm-water pond

The capacity of the warm-water pond depends on the maximum volume of cooling water accumulating. Allowing for a reserve the capacity of the warm-water pond should be about the same as the total volume of the pressure tank.

Pump power

Pumps for cold water and warm water should be capable of delivering water at about the same feed rates and at the required pressure.

Table 2 Suggestions for a thermal audit in plants processing Styropor

Molding	A Heat produced	B Heat needed	Possibilities for heat transfer
Molded part	1 Condensate and cooling water from molding machines 2 Exhaust steam from preexpanders	1 Preheating boiler feedwater (55 – 60 °C) 2 Space heating (offices, stores, silos) 3 Preheating drying-tunnel air	• *Fixed-plate heat exchanger* A1 and A2 can provide heat for B1 and B2 (A1 can be cooled to 25 – 45 °C in this way, depending on the time of year) • *Heat pump* A1 can provide heat for B1, B2, and B3 (A1 can be cooled to 15 – 20 °C without a cooling tower; boiler feedwater can be heated to temperatures exceeding 60 °C)
Block	1 Exhaust steam from block molds (can also be stored) 2 Exhaust steam from preexpanders	1 Preheating boiler feedwater 2 Space heating (offices, stores, silos)	• *Fixed-plate heat exchanger* A1 and A2 can provide heat for B1 and B2

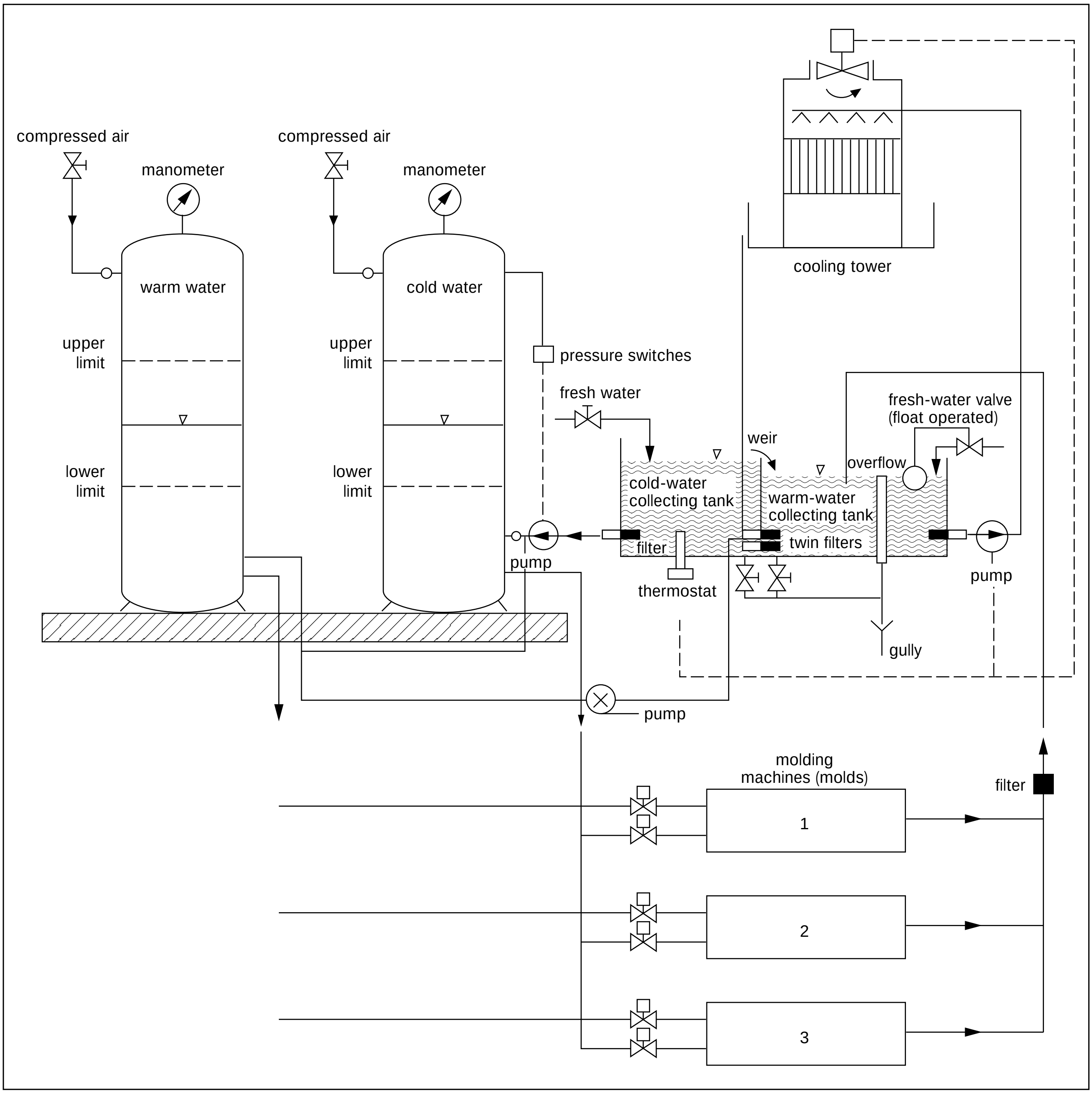

Fig. 1 Suggested arrangement of dual cooling circuits

5 Operation and design of a cooling tower

The required cooling capacity of a cooling tower is calculated from the following data:

- the design wet-bulb temperature of the air entering;
- the average rate of flow of water to be cooled;
- the temperature of the water on entering the tower;
- the temperature of the water on leaving the tower.

The wet-bulb temperature of air should be regarded as a measure of the temperature-dependent humidity of the air. It depends on the location where the tower is built. We recommend in each case that the wet-bulb temperature of the air be agreed with the supplier of the cooling tower. In doing so it should also be confirmed that on the basis of the chosen type of cooling tower and the wet-bulb temperature of the air the temperature of water leaving the tower will never exceed 25 °C.

The temperature of the cooling water leaving molding machines is generally 60 – 80 °C. The first of the subsequent coolers (e.g. heat exchanger) will therefore be fed with cooling water at this temperature. The final cooler in the cooling water circuit is usually a cooling tower which should cool the water to 20 °C and at least to 25 °C.

This does not take account of heat losses in water discharged to waste so that the value determined in this way for the amount of cooling water required per hour lies on the safe side.

The design of the cooling tower should follow recommendations such as those given in BS 4485: Part 3: 1988, Water cooling towers – Code of practice for thermal and functional design, DIN 1947 : 1989 (available in English), or similar standards.

6 Notes on water treatment

General

The increase in the concentration of salts in the cooling water brought about by evaporation (in the cooling tower) can be determined by evaporation, chemical analysis or by measuring the electrical conductivity. The level of the salt concentration provides information on the water-softening measures to be taken.

Due to formation of deposits on cooling surfaces temporary hardness in the added water can impair the performance of the cooling tower. It should be kept low by chemical pretreatment of the water.

It is, however, often more economic to use deionized water (produced for instance by reverse osmosis). This greatly reduces the rate of increase in the accumulation of dissolved salts and the need for frequent bleed-off.

The cooling water can further be contaminated by dust in the aspirated air and by beads of cellular material. Details of the removal of the coarser foreign matter are described in Technical Information leaflet TI 361. Occasionally traces of oil and grease are encountered in the cooling water. If these deposit as films on cooling surfaces, wetting by cooling water is hindered and rates of heat transfer are reduced. Oil and grease can be removed, e.g. by using oil traps and/or treatment with activated charcoal.

The principal sources of make-up water are:

- surface water (from rivers and ponds);
- spring water; and
- mains supplies.

The type of treatment depends on the composition of the water. After treatment, the water should not:

- tend to deposit scale anywhere in the cooling circuit and especially around the steam slot nozzles;

In order to meet these requirements it is recommended that as soon as a new Styropor molding shop is planned an independent analysis of the available water be commissioned. The method of treatment should be discussed with the water treatment company in question. The quality of the water resulting from this must be compatible with materials used in the plant. If the water to be treated is to be used for purposes other than the cooling of molding machines (e.g. for cooling reciprocating compressors) it is likewise necessary to take the manufacturer’s instructions into account.

A range of treatment methods are used for the various types of water (surface water, spring water, mains supply). The relevant specialist literature contains details of these. Examples include:

- Water Treatment Handbook, Degrémont S.A., Paris
- Nalco Water Handbook, The Nalco Company, Oak Brook IL
- Permutit Handbook.

Circulating cooling water

However low the initial concentration of dissolved salts in cooling water, the loss of water by evaporation will eventually cause the concentration to reach the maximum that can be tolerated. The level of this maximum depends on the composition of the dissolved impurities and must be decided on from case to case. When (or before) it is reached, some of the water must be removed and replaced by purer make-up water.

7 List of Suppliers

Manufacturers of heat-exchange pumps

Wet cooling towers, air coolers and heat exchangers

Fixed-plate heat exchangers

Please contact suppliers or the Technical Services of BASF Aktiengesellschaft.

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Device for abating pollution of waste water in plants processing Styropor

Disposal of waste in public waterways is prohibited, even if it does not give rise to any adverse changes in the physical and chemical properties or the biological condition of the water. Likewise, solid contaminants must not be allowed to interfere with the free flow of water.

Although preexpanded Styropor beads and cellular material produced from them do not affect the properties of water in any way, because of their closed-cell structure and low density they remain permanently on the surface of the water and are thus unsightly.

Various traps have been designed to prevent these materials from entering drainage systems that lead into rivers, lakes or other public waterways.

Two of these traps are described below.

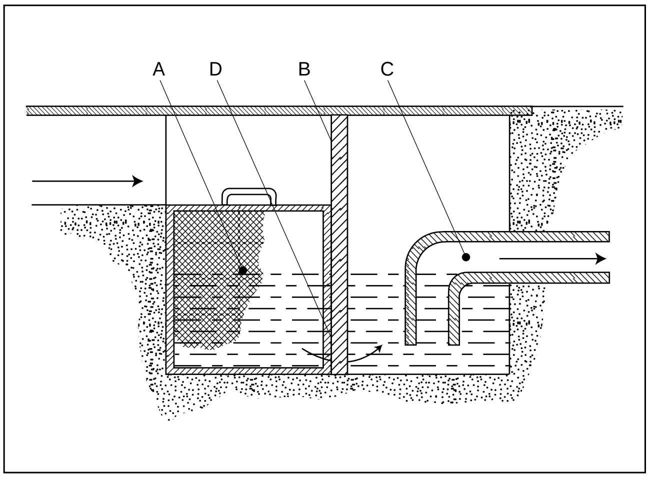

Fig. 1 Construction with covered drains

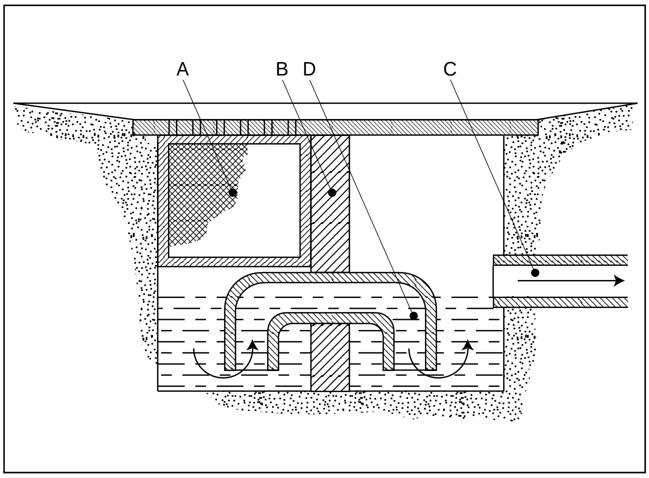

Fig. 2 Ground-level gully

Fig. 1 shows a design that is used in covered drains. Fig. 2 shows the corresponding design in a ground-level gully. A stainless-steel, fine-mesh strainer (A) is fitted in a pit divided by a partition (B). In Fig. 1, the partition (B) may consist of wooden planks with slots or holes at the lowermost end to allow passage (D). In Fig. 2, a double-bend spillway is let into a concrete or brickwork partition (B). In both designs, the depth of the water seal below the outlet should be at least 20 cm to ensure that no expanded Styropor particles can enter the outlet even when the strainer is removed for cleaning. If the water does not run off from the trap by gravity, the outlet (C) would have to be replaced by a pump inlet. In this case, a fine brass strainer must be fitted to the pump intake.

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4 Processing

Losses in weight and volume during processing

There are two reasons for material losses suffered by Styropor during processing.

1. Blowing agent losses during production and storage of expanded material

The loss in weight due to the emission of blowing agent during processing largely depends on the following factors:

- the size of the beads and their density after preexpansion;
- the conditions under which the preexpanded beads were stored before molding;
- the size and shape of the expanded material and the length of time for which it was stored.

If the expanded material is produced with beads of density 20 kg/m^3 and the average storage temperature is 20 °C, the following losses in weight can be expected during the individual stages in processing:

preexpansion with 1 day intermediate storage	about 2 %
expansion	about 2 %
storage (8 days)	about 1%
further storage	about 1%
loss in weight max.	about 6 %

2. Losses in cutting blockware

Expanded blockware is normally trimmed before it is cut up into panels. The ensuing losses in weight and volume depend on the mold oversize and shall not be dealt with here. (In modern production units, this material is reground to a suitable particle size and immediately reused for certain applications in which allowance is made for the properties attained in the production of the blockware. Since moldings are not trimmed or cut, the only losses that occur are those caused by the release of blowing agent. Obviously, the conditions for the production of blanks are similar to those for blockware.)

The actual losses suffered in the production of board from blockware greatly depend on the method adopted for cutting.

Cutting with a belt knife

Hardly any losses occur in this method of splitting blocks.

Cutting with a saw

The losses in cutting depend essentially on the thickness and set of the saw and on the required thickness of the panel. Each cut by a normal band saw involves a loss of about 1.2 mm (thickness of saw blade 0.8 mm including the set).

Cutting by a hot wire

The cut formed by a hot wire differs from that formed by a mechanical cutter in that it depends considerably on the density of the expanded material. Low densities give rise to wider cuts than high densities. The thickness of the wire is another significant factor that affects the width of the cut. It can generally be assumed that the width of the cut is roughly twice the thickness of the wire. Thus, if the wire thickness is 0.4 mm, a cut of about 0.8 mm width will be obtained. The diameter of the wires used in practice is 0.4 – 0.8 mm.

In modern cutters, the wires are simultaneously oscillated and heated to a temperature substantially lower than that required for cutters in which the wires are only heated.

The oscillating heated wires are of 0.3 – 0.4 mm diameter and are produced from high-strength, alloy steels. The losses in volume in this method are roughly halved.

The width of the cuts obtained in expanded blockware depends on the nature and thickness of the saw blade or wire and varies between 0.5 and 1.5 mm. When panels of 20 mm thickness are being produced with a saw, the loss in weight is 2.5 – 7.5 % (density about 20 kg/m^3). It is correspondingly higher for thinner panels and less for thicker panels.

Losses in volume but not in weight occur if the blocks are cut by a hot wire. The reason for this is that the polystyrene melt formed during cutting remains on the surface of the expanded material. When panels of 20 mm thickness and 17 kg/m^3 density are being produced, the loss in volume lies between 2.5 and 7.5 %. It is correspondingly greater for thinner panels and less for thicker panels.

Summary

1. The maximum loss in weight that occurs during the production and subsequent storage of blockware and moldings is 6 %.
2. Sawing involves an additional loss in weight, which depends on the saw blade and the number of cuts per block, i.e. the board thickness.
3. A loss in volume but no (additional) loss in weight occurs if blockware is cut by a hot wire.

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Manufacture of Styropor F-grade foams from a fire safety perspective

Styropor F grades are suitable for making foams that fulfill special fire safety requirements (e.g. Class B 1 materials according to DIN 4102).

This suitability can only be guaranteed when certain conditions are met.

1 Sufficient aging of the foam

Styropor F grades comprise polystyrene or styrene copolymers and contain a mixture of a low-boiling hydrocarbon blowing agent and a flame retardant. During manufacture, most of the original blowing agent is liberated. After the foam has been expanded, the blowing agent content drops relatively quickly down to 10 – 15 %, and is only given off slowly from then on. The foam only gains its full fire safety properties when most of the residual blowing agent has evaporated away – something that occurs when the foam has been aged for about 14 days.

2 Mixing with other grades

Styropor F grades must not be mixed with other Styropor grades or expandable polystyrene products from other producers as this affects its fire behavior. In addition, no waste material from previously preexpanded Styropor F foam may be admixed.

3 Mold release agents

As a rule, mold release agents have an unfavorable effect on the fire behavior of Styropor F grades. If the use of such an agent is unavoidable, the fire behavior of the foam must be tested in each case.

Effective demolding without the use of a release agent is achieved by using molds with non-stick coatings (e.g. Teflon®). These are expensive, however.

4 After-treatment of the foam

The fire behavior of Styropor F grade foams can also be affected by after-treatments such as antistatic finishes, lacquer coatings or similar, and also when pigments are used to color the raw material or the preexpanded beads.

It is therefore strongly recommended that the foam's fire performance be tested in each individual case.

Note

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4 Processing

Conveying raw materials

Handling raw Styropor

The first step in expanding Styropor consists of transporting the raw material from the containers into the bins on the preexpanders.

Plans for new factories should ensure the shortest possible routes to the bins. The capacity should be roughly twice the requirements to allow for future growth. The following demands are imposed on the handling equipment:

- adequate capacity
- no rough treatment
- no breakdowns
- minimum maintenance work
- low cost of acquisition
- low energy consumption per unit output

The equipment on the market can be divided into two groups.

I Mechanical conveyors

(a) Bucket conveyors (gastight designs are available)
(b) Rigid screw conveyors
(c) Flexible screw conveyors

II Pneumatic conveyors

(a) Injector-fed
(b) Compressor-driven

Preference is given to mechanical conveyors, because they are more reliable and give rise to less abrasion. Conveyors that fall under the headings I a, I b and II b can be used only in conjunction with feed stations for cardboard containers (cf. Fig. 1).

If there is sufficient headroom (at least 2 m above the upper edge of the preexpander bins), cardboard drums containing the raw material can be placed above the bins. After the drums have been slit along the lines marked for the purpose, the raw material can flow by gravity into the bins.

Drums are best emptied with the aid of an upturning device. In this case, all conductive parts must be connected and safely earthed.

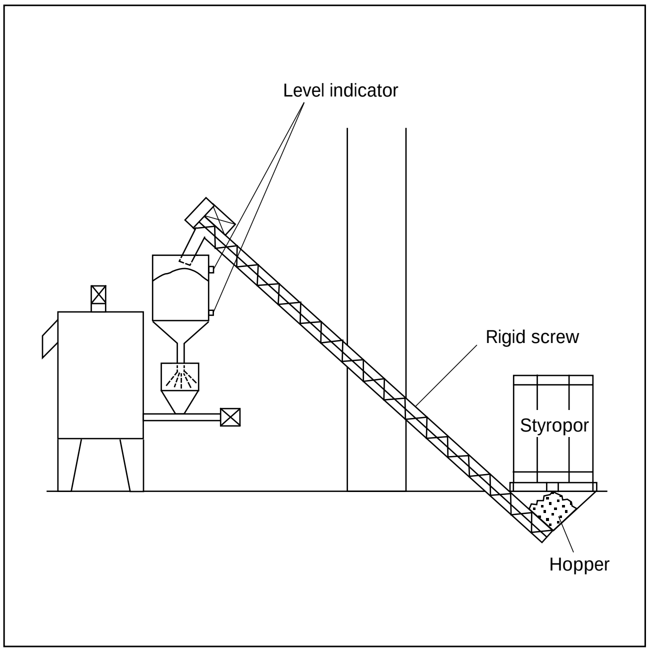

Fig. 1

Mechanical conveyors

Good results can be obtained with bucket and rigid screw conveyors.

(a) Bucket conveyors

Bucket elevators allow very high outputs, low energy consumption, and minimum abrasion. Their floor space requirements are very small. In principle, they are installed and arranged in the same way as the rigid screw conveyors described below (cf. Fig. 1).

(b) Rigid screw conveyors

Rigid screw conveyors allow very high outputs in relation to their diameter (cf. Fig. 2). For this reason, the storage tanks should be designed to accommodate at least one ton of Styropor. The raw material is fed to the screw from a hopper (cf. Fig. 1). The rigid screws permit conveyance over distances of up to about 10 m. Bends, particularly those intended to allow horizontal conveyance, greatly increase the costs, but are fundamentally feasible. They are also resorted to in special cases. Abrasion is very slight. Other advantages are the low costs of acquisition and the low operating costs.

(c) Flexible screw conveyors

These consist of a steel wire coil that rotates in a flexible pipe. The drive unit is above the discharge. The output is controlled by means of a sliding sleeve in the feed section. The feed may be horizontal or vertical, but the feed rate in the horizontal direction may be more than twice as high. The figures quoted in Fig. 3 apply to a flexible screw (d = 45 mm) with an enlarged feed section.

Flexible screw conveyors cause very little abrasion and are even suitable for colouring the raw material.

Level controllers

Filling the preexpander bins cannot be synchronized with the withdrawal of raw material. Consequently, the conveyors must run intermittently, and level limit switches are thus essential. These switches are usually inductive.

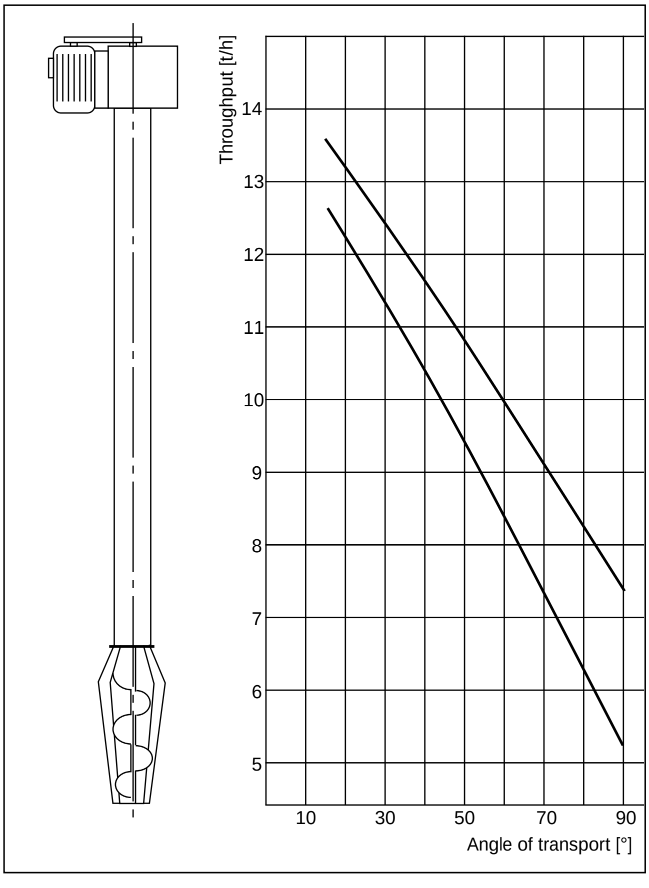

Fig. 2 Rigid screw (Svea)

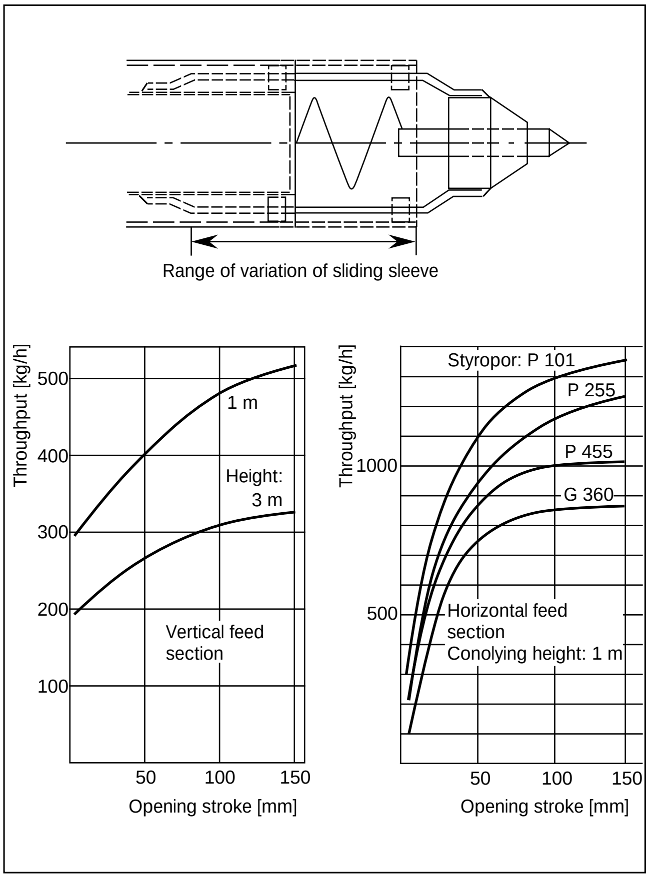

Fig. 3 Feed section of rigid screw (Hindermann)

Pneumatic conveyors

Injector-fed

The Styropor is fed to the pneumatic conveyor by means of a compressed air injector. Its inlet is drawn out to form a suction tube, which should be fitted with an additional adjustable orifice to allow setting of the solids-to-air ratio. The usual design for this purpose is a coaxial sheath. The air pressure allows the flow rate of material to be regulated. The suction tube is simply inserted in the raw material tank, and the injector sucks the Styropor up and conveys it into the bins. Thus the pneumatic conveyor is a pressure system.

The disadvantage of injector-fed pneumatic conveyors is the high velocity at which the raw material is conveyed. It may be responsible for damaging the surfaces of the Styropor beads at bends in the conveyor pipe. The abraded material thus formed is deposited in zones of lower velocity and thus gives rise to difficulties.

Another disadvantage is the high air consumption and the associated high operating costs.

In modern plants in which Styropor is processed, injector-fed pneumatic conveyors have been largely replaced by systems that function more economically and handle the Styropor under milder conditions.

Compressor-driven

In this case, the material is drawn direct into the pipe of the pneumatic conveyor by a blower, usually of the side-channel type. The blower is mounted on a separator, which also serves as a surge tank. Thus the entire system is under vacuum. When the conveyor is started up, the bunker discharge is automatically closed by the vacuum, and the material is deposited in the separator. The air escapes through a filter. Vacuum-type pneumatic conveyors usually operate intermittently.

The duration of conveyance can be controlled by a timer or a springloaded discharge valve. There are also level switches. If the cross-section of the conveyor pipe is small, the velocity is very high. Consequently, vacuum-type pneumatic conveyors must be designed to ensure minimum abrasion. In other words, there should be no sharp bends, etc. In common with the injector-fed types, these conveyors run the risk that the high velocities can abrade the beads and cause deposits to be formed on the blower filter. For this reason, various manufacturers offer vacuum conveyors in which the filter can be kept free by a counter-current of air. This design considerably reduces the risk of shutdown.

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Design of pneumatic conveyors for preexpanded Styropor

1 Introduction

Pneumatic systems, i.e. the movement of solids suspended in a stream of air, represent an efficient means of conveying freshly expanded Styropor beads from the preexpanders to the aging silos and aged beads from the silos to the feed hoppers of moulding machines.

2 Fundamentals of pneumatic conveyance

Pneumatic conveyance may assume various forms, e.g. particle entrainment, fluidization, plug flow, blow tank, and alternating deposition and refluidizing. It is only in the first two that flow is stable. The main parameters that decide the type of flow are the size, shape, and density of the particles and the solids ratio μ, i.e. the ratio of the mass flow rate of solids m_s to that of air m_a. Since the solids usually flow more slowly than the air through the pipeline, the solids ratio is generally not identical to the mass ratio of the two phases within a given volume. Nevertheless, it can be determined if certain simplifying assumptions are made.

The energy required for pneumatic conveyance is the sum of the following components:

- the work done in suspending the particles
- the work done in accelerating the particles
- the losses in mechanical energy caused by impingement of the particles against the walls and against each other
- the wall friction losses caused by air flow

For our purposes, it is assumed that the work done in suspending particles is negligibly small. In other words, the material to be conveyed is comparatively light, and the lines are essentially horizontal.

3 Fan/blower characteristic and operating point

The characteristic for the fan or blower in pneumatic conveyor systems is obtained by plotting the air pressure head $\dot{p}_a$ against the rate of discharge $\dot{V}_a$ at constant speed of rotation *n*. If the air flow is throttled and the speed n remains constant, the operating point will move along the characteristic.

The pressure drop Δp in a given system is the sum of the pressure drops in the various sections, elbows, junctions, and other pipe fittings, i.e.

$$\Delta p = \Sigma \left(\lambda \frac{l}{d} \frac{\varrho_a}{2} w_a^2\right) + \Sigma \left(\zeta \frac{\varrho_a}{2} w_a^2\right) \qquad (1)$$

where

λ = Fanning friction factor for the straight section of pipe

l = Length of the straight section of pipe

d = Diameter of the straight section of pipe

ϱ_a = Density of the flowing medium (air)

w_a = Flow velocity of air

ζ = Friction factor for the elbows, junctions, etc.

If the compressibility is neglected, the volume flow rate V_a of the air is directly proportional to the air velocity. Hence the equation can be rewritten as follows.

$$\Delta p \sim \dot{V}^2 \left(\Sigma \lambda \frac{l}{d} + \Sigma \zeta\right) \qquad (2)$$

The expression within the square brackets is a constant for a given system of pipelines and represents a certain throttling effect.

Hence

$\Delta p \sim \dot{V}_a^2$

The parabolic curve obtained by plotting Δp against $\dot{V}_a$ is referred to as the throttling curve or the characteristic for the system.

Fan characteristics for various speeds *n* and characteristics for various pipeline systems are shown in Fig. 1.

The operating point for the system is the intersect of the fan characteristic concerned with the characteristic for the system. It represents the volume flow rate of air at which the fan pressure just suffices to overcome all pressure losses. The figure read off for the total pressure drop in the system indicates the necessary fan pressure.

Typical values for the Fanning friction factor are $\lambda \approx 0.015 - 0.020$ for pipes of normal roughness. Dimensionless friction factors for 90°-bends of radius *R* in pipe of internal diameter d are listed against R/d in Table 1.

Table 1 Friction factors

R/d	**2**	**4**	**6**
ζ	0.3	0.23	0.18

Change in cross-section of the pipe system should be avoided. Even if it is slight, it exerts a considerable effect on the pressure drop.

4 Feed devices

The means adopted for introducing preexpanded Styropor into the air stream depend on the material's density and the duration of the aging period. Some suitable devices are shown in Fig. 2.

(a) Blowing seal feeder for apparent densities of 8 –150 kg/m³ immediately after preexpansion.

The blowing seal feeder is particularly easy on the material to be conveyed. It functions reliably and is safeguarded against overloads. Owing to its high capacity, it is economic and eminently suitable for very high Styropor mass flow rates.

(b) Blower-actuated injector

This device is suitable for apparent densities of 20 –150 kg/m³ immediately after preexpansion and for small to moderate Styropor mass flow rates up to about 600 kg/hour.

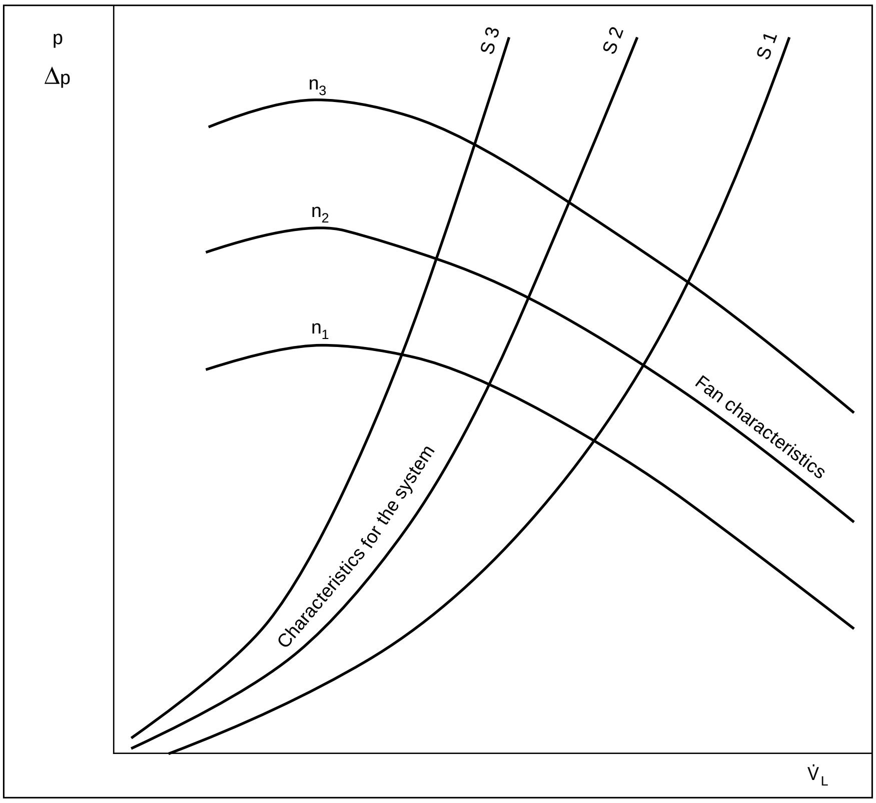

Fig. 1 Characteristics for pneumatic conveyors

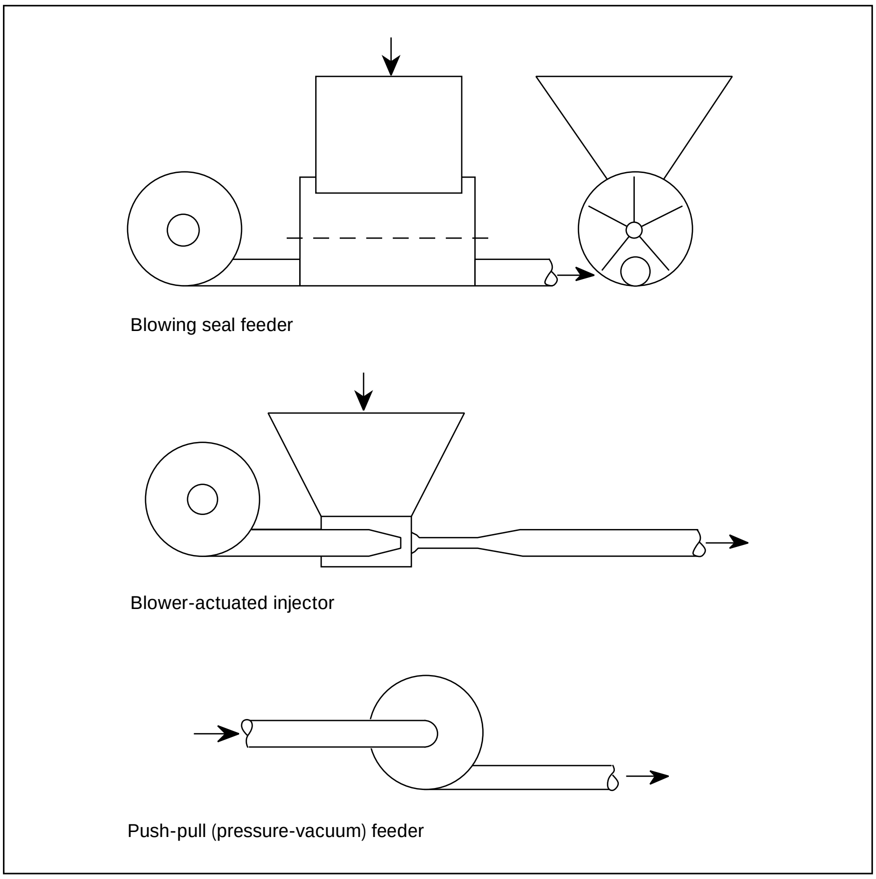

Fig. 2 Feed devices

Table 2 Operating conditions for various feed devices

Type	ϱ_{st} **kg/m³**	**W m/s**	ν **%**	ν_{max} **%**
Blowing seal	> 8	6 – 8	10	10 –16
Injector	> 20	10 –15	0.75	2
Push-pull system	>50	10 –15	3	10 –16

(c) Push-pull systems

Owing to the risk of compaction and damage to the beads, they are suitable only for apparent densities of 50–150 kg/m^3 immediately after preexpansion and for densities of 30–150 kg/m^3 after intermediate aging.

Certain limits, above which blockage may occur, are imposed on the solids mass ratio $\mu \approx \dot{m}_s/\dot{m}_a$, the solids volume ratio $\nu \approx \dot{V}_s/\dot{V}$, and the air velocity w. These limits depend on the type of feed device.

Table 2 presents figures for the density ϱ_{st} for which each type of feeder is suitable, reliable design values for the air velocity w and the solids volume ratio ν, and the limits ν_{max} above which blockage can occur.

5 Determination of fan characteristics

Blowers with delivery heads of up to about 30 mbar are mostly used for the pneumatic conveyance of preexpanded Styropor. Since the solids ratio in the conveyance of preexpanded Styropor is comparatively small, the Styropor volume fraction in the air stream can be neglected as a first approximation. This assumption introduces a factor of safety in the selection of the fan, i.e. the rate of air discharge is somewhat increased.

Eqn. (3) follows from the definition of the solids volume ratio.

$$\dot{V} = \frac{\dot{V}_s}{\nu} = \frac{\dot{m}_s}{\varrho_s \cdot \nu} \qquad (3)$$

An empirical relationship exists between the apparent density ϱ_{st} and the apparent density ϱ_s, i.e.

$$\varrho = 0.6\ \varrho_s \qquad (4)$$

Eqn. (3) thus becomes

$$\dot{V} = \frac{0.6\ \dot{m}_s}{\nu\ \varrho_{st}} \qquad (5)$$

The pneumatic conveying system can then be roughly designed from Eqns. (1)–(5). The procedure is as follows (cf. Figs. 3 and 4).

The total volume flow rate $\dot{V}$ is calculated from the desired amount to be conveyed (usually the output from the preexpander), the apparent density, and the solids volume ratio as read off from Table 2. Alternatively, $\dot{V}$ can be derived from Fig. 3 or the lower part of Fig. 4.

The characteristics for a model system are presented in Figs. 3 and 4 (above). The pipeline in the system consists of six elbows (90 °) of radius *R* = 2d and straight lengths of 20 m, 40 m and 60 m and different diameters. If the pipeline under consideration differs greatly from the model, the pressure drops must be calculated from Eqn. (1) or (2).

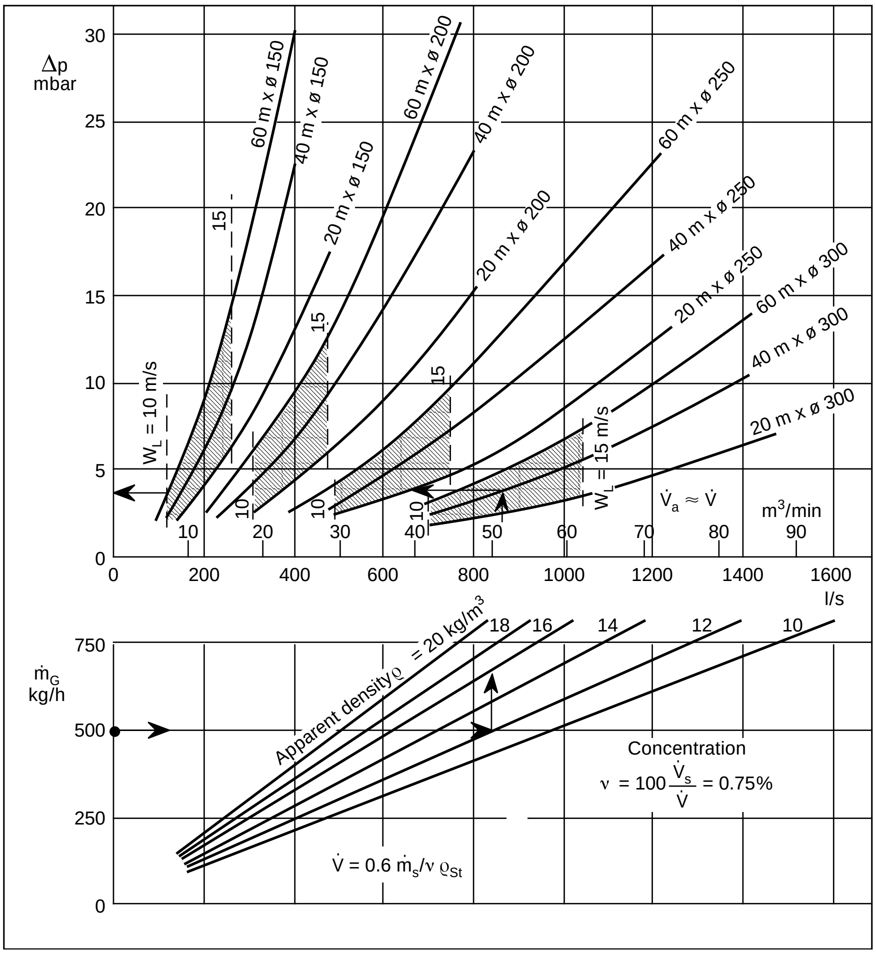

Fig. 3 Pneumatic conveyor fed by blower-actuated injector (design diagram)

However, it usually suffices to follow the arrows drawn in the diagrams and read off the required value for $\dot{V}$ In this case, preference should be given to values within the hatched zones, i.e. the recommended velocity ranges.

Fig. 5 is obtained by inserting the expression for $\dot{V}$ in Eqn. (3) in the pipe flow equation $\dot{V} = w\ \pi\ d^2/4$. It allows the requisite air velocity to be determined by following the arrows.

Since the pressure drop Δp is related to the friction factor ζ, the blower pressure required will change proportionally if the medium is another gas and not air.

Even if the solids ratio is low, the total pressure *p* required can be determined approximately from the pressure p_a required for the air alone by introducing an imaginary value for the density ϱ of the stream of air + solids. The pressure *p* would then be given by

$$p = p_a\ \frac{\varrho}{\varrho_a} \qquad (6)$$

The mass flow rate will then be given by Eqn. (7).

$$\varrho\dot{V} = \varrho_a\dot{V}_a + \varrho_s\dot{V}_s \qquad (7)$$

(subscripts a = air and s = solids)

The density ratio will then be given by

$$\frac{\varrho}{\varrho_a} = \frac{\dot{V}_a}{\dot{V}}\left(1 + \frac{\varrho_s\ \dot{V}_s}{\varrho_a\ \dot{V}_a}\right) = \frac{\dot{V}_a}{\dot{V}}\ (1 + \mu) \qquad (8)$$

Inserting the ratio of the volume fraction of solids to the total volume, i.e. the concentration $\nu = \dot{V}_s/\dot{V}$, gives

$$\frac{\varrho}{\varrho_a} = 1 + \nu\left(\frac{\varrho_s}{\varrho_a} - 1\right) = \frac{p}{p_a} \qquad (9)$$

The pressure ratio p/p in terms of the apparent density ϱ_{St} [kg/m^3] is obtained by substituting the empirical relationship given by Eqn. (4) and the numerical value for the density of air $\varrho_a \sim 1.25$ kg/m^3 in Eqn. (9), i.e.

$$\frac{p}{p_a} = 1 + \nu\ (^4/_3\ \varrho_{St} - 1) \qquad (10)$$

The relationship expressed by Eqn. (10) is presented graphically in Fig. 6 for the various feed devices and for preexpanded Styropor of various apparent densities. It can be used to determine the factor by which the pressure required for pneumatic conveyance exceeds that required for the air alone. An example is shown by the arrows.

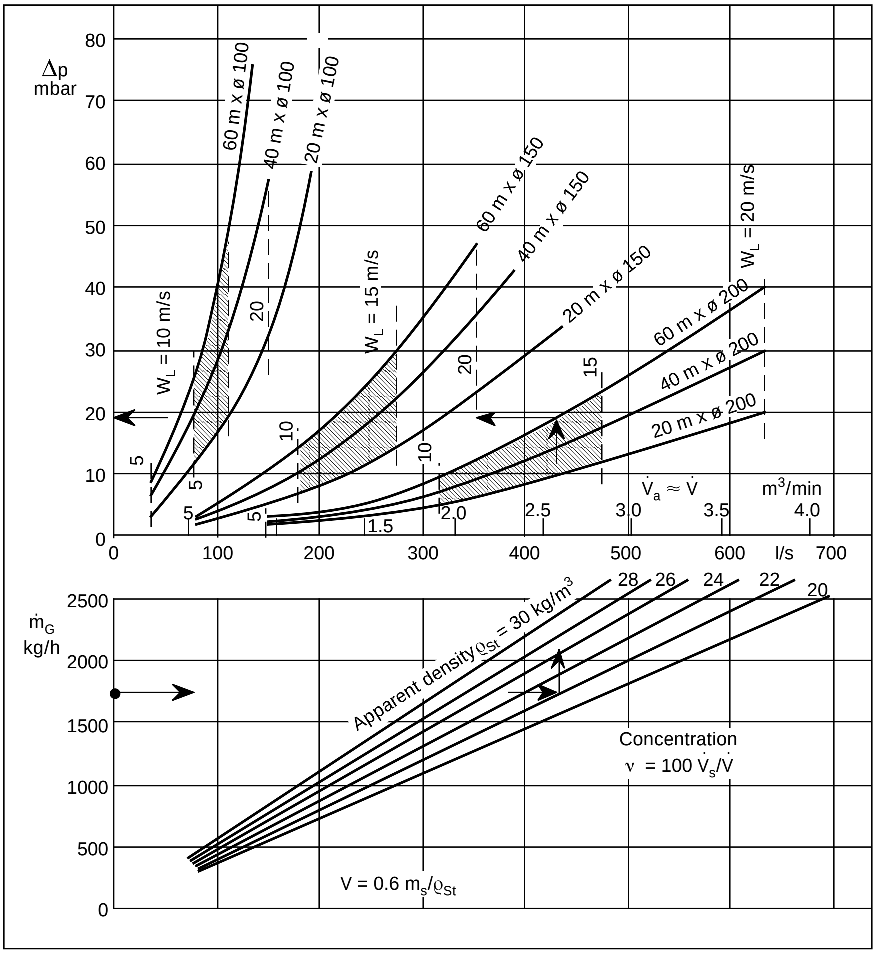

Fig. 4 Pneumatic conveyor fed by push-pull system (design diagram)

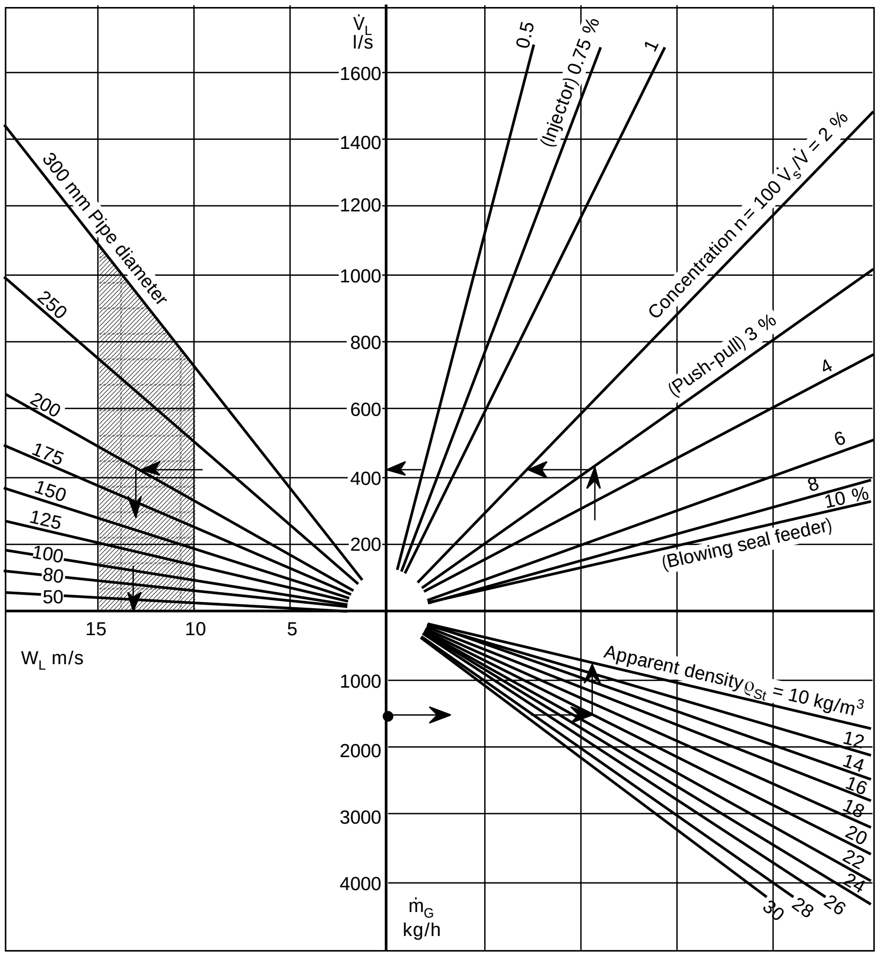

Fig. 5 Determination of volume and mass flow rates

At least the pressure thus determined must lie on the characteristic for the fan selected. The value should not be exceeded by too much, as otherwise an excessively high flow velocity may result and lead to an increase in the apparent density, i.e. compression of the material.

The difference between the solids ratio μ and the concentration ν is again stressed. The relationship between them is shown in Fig. 7.

6 Experience gained in practice

Slight clumping of the preexpanded Styropor suffices to block injectors. For this reason, a screen must be installed between the preexpander and the injector. If necessary, it can be combined with a device for breaking up any lumps. A 4-m length of straight pipe should be fitted on the downstream side of the injector to allow the preexpanded beads to be accelerated to the velocity of the air stream. Flexible hoses and filament-wound tubes incur higher pressure drops. Closely spaced bends cause a reduction in velocity and increase the risk of blockages.

The push-pull method, i.e. drawing in air and beads through the fan, is the simplest and most reliable means of pneumatic conveying. Even fairly large lumps do not give rise to blockages, but it is still advisable to screen the material, because lumps cause difficulties in the moulding stage. A disadvantage of this technique is that the impact against the fan rotor flattens the preexpanded particles and thus increases the apparent density, e.g. by about 2 kg/m^3 for beads of 20 kg/m^3. During subsequent storage, the increase is reversed by roughly 50%. In practice, allowance is made for the compression set by preexpanding to a somewhat lower density. If the apparent density is higher than about 30 kg/m^3, the compression set is negligible. The fan is best located at the system outlet, since blockages are less likely in suction than in pressure lines. Nevertheless, the installation should always be emptied to avoid blockages before the fan is shut down. A second inlet orifice is advisable that admits measurable and reproducible amounts of air.

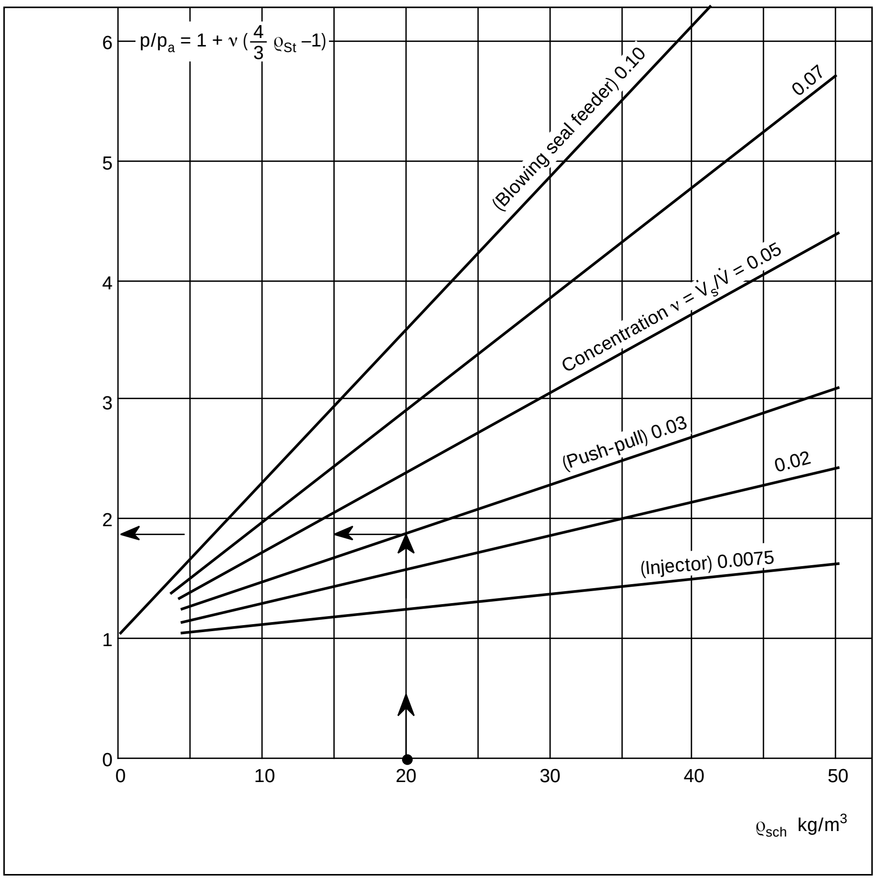

Fig. 6 *Blower pressure required for pneumatic conveyance of Styropor in relation to the pressure required for air alone*

Neither injectors nor pressure-vacuum systems are suitable for conveying large quantities of freshly preexpanded Styropor of low density, e.g. after the second preexpansion stage. The only device that can be recommended for this purpose is the blowing seal feeder. Its maximum output coincides with the medium range of speeds. For instance, in the 30 – 40 min^{-1} range of speeds for a blowing seal feeder of medium size (cf. Fig. 8) that was designed by BASF, the output is about 150 m^3/h or 2000 – 3000 kg/h (ϱ_{st} = 13 – 20 kg/m^3). In this case, too, screening is unnecessary, but is still advisable in order to avoid difficulties in subsequent processing.

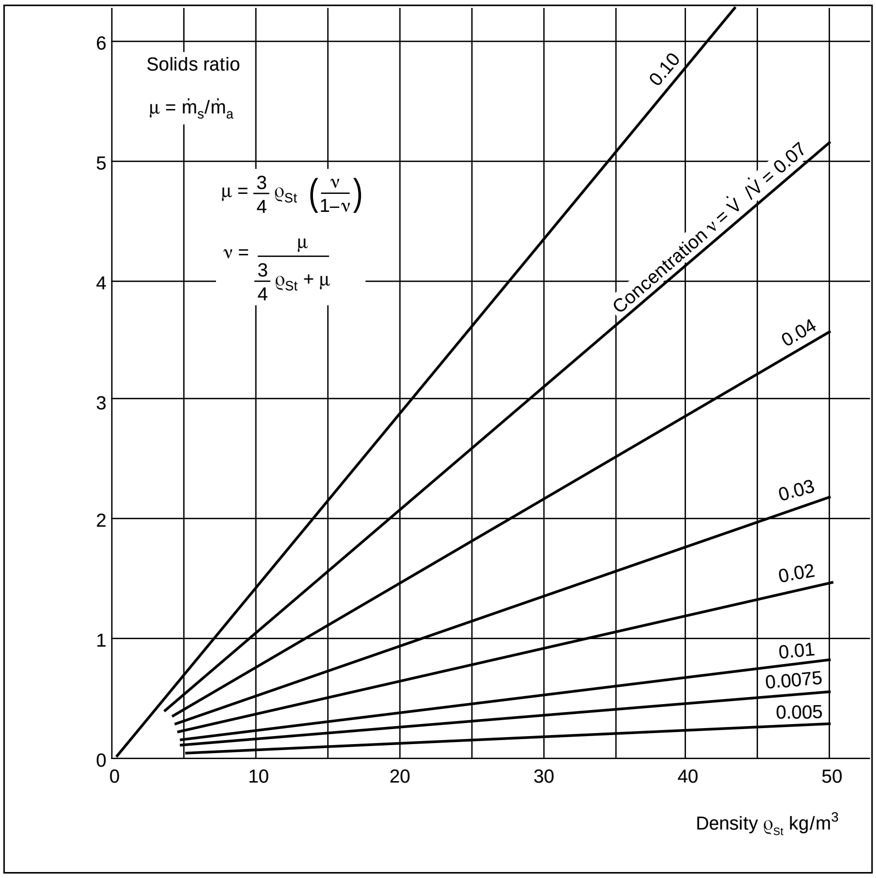

Fig. 7 *Relationship between solids ration μ and concentration*

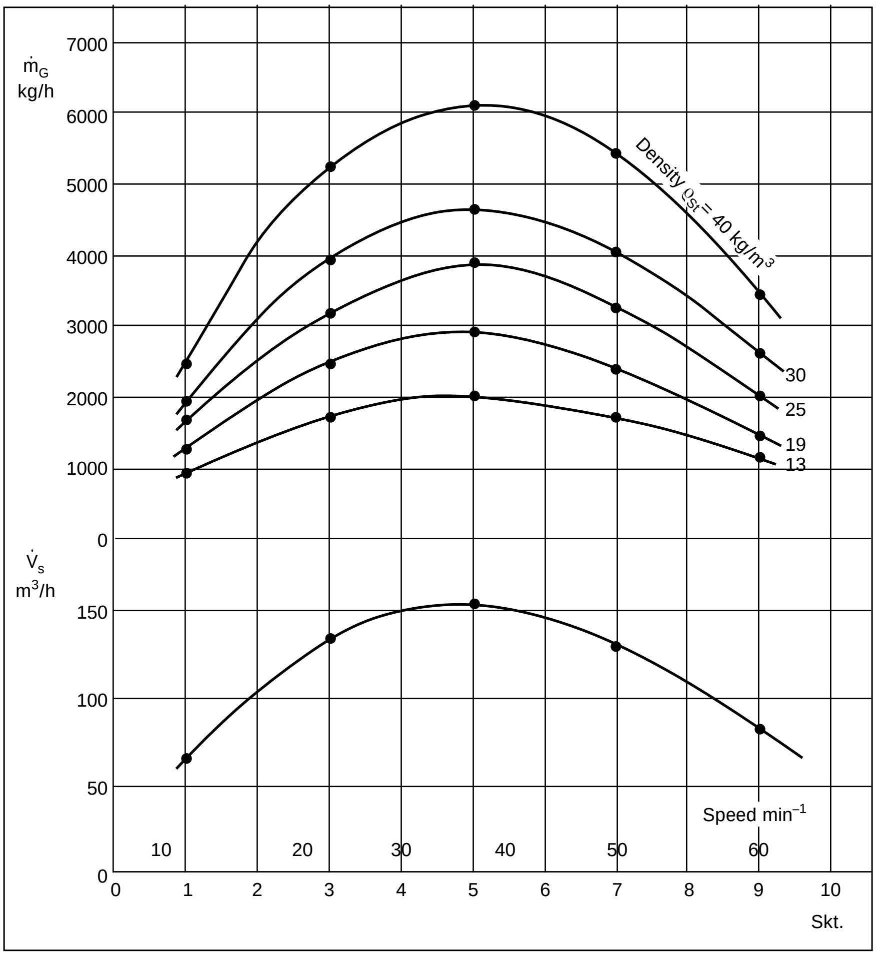

Fig. 8 Performance characteristic of Rauscher-BASF blowing seal feeder

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

Key to symbols used

d [m] = Pipe diameter

R [m] = Radius of pipe bend

l [m] = Length of straight section of pipe

λ = Fanning friction factor for straight section of pipe

w [m/s] = Flow velocity of air

m_S [kg] = Mass of Styropor (solids) conveyed

$\dot{V}_s$ [m³/min] = Volume flow rate of Styropor (solids)

$\dot{V}$ [m³/min] = Total volume flow rate (air + Styropor)

$\dot{V}_a$ [m³/min] = Volume flow rate of air

ν [%] = Concentration (in terms of volume)

ν_{max} [%] = Concentration above which blocking can occur

μ = Solids ratio = $\frac{1}{\nu}$

ϱ_s [kg/m³] = Density of Styropor

ϱ_a [kg/m³] = Density of air

ζ = Friction factor for elbows, junctions, etc.

$\dot{m}_s$ [kg/h] = Mass flow rate of Styropor (solids)

$\dot{m}_a$ [kg/h] = Mass flow rate of air

p [mbar] = Pressure

p_a [mbar] = Air pressure

Δp [mbar] = Pressure drop

n [min⁻¹] = Speed

π = 3.14

s = System characteristic

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4 Processing

Safety recommendations for the handling of expanded particles

Styropor, the expandable polystyrene (EPS) supplied by BASF, consists of polystyrene or styrene copolymer in which a low-boiling blowing agent has been incorporated. Even after the raw material has been expanded, Styropor is combustible owing to the basic materials from which it has been produced.

Examples of applications for these expanded particles are aerating agents for building materials (as light aggregate for plasters, mortar, and concrete; as pourable thermal insulation in two-leaf walls); and filling material for upholstered chairs, couches, cushions, and toys.

Other potential applications arise from the possibility of further processing these loose particles into foamed blocks and mouldings. In this case, the loose individual particles are fused together. However, applications of this nature are not discussed in this Technical Information Bulletin.

Because they still contain large amounts of blowing agent, freshly expanded Styropor particles may take fire comparatively rapidly when they are brought into contact with any source of ignition. Examples are open flames, sparks from welding and grinding machines, electrical sparks, and electrostatic discharges. As a rule, the pentane vapours are first of all ignited and conduct the flames further onto the surfaces of the loose-fill material until it, finally, is completely burnt.

In contrast to Styropor P, aged Styropor F particles, which are provided with special flame retardants, ignite only on longer exposure to the flame and extinguish automatically when the source of ignition is removed.

Thus the risk of fire on handling expanded Styropor particles depends considerably on the grades of raw material to be processed. In the most unfavourable case, it can be compared with the fire hazard from cellulosic materials, e.g. paper and wood (rooms in which paper is handled, packaging lines, upholstery shops and carpenter's workshops).

Particular care must be devoted to storing the particles during the first 3 – 4 weeks after they have been expanded. In this time, the material still contains large amounts of volatile blowing agent. Together with air in certain concentrations, these vapours may form explosive mixtures. For this reason, it is absolutely necessary to keep the particles away from all sources of ignition that may come into consideration. A special reminder is drawn to a strict ban on smoking. Rooms in which expanded Styropor particles are stored must be well ventilated in order to prevent these explosive mixtures from collecting. Since pentane vapours are heavier than air efficient ventilation must be present, in particular, near the floor. A routine check of the air composition is advisable and can be carried out by gas warning instruments. Examples of manufacturers of these are Auergesellschaft mbH, Thiemannstr. 1, D-12059 Berlin; Drägerwerk AG, Moislinger Allee 53/55, D-23542 Lübeck; or Gesellschaft für Gerätebau, Klönnestr. 99, D-44143 Dortmund.

In addition, suitable means of extinguishing e.g. Powder Extinguisher PG 12, should be made available in rooms where Styropor is stored or processed.

Extinguishers that take effect automatically are advisable in poorly accessible places.

The transportation of expanded particles in unventilated or closed vehicles is impermissible. We recommend that our “Guidelines for transportation” be consulted for storage and transportation of the raw material.

Note

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4 Processing

Preexpansion of Styropor

This Technical Information Bulletin describes ***preexpansion****, the first of three stages usual in the conversion of Styropor to moulded EPS. The successive stages are*

- preexpansion
- intermediate aging
- moulding.

Contents

Principles

Styropor consists of beads of a thermoplastic, polystyrene, incorporating a volatile hydrocarbon, which functions as an expanding agent. When Styropor is heated, each bead softens and begins to swell as thousands of bubbles of vapour form and expand. Within less than a minute, the volume of the beads may be about fifty times what it was.

Heat transfer

The preferred heat-transfer medium is live steam, which has two unique properties:

- it condenses at a convenient temperature, releasing large quantities of heat;
- it enters individual cells, passing through their polystyrene walls, faster than the vapour of the expanding agent can leave them.

Steam suits the highly favourable expansion behaviour of Styropor beads almost ideally. Other heat-transfer media – such as water and air – and other methods of energy transport – such as high-frequency and microwave heating – have been tried and found uneconomic; they are hardly used at all in practice.

Density

The bulk density of preexpanded beads is a measure of the extent to which they have expanded. Fig. 1 shows how its value can change with residence time in a batch preexpander. The length of time before the minimum is reached depends on

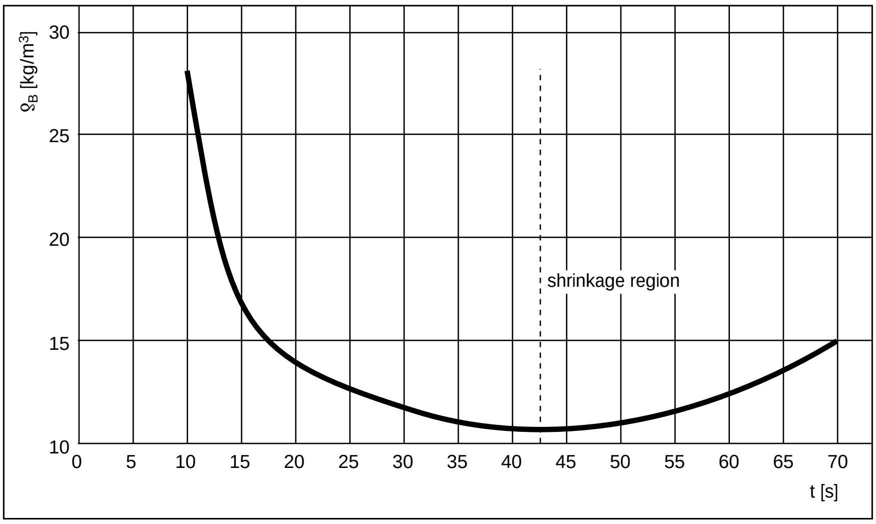
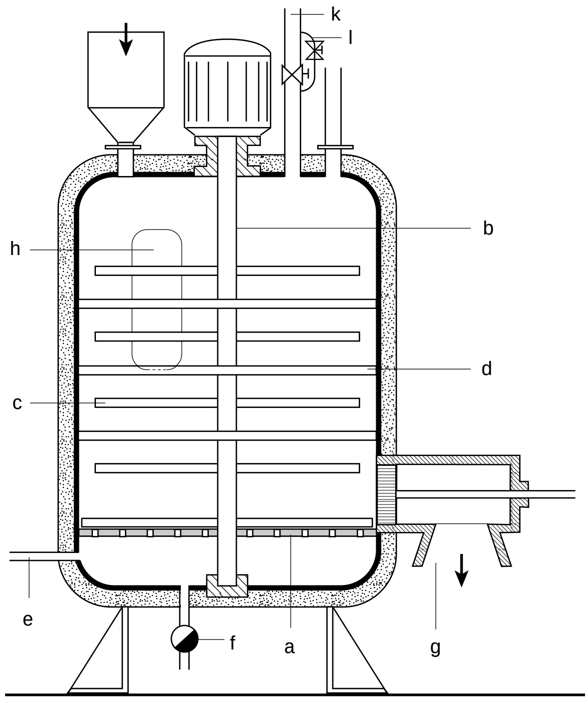
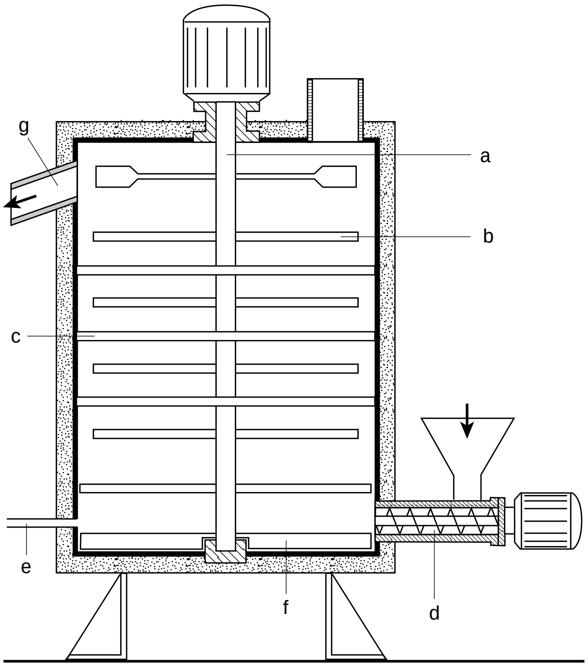


Fig. 1 Variation of bulk density, ϱ_B, with time, t, in a batch preexpander



a = Perforated floor
b = Stirrer shaft
c = Stirrer am
d = Breaker
e = Steam inlet
f = Condensate outlet
g = Product discharge
h = Window
k = Air vent
l = Bleed line

Fig. 2 Typical batch preexpander



a = Stirrer shaft
b = Stirrer arm
c = Breaker
d = Feed screw
e = Steam inlet
f = Scraper arm
g = Produkt discharge

Fig. 3 Typical continuous preexpander

the condition of the steam, the design of the preexpander, and the type of Styropor. The value of the density at the minimum depends mainly on the type of Styropor.

The apparent density of the final moulding is roughly the same as the (bulk) density of the preexpanded beads. Since the mould cavity is always filled, further expansion of the preexpanded beads is just sufficient to close the interstices and weld the beads together.

2 Types of preexpander

General

Preexpansion can be carried out batchwise or continuously. Both the sealed batch preexpanders (cf. Fig. 2) and the vented continuous preexpanders (cf. Fig. 3) are generally in the form of upright cylinders, but a few designs are based on horizontal or inclined forms.

Batch preexpanders

Fig. 2 illustrates a typical batch preexpander. The vessel is charged with an appropriate mass of fresh Styropor beads and purged with steam to remove most of the air. While the beads are agitated by a stirrer, further steam is admitted until the pressure reaches the desired value. Since the level of the material in the vessel rises as the beads expand, the beads can be discharged shortly after the required degree of expansion (detected by photoelectric sensing) has been attained. Alternatively, expansion can be stopped after a fixed time, use being made of a density-time curve such as that shown in Fig. 1.

The pressure in a batch preexpander can exceed atmospheric pressure, so that steam temperatures can be appreciably greater than 100 °C.

Continuous preexpanders

A common type of continuous preexpander is shown in Fig. 3. Raw Styropor is introduced continuously at the bottom and expanded beads leave at top. As in a batch preexpander, the beads are agitated by a stirrer. Steam is supplied steadily at a fixed rate; the inlet excess pressure is kept as low as possible, generally 0.1 – 0.3 bar.

As a rule, the expanded beads leave the vessel through an opening at a constant height and their residence time is adjusted by varying the feed rate (cf. § 3).

The rate of throughput of a single continuous preexpander can be very large.

3 Regulation of density

General

Nearly all physical properties of expanded polystyrene are dependent on density. Choosing the appropriate value, obtaining it by preexpansion, and ensuring that it remains constant are therefore important.

In batch preexpansion

Standard modern batch preexpanders are designed for excess pressures of up to 1 bar, but special versions allowing excess pressures of 2 – 5 bar are available. Older batch preexpanders may be unsuitable for excess pressures greater than 0.5 bar.

For preexpansion of the commoner types and grades of Styropor, steam excess pressures of 0.1 – 0.5 bar are generally chosen. The precise value depends on the type of Styropor as well as the required density.

The density of the preexpanded beads can be adjusted in any of three ways:

- by charging with a constant mass of Styropor and discharging after a preset time;
- by charging with a constant mass of Styropor and discharging when the level of the beads reaches a preset height (detected by beam and photocell);

- by charging with a *preset* mass of Styropor and discharging when the level of the beads reaches a *fixed* height (detected by beam and photocell).

Only the second and third methods are employed for automatic density-based control.

Pressurized batch preexpanders are suitable for the greatest range of densities, *viz* $10 – 250\ \mathrm{kg\ m^{-3}}$.

In continuous preexpanders

Usually the rate of flow of steam is fixed (by adjustment of the inlet pressure) to suit the size of the vessel. The density of the expanded beads, which may be adjusted by changing the rotational frequency of the feed screw, can be controlled automatically.

Continuous preexpanders function best over a limited range, usually $14 – 30\ \mathrm{kg \cdot m^{-3}}$.

"High" densities

It may be seen from Fig. 1 that the density-time curve for Styropor in steam at atmospheric pressure is exceedingly steep initially. Better control of the final average density and less variation among the densities of individual beads is obtained if the heat-transfer medium is made less effective. This can be done by mixing the steam with air, which has two immediate effects:

- the partial pressure of the steam, and hence the temperature of the mixture, is reduced;
- the heat transfer coefficient is also reduced.

The principal consequence of these effects is that the density-time curve is altered in such a way that it is easier to stop the expansion process when the density attained is close to that required.

A further consequence is that on the one hand the beads are more thoroughly mixed, which reduces differences in residence times, while on the other the effect of those differences is diminished: the expanded beads are more homogeneous with respect to density.

Two ways of mixing air and steam have proved useful in practice:

- In continuous preexpanders, where the inflow of steam is steady, the air (restricted by a needle valve) can be introduced by means of an ejector in the steam inlet. This simple method is suitable for densities ranging from the lowest attainable up to about $30\ \mathrm{kg \cdot m^{-3}}$.
- In batch preexpanders, direct introduction of air into the steam line is controlled via the temperature of the air-steam mixture introduced into the vessel, whose air-escape vent is kept open. This method can also be used for continuous preexpansion.

The density of beads preexpanded in batch preexpanders has no upper limit (other than the density of the raw Styropor), but it is not practicable to expand beads to a density greater than about $60\ \mathrm{kg \cdot m^{-3}}$ in a continuous preexpander.

Especially low densities

Preexpanded beads of density less than $14\ \mathrm{kg \cdot m^{-3}}$ are best obtained by repeated expansion. The first step involves expansion in a normal continuous preexpander to a density about half as much again as the required final density. After an intermediate period of 4 –10 h, the expanded beads are introduced into a second continuous preexpander by means of a special feeder. Feed screws of diameter 200 – 300 mm, which can handle preexpanded beads at the rate of $60 – 100\ \mathrm{m^3 \cdot h^{-1}}$, have proved suitable for this.

The equipment used for repeated expansion is shown diagrammatically in Fig. 4.

Measurement and control

The bulk density of preexpanded beads has to be measured frequently, both when operating conditions are set up and for quality-control purposes. In practice, the measurement can be and is carried out manually or automatically.

To measure bulk density manually, fill a tared cylindrical vessel (height about twice the diameter) of capacity $5 – 10\ \mathrm{dm^3}$ with the preexpanded beads; vibrate or tap the vessel lightly; top up with more beads and level with a straight edge; reweigh.

In manual determinations, the precise procedure for filling the vessel (e. g. tapping and levelling) is unimportant, but it must always be followed exactly. Similarly, the sample should always be taken from exactly the same place, preferably at the end of the fluidized-bed dryer if there is one. The volume of the vessel need only be determined once.

Automatic density determinations are carried out analogously at preset intervals. The mass values are generally used for controlling density, e. g. by adjusting the feed rate of a continuous preexpander or the mass (or final volume) of batches in a batch preexpander. Deviations from set values can be kept quite small.

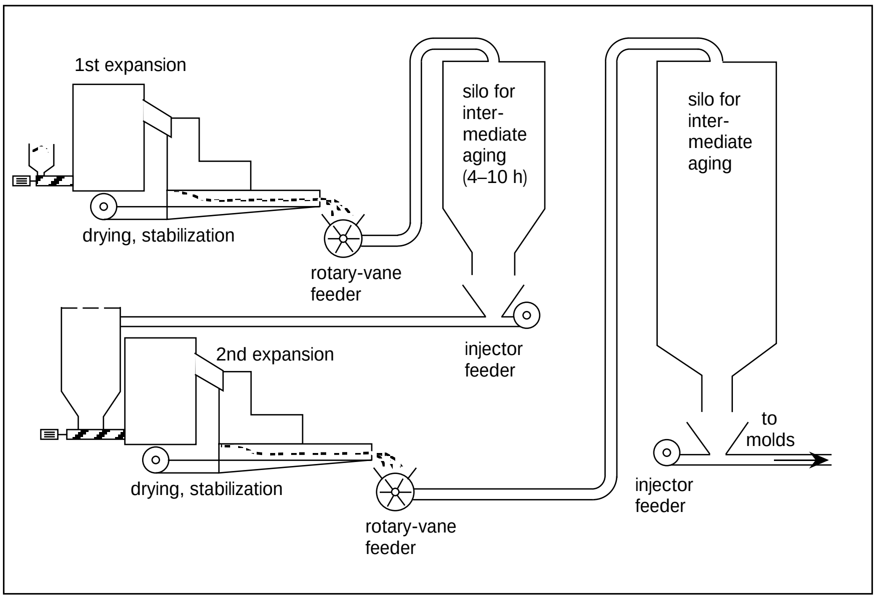


Fig. 4 Plant for repeated expansion of Styropor

4 Preexpansion shops

Modern preexpansion plant is made up of the following components (cf. Fig. 5):

- programmable control, interactive VDU, function display;
- feeder and conveyor system for raw Styropor;
- preexpander;
- fluidized-bed dryer, screen, and clump-disintegrator (particularly needed for shaped mouldings);
- automatic density-measurement, possibly with feed-back control;
- feeder for pneumatic conveying system for preexpanded beads;
- data recording with interface to management data system.

Safety

Electrostatic charges

To prevent spark discharges, all metallic equipment must be connected electrically and earthed (earthed equipotential bonding). Further information is given in our brochure “Precautions against Fire for Processors” and in the Technical Infommation Bulletin Tl 460, “Conveying raw Styropor”*.*

Steam

To conform with regulations and in the general interest of safety, arrangements must be made to ensure that motors etc. are isolated from the electricity supply and steam is shut off *automatically* when stirrers or other moving parts are stationary or doors and covers are open.

Emergency shut-down devices have proved useful in dealing with situations such as failure of electricity supplies, seizing-up due to extreme clumping, etc. The entry of more raw Styropor is prevented by a sliding shutter, the steam supply is shut off, and compressed is fed through the steam inlet. This cools the interior of the preexpander and prevents fusion of the beads.

5 Steam supplies

Detailed advice is to be found in our Technical Infommation Bulletin Tl 0-340, “Steam for processing Styropor”, but the principal recommendations that concern preexpansion are given below.

The aim should be that the steam entering preexpanders is dry and saturated. To be certain of avoiding superheating, place the final reducing valve some distance before the steam inlet of the preexpander.

Steam velocities may not exceed $50\ m \cdot s^{-1}$, and pipes should be sized to give velocities of about $25\ m \cdot s^{-1}$, water droplets must be removed from the steam before it enters the preexpander, e. g. by means of a cyclone separator.

Continuous preexpanders must be supplied steadily with steam of constant quality, otherwise the product will lack uniformity. Common sources of fluctuations in steam pressures include:

- oversized reducing valves:
- intermittent withdrawal of steam by another user.

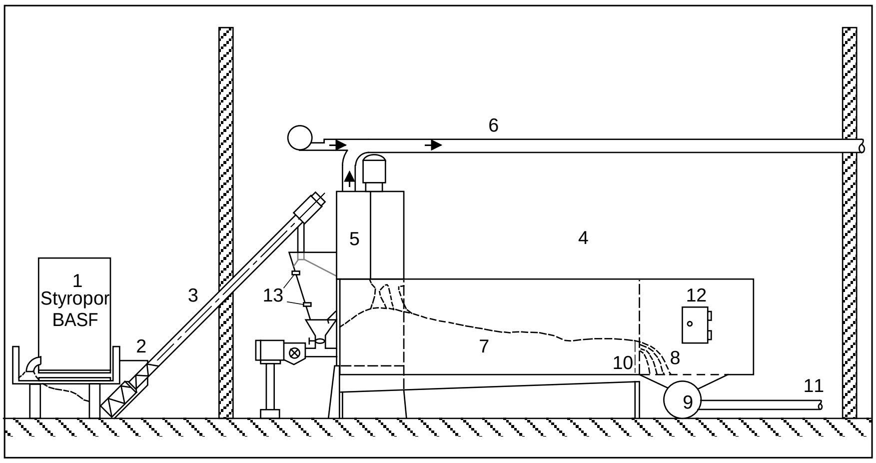


Fig. 5 Material transport, drying, and sieving in a preexpansion shop

1 Styropor container
2 Feeder
3 Screw conveyor
4 Preexpansion shop
5 Preexpander
6 Exhaust duct
7 Fluidized-bed dryer
8 Parallel-bar screen
9 Rotary vane feeder
10 Adjustable weir
11 Duct for preexpanded beads
12 Sampling door
13 Level switches

Steam requirements

In theory, the massic heat demand for preexpanding Styropor is only $134\ kJ \cdot kg^{-1}$, which is equivalent to a massic saturated steam demand of ca. $60\ g \cdot kg^{-1}$ if the temperature of the steam and its condensate is 100 °C. In fact, it is not possible to give exact values for steam requirements because of the considerable effects of many factors, in particular those of the following:

- the insulation of the expansion vessel (condensation on the walls of the vessel wastes heat);
- the final density of the preexpanded beads;
- the expansion characteristics of the grade of Styropor processed;
- the condition of the steam;
- the altitude of the plant (this does not affect batch preexpanders).

In practice, the massic demand for saturated steam is $150 – 400\ g \cdot kg^{-1}$, depending on circumstances. When expansion is repeated, the massic demand in the second stage is about $100\ g \cdot kg^{-1}$.

6 Drying preexpanded Styropor

The preexpanded beads are superficially moist when they are discharged, and it is advisable to dry them before they are removed to silos for intermediate storage. For this the fluidized-bed dryer has proved useful, since it also allows the pressure inside the cells of the beads to recover, making the beads better able to withstand handling (cf. Tl 0-560, “Drying preexpanded Styropor”). Where preexpansion is carried out batchwise, the fluidized bed also serves as a buffer between preexpander and conveyor, making the flow of product more even.

Supplying warm air to fluidized-bed dryers is generally unnecessary and may cause excessive dryness and therefore retention of electrostatic charges. However, if there are certain production difficulties, or the bed is too short, warm air can be helpful.

7 Conveying materials

Raw Styropor

Detailed advice is given Tl 460, “Conveying raw Styropor”.

Screw conveyors and bucket elevators have proved suitable for conveying raw beads to preexpanders. The carrying capacity of either is great enough for the largest modern preexpander, and they both move the beads without damaging them.

The limited capacity of vacuum pneumatic conveyors makes them suitable only for preexpanders with low throughputs. The beads, travelling at high velocities, can also suffer damage through impacts and lose coatings through abrasion. Furthermore, there is an enhanced risk of electrostatic charging.

Preexpanded Styropor

Detailed advice is given TI 0-461, “Conveying preexpanded Styropor”.

Freshly preexpanded Styropor beads are easily crushed and need to be conveyed pneumatically and as gently as possible. Rotary-vane feeders offer both high throughputs and damage-free handling. Air-driven ejectors allow only limited loading and therefore lower maximum throughputs. If a centrifugal fan is used for conveying preexpanded beads, considerable increases in density can be expected.

Bends in the ducts carrying preexpanded beads must be generously dimensioned, and the design of the system should be such that velocities are in the range 10 –15 $m \cdot s^{-1}$. All metal parts must be linked electrically (earthed equipotential bonding); any transparent sections provided for observation must be bridged.

After preexpanded beads have been allowed sufficient recover time they pass through fans undamaged.

Note

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BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

BASF

34346 July 1995

4 Processing

Expanding fine Styropor beads to very low bulk densities

Several finer grades of Styropor are employed in the form of expanded beads as aggregates for lightweight concrete, mortar, and plaster or as microvoid-formers in clay for fired-clay masonry units. The densities of the expanded beads should be as low as possible, to minimize costs. This aim can be achieved by the methods described below. Methods used for Styropor VP 800, which are given in the relevant Technical Leaflet, are not dealt with here.

Newly expanded Styropor beads are crushed by atmospheric pressure if they have grown beyond certain limits. This is because the vapour filling the cells initially is replaced only slowly by air, and the inside pressure falls sharply on cooling. Even after aging to re-establish equilibrium conditions, the beads may not fully recover their maximum volumes.

The lowest densities that can be attained in practice depend both on the capacity of the Styropor beads to expand and the equipment used. The value of 12 $kg \cdot m^{-3}$ has proved a realistic lower limit for beads used as lightweight aggregate. Further details are given in the Technical Information Bulletins TI 540, “Preexpansion of Styropor”, and TI 570, “Aging preexpanded Styropor beads”.

Preexpanders

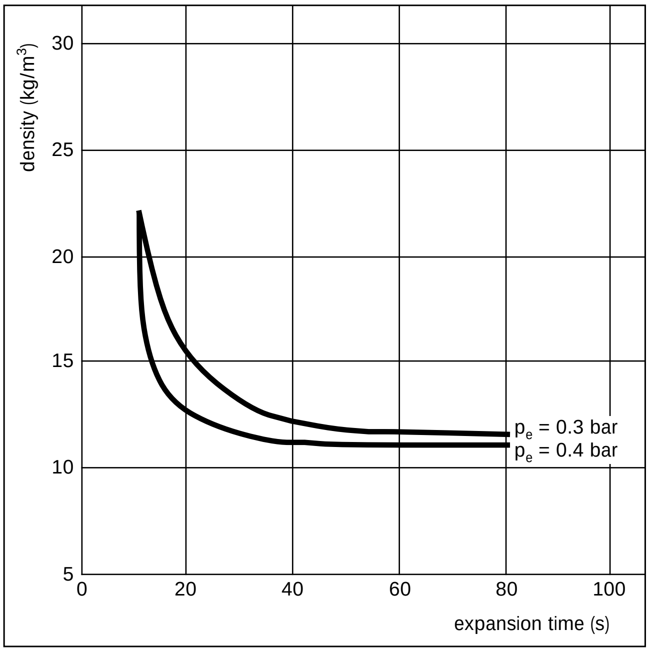
Continuous preexpanders can be used to obtain expanded Styropor beads of the required density, 12–13 $kg \cdot m^{-3}$, but only by two-stage expansion. It is however preferable to carry out the process in a single stage, using a batch preexpander (in which the excess pressure can reach 0.2 – 0.5 bar), as described in TI 540, “Preexpansion of Styropor”.

Air enters a batch preexpander each time it is emptied, so care must be taken to ensure that when fresh steam is admitted it rapidly purges the vessel of all air. If this is not done, the temperature of the steam will not be that of saturated steam at the pressure indicated. The beads expand at a rate dependent on the steam pressure, but the curves shown below are typical, and the density aimed at can generally be reached within 40 s. However, the rate of expansion is also dependent on the design of the preexpander.

Measuring bulk density

It is best to weigh the beads in a 5-litre or 10-litre aluminium beaker, to minimize errors. The filling method should be easily reproducible. The balance, which can be of any type – mechanical or electronic – should weigh to within 0.1 g or less and be suitable for loads of up to at least 1.5 kg.

The density of Styropor beads that have just been expanded will be higher than after they have been aged, because of moisture and compression; this must be allowed for when checks are made. After the expanded beads have aged, they should be dried before any new density measurements are made.



Expansion of Styropor VP 502

Safety precautions

Styropor beads contain a flammable hydrocarbon (pentane) as expanding agent. Explosive air-hydrocarbon mixtures can be formed wherever they are stored or processed. Expanded Styropor also contains minor amounts of pentane. All sources of ignition must be excluded, in particular, naked flames (smoking prohibitions must be enforced), welding, electrical devices producing sparks, and electrostatic charges.

The relevant limits for pentane and styrene in the air at workplaces (e.g. threshold-limit values etc.) must be maintained. Information about these is given in the appropriate Safety Data Sheets for Styropor.

TI 290, “Testing air for hydrocarbons”, gives tests that may be carried out. Our brochure “Precautions against Fire for Processors” provides more general information.

Advice on precautions against the accumulation and spark discharge of electrostatic charges is available from various national organizations.

Once drums or other containers for Styropor have been opened, their contents should be used as soon as possible. Replace the lids of partly filled containers.

The transport of Styropor or expanded Styropor in closed vehicles is not permissible.

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4 Processing

Drying preexpanded Styropor in fluidized beds

1 Principle of fluidization

If the velocity of a gas flowing upwards through a bed of solids is steadily increased, a point will be reached at which the bed expands and the particles begin to float. This point is referred to as the commencement of fluidization, and the bed at this stage assumes the characteristics of a liquid. If A is the area of the bed cross-section and Δp is the pressure drop suffered by the gas in flowing through the bed, equilibrium of forces exists at the commencement of fluidization between $A\Delta p$ and the weight of the bed plus the flowing medium. As an approximation, the forces of friction at the walls confining the bed can be neglected. With a further increase in gas velocity, the particles become more widely separated, and the pressure drop becomes steady despite the higher superficial velocity. If any individual particles become entrained in the stream of gas above the bed, the upward force exerted on them by the gas becomes considerably less in this zone. Consequently, the force of gravity predominates, and the entrained particles dropped back into the bed. As a result, the upward gas/solids interface is usually sharply defined, similar to the free surface of a liquid. The solids also flow along the bed towards the overflow, as if they were a liquid.

Fluidized beds offer many advantages in heat and mass transfer processes. Owing to the intensity of the mixing effect, all the particles receive the same treatment within the bed. Since the force of gravity tends to find equilibrium with the upward force exerted by the stream of gas, the bed automatically remains fluidized within wide limits. Another great advantage is that the costs for equipment, operation and maintenance are comparatively low.

2 Advantages of fluidized beds

Pre-expanded particles contain moisture to various extents on leaving the pre-expander. They must be dried, because moist beads are unsuitable for moulding.

Beads dried in a fluidized bed are free-flowing, do not present any troubles in pneumatic conveyance, and permit reliable control of the apparent density. They absorb air more readily and are less liable to damage during transportation.

3 Fluidized beds for drying pre-expanded Styropor

Description

A fluidized bed designed for drying pre-expanded Styropor is shown in Fig. 1. A radial-flow fan with a throttle at the inlet forces air through a diffuser into a tapering air duct. The upper end of the duct acts as the air distributor. It consists of a woven filter of ca. 400 µm mesh. The fabric is supported at several points on the frame in order to reduce sagging and inflation. A chute inclined at an angle of 45° is located at the inlet to the air duct. The pre-expanded beads proceed directly from the pre-expander to the inlet and slide gradually down the chute to form the fluidized bed.

An overflow weir of adjustable height is placed at the end of the fluidized bed. Further details are given below under the heading "Fluidized bed design".

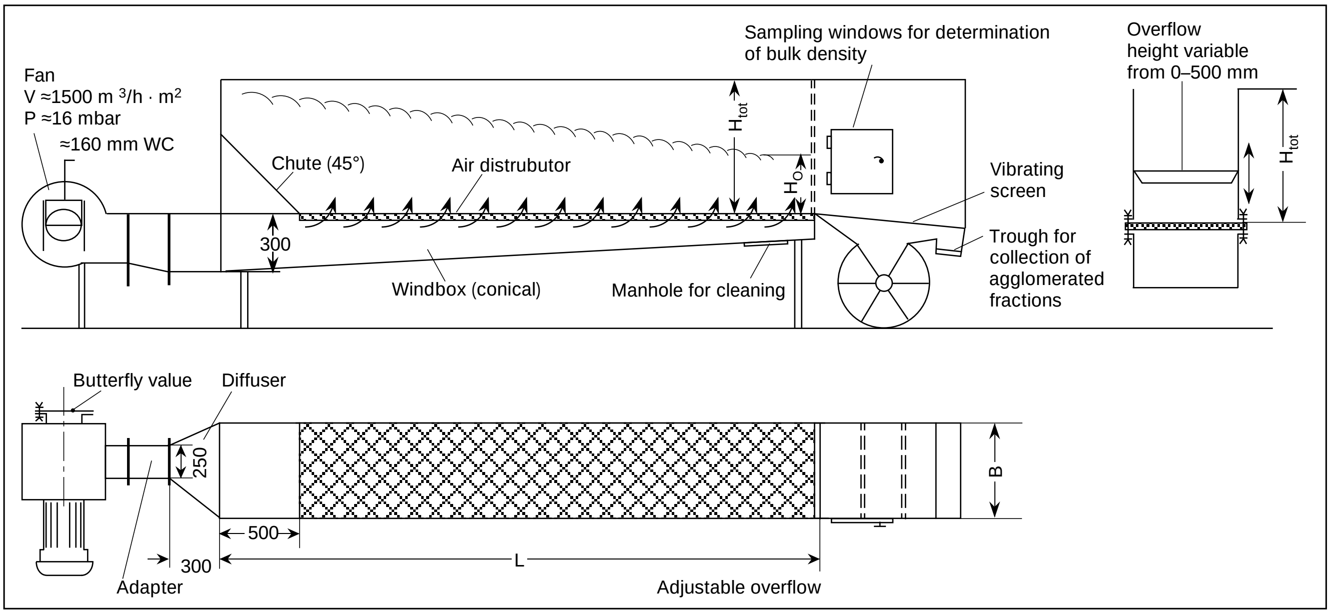

Fig. 1 Example of a design for a fluidized bed drier for pre-expanded Styropor.

Drying parameters

In most cases air at 20 – 30 °C suffices for drying the pre-expanded beads. If the air flow rate and temperature are kept constant, the attainable residual moisture content depends on the following parameters.

a) The initial moisture content of the pre-expanded beads.
Continuously expanded beads usually have a moisture content between 2 % and 5 % wt. In exceptional cases, e. g. during startup, it may be as high as 10 %.

b) The average residence time in the fluidized bed (cf. Fig. 2)
The apparent density of the pre-expanded beads is reduced somewhat by drying in a fluidized bed. It has been found that the apparent density of the dried beads is up to 1 kg/m^3 less than that of the moist beads in the 15 – 26 kg/m^3 range and is not affected by subsequent pneumatic conveying.

Operating conditions

It has been demonstrated by experiments that the average air velocity at the distributor inlet should be v = 0.40 – 0.45 m/s. Obviously, the same numerical value applies to the volume flow rate per unit area of free cross-section, i. e.

$\dot{V}$= 0.40 to 0.45 m/sm^2
≈ 1500 m/(hm^2)

Hence the total air requirements are

$\dot{Q} \approx \dot{V}$lb,

where lb is the cross-sectional area of the bed.

If the fluidized bed distributor is a woven fabric of 400 µm mesh, the fan pressure required to maintain this flow rate would be about 16 mbar = 160 mm WG. Hence the power requirements per unit area would be about 1 kW/m^2.

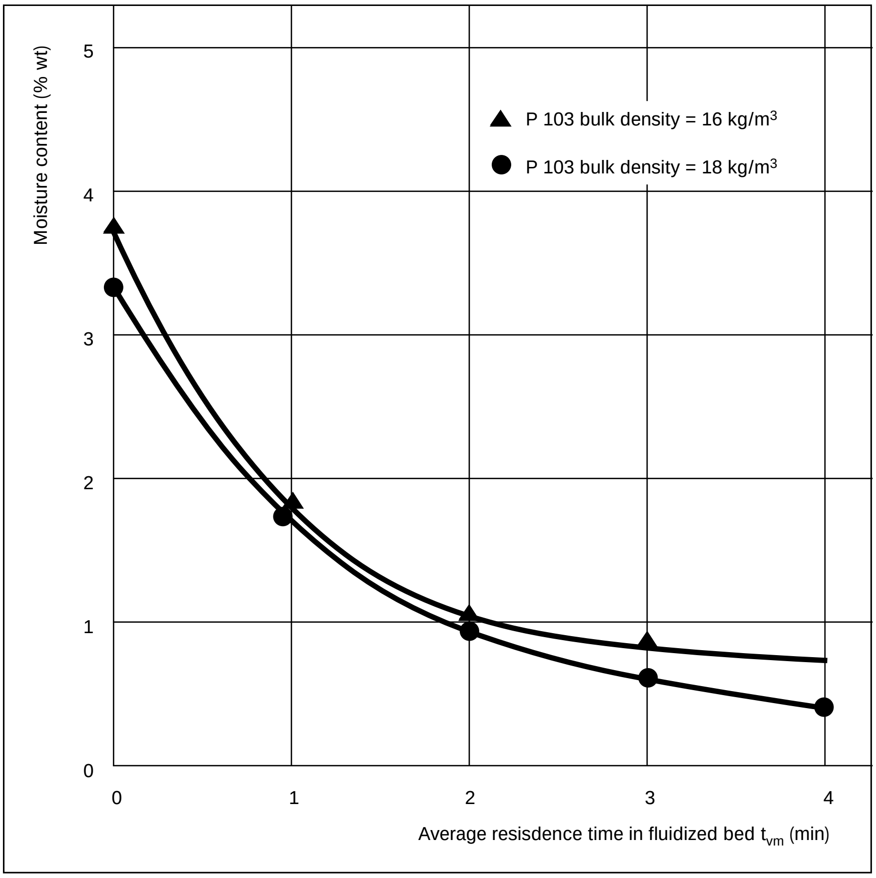

Fig. 2 Drying curves for pre-expanded Styropor with various initial moisture contents.
Superficial velocity of air in fluidized bed: 1500 m/hm^2
Fan pressure: 16 mbar = 160 mm WG
Air temperature: 22°C

The height of the overflow weir in the fluidized bed is usually set at 30 – 50 cm. Preference is given to values at the upper end of this range in order to ensure a longer residence time. If the height can be adjusted from zero upwards, flow within the ducts and drying can be more easily regulated, and emptying and cleaning can be facilitated.

Fluidized bed design

The time required for drying in the fluidized bed is obtained from the difference between the initial and final moisture contents. The initial moisture content of the freshly expanded material is determined by weighing a given amount before and after a period of intense drying. The figure selected for the final moisture content should be about 1%, at which value the beads are sufficiently free-flowing. The average residence time t for the material in the fluidized bed can then be read off from Fig. 2. The effective volume of the fluidized bed is given by

$$V_{Fl} = flbH_o = \dot{V}_{St}t/60f$$

where

V_{Fl} (m) = volume of fluidized bed
l (m) = length of fluidized bed
b (m) = breadth of fluidized bed
H_o (m) = height of overflow weir (max.)
$\dot{V}_{St}$ (m/h) = volume flow rate of pre-expanded Styropor (pre-expander output)
t (min) = average residence time in fluidized bed
f = factor (1.2)

Width of fluidized bed

The type of pre-expander should be taken into consideration in selecting the width b of the fluidized bed. The following figures are recommended:

- pre-expanders for mouldings
  b = 0.4 – 0.6 m
- pre-expanders for blockware
  b = 0.6 – 0.8 m

Height of fluidized bed

The walls of the fluidized bed should be as high as possible, and a cover should be dispensed with. At the sides of the bed, the height of the walls H_{tot} depends on the particle size. Its relationship to the height of the overflow weir H_o should be as follows:

- Material for mouldings:
  $T_{tot} = 3H_o$
- Material for blockware:
  $H_{tot} = 2H_o$

If these suggestions are adopted, the troublesome projection at the pre-expander outlet can be dispensed with.

Air distributor

Air can be uniformly distributed over the cross-section of the fluidized bed by means of a fairly tightly woven fabric filter. Good results have been obtained in practice by the following types of filter cloth:

- Monofilament polyamide fibres; 150 – 200 µm mesh
- Multifilament polycaprolactam fibres; 300 – 400 µm mesh

For coarse beads, perforated sheet metal distributors offer the following advantages over woven filters.

- The volume of the fluidized bed remains constant.
- They are mechanically robust.
- They are easy to clean.
- They do not rot.

However, the nature of the preparations is a very important factor. If the void fraction is 1.6 – 2.0 %, their diameter should be at least 1 mm.

Startup devices

Contrivances that have been introduced to facilitate startup are air louvres in the windbox and means for horizontal air currents. However, they have not proved successful in practice.

Maximum output

Fans with the performance characteristics quoted above permit pre-expanded Styropor to be dried at a maximum rate of 350 kg/h per unit area of fluidized bed. The apparent density of the beads may be as high as 50 kg/m^3. Hence, if the figure quoted above for the air requirements per unit cross-sectional area is taken, i. e.1500 m/hm^2, the volume of air required for drying each kg of Styropor is 4 – 4.5 m.

4 Safety precautions

The place of work must be well ventilated in order to avoid the accumulation of explosive blowing agent/air mixtures (cf. Tl 290 “Determination of pneumatogen content in air”).

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67056 Ludwigshafen

Technical Information

36144 February 1996

Styropor® 570

BASF Plastics

4 Processing

Intermediate aging of preexpanded Styropor

This Technical Information Bulletin describes ***intermediate aging****, the second of three stages usual in the conversion of Styropor to moulded EPS. The successive stages are*

- *preexpansion*
- *intermediate aging*
- *moulding.*

Contents

Principles

After preexpansion, the Styropor beads – which now have a cellular structure – are exposed once more to air at ambient temperature and pressure, in which they undergo further rapid changes.

The thin-walled cells are still filled with the vapours of water and pentane, but the total vapour pressure is no longer greater than atmospheric pressure and sinks fast as the beads continue to cool. The water condenses first, and once the temperature approaches ambient temperature it makes little contribution to the inside pressure. The vapour pressure of the much more volatile pentane would remain appreciable, but the residual pentane starts redissolving in the polystyrene cell walls.

Because of the considerable difference that develops between the pressure in the cells and the pressure of the air round the beads, the beads would tend to shrivel were it not for the stiffness of the cellular polystyrene structure, which also increases as the beads cool. Until pressure equilibrium is regained through the entry of air by diffusion, which is a slow process, the thin cell walls are all that prevents collapse.

Freshly preexpanded beads are thus extremely vulnerable, especially if their density is low, and the cell walls are correspondingly thin. They can be damaged by mechanical pressure (e.g. while being conveyed pneumatically) or even by excessively rapid cooling (e.g. through a stream of cold air). Before further handling they need preliminary conditioning, which allows them to become uniform in temperature and start filling with air.

In practice, preliminary conditioning takes place in the dryer, which is almost always a simple fluidized-bed dryer (cf. Technical Information Bulletin TI 0-560 e, “Drying preexpanded Styropor”). However, at least one machinery manufacturer also offers a form of vacuum dryer. Both types of dryer remove superficial water from the preexpanded beads, making them suitable for trouble-free transport (in a pneumatic conveyor) to the silo in which intermediate aging takes place and ensuring that they remain free-flowing in the silo. At the same time, the beads become sufficiently stable – for the time being – by cooling and taking up some air.

2 Handling preexpanded Styropor

After the preexpanded beads have been dried superficially, they must be removed gently to the aging silo by means of a pneumatic conveying system. Pressure conveying systems are used almost exclusively for this purpose, and as a rule the beads are introduced by rotary-vane feeders of the blowing-seal type (cf. TI 0-461 e, “Conveying preexpanded Styropor”).

Blowing-seal feeders are equally suitable for both very low densities (10 $kg \cdot m^{-3}$ or less) and very high ones (100 $kg \cdot m^{-3}$ or more). They are very reliable and do not harm the still quite fresh preexpanded beads. Because the volume fraction of solids in the air-solids mixture can be as high as 0.1, systems based on blowing-seal feeders are economic even at high rates of mass flow.

For low to medium rates of mass flow (< 600 $kg \cdot h^{-1}$), ejectors can be used to introduce the preexpanded beads into the air stream.

While the beads are being carried from the dryer to the silo, further loss of moisture occurs, but drying and final stabilization of preexpanded beads takes place in the aging silo.

3 Duration of intermediate aging and conditions

The aging process for preexpanded beads does not involve “aging” in the sense often applied to the chemical changes to which many polymers are subject, but it is not simply a matter of temporary storage either. When fresh, the beads contain too much water (mass fraction up to 5 %) and possibly too much pentane, but their cells contain too little air. The aim of intermediate aging is to make the beads fit for moulding.

At the beginning of the process the pressure within the cells is still much less than atmospheric pressure, but it gradually increases as air round the beads diffuses through the cell walls. The rate of air uptake depends primarily on the size, density, and temperature of the beads. Usually the beads are kept with free access to air at ambient temperature, and under these conditions equilibrium is nearly reached after about 12 h. Preexpanded beads that are to be expanded a second time – e.g. to make them suitable for moulded blocks of very low density – are kept for only 4 – 8 h before re-expansion.

The air in the cells at the end of the intermediate aging period serves two purposes. Firstly, it increases the resilience of the beads and their resistance to pressure, so they can withstand the handling they receive before and during the subsequent moulding process; this improvement is essential for beads in the lower part of the density range. For instance, only adequately aged beads can pass through a blower without being made denser. And secondly, the air is also needed for the extra expansion that has to take place when the beads are moulded by exposure to steam. If low-density beads are not aged long enough, and the air pressure in the cells is too low, the moulded material will lack dimensional stability or be denser than required.

During the intermediate aging process, the expanded beads lose expanding agent (pentane), though much slower than they gain air. The rate of loss depends on the permeability of the polymer to pentane and may therefore vary from product to product.

If the density of the beads is at the lower end of the usual range, it is possible that excessive loss of pentane before the beads are moulded will lead to inadequate expandability and therefore inadequate strength, even though air uptake is sufficient. On the other hand, some loss of pentane may be desirable – the greater the density, the greater the need to reduce the pentane content. Too much pentane in the preexpanded beads can have adverse effects on moulding characteristics and the behaviour of the moulded material (cf. TI 0/2-110 e, “Shrinkage and aftershrinkage of Styropor block and board”).

High-density preexpanded beads of standard types of Styropor become stable after only short intermediate aging periods, but at that stage they contain much too much pentane for satisfactory processing. If they were moulded then, the properties of the moulded EPS would be very uneven, and the moulding cycle would last too long. A way of avoiding the prolonged aging periods usually required for high-density beads is to make use of one of the special types of Styropor with reduced proportions of expanding agent.

Broadly speaking, high-density preexpanded beads need to be aged until they have lost enough expanding agent, while low-density beads must be aged for shorter periods – only long enough to ensure adequate uptake of air but not so long that serious losses of pentane occur. In both cases, intermediate aging reduces the proportion of residual moisture enough to ensure trouble-free handling during subsequent processing. It is in fact advantageous if the mass fraction of water before moulding is 0.5 –1.0 %, since this reduces any tendency to retain electrostatic charges.

Even if the ideal aging period could be found for any given product, it would be both uneconomic and impracticable to adhere to it exactly. In practice, it is required of all products that the preexpanded beads can be moulded after the shortest possible aging period and that they do not change much while being aged for longer periods. The quality of today’s raw materials is such that this requirement can be satisfied. For densities in the range 15 – 20 $kg \cdot m^{-3}$, aging times of from 12 h to 24 h are usual.

A simple way of reducing the time required for intermediate aging of a batch of preexpanded beads is to incorporate a measured quantity of reground EPS. It must be realized though that this can lead to changes in processing characteristics and the properties of the moulded material.

4 Silo construction

Requirements

Separate sets of silos are needed for every type and grade of Styropor, each set consisting of at least one silo for each density. The silo capacity must be enough to allow production for two or two and a half days. Where there is a choice, several small silos are better than one large one, since they allow more flexible working.

Silos for intermediate aging built under cover should be square or rectangular in plan – for better space utilization – , and their height should be twice the greater horizontal dimension or more. Slender silos give steady material discharge. The sides of the hopper below the bin should be inclined to the vertical at angles of between 30° and 45°, either symmetrically or asymmetrically.

Indoor silos often consist of earthed metal or wooden frameworks lined with woven jute or other fabrics made from natural fibres, which hold enough moisture to dissipate electrostatic charges. Synthetic fabrics are also suitable, but they should incorporate connected threads of aluminium or another good conductor at regular intervals.

Large masonry silos are also in use. It has been found best if these have hoppers constructed of perforated or woven metal, which allow pentane vapour (which is denser than air) to escape through the bottom.

Metal feed bins, which are generally placed beside the moulding machines or form part of them, must be bonded to pipework and the frame of the machine, like all other metal equipment.

For intermediate aging outdoors, cylindrical metal silos of the type used in agriculture for grain storage may be used. The preexpanded beads should be thoroughly dried, in a fluidized-bed dryer, for instance, before being introduced into such silos. Like the masonry silos, they should have hoppers made of readily permeable material.

Silo inlets should be arranged so that the path traversed by the preexpanded beads within the silo is as long as possible. For instance, if the silo is rectangular in plan, the axis of the duct should be horizontal and in line with a diagonal where it joins the silo. In a cylindrical silo, the inlet should be tangential.

In Germany, silos for preexpanded beads must meet the requirements of the companies insuring industrial plant, published in the leaflet "Special Safety Precautions in Establishments that Manufacture or Process Expanded Polystyrene."*

Outdoor silos

Enclosed silos that are constructed from non-combustible materials but are not fire-resistant should normally be at least 10 m from other parts of the plant. Silos with walls, roofs, and floors of metal sheet (galvanized or painted steel or aluminium) or of thin concrete or brickwork belong in this category.

The safety distance for silos constructed from wood, plastics, or woven wire is 15 m.

No safety distance is required if the silos, regardless of their construction, are separated from the rest of the plant by a wall whose fire resistance meets the requirements for a compartment wall.

Silos for intermediate aging with solid walls may not afford unrestricted air uptake or adequate escape of pentane, especially if they are outdoors. Generally speaking, permeable enclosures in heated buildings are advantageous.

Silos in buildings

In buildings, enclosed silos that are constructed from non-combustible materials but are not fire-resistant should be separated from other parts of the plant by elements of structure with 90-min fire resistance. Silos with walls, roofs, and floors of metal sheet (galvanized or painted steel or aluminium) or of thin concrete or brickwork belong in this category.

Silos constructed from combustible materials should be separated by compartment walls from other parts of the plant within buildings. This applies to silos with walls, roofs, or floors constructed from hardboard, plywood, chipboard, rigid or flexible plastic sheet, coated fabric, fabric made from natural or synthetic fibres, or woven wire.

The capacity of each feed bin (no more than one for each block mould or moulding machine) may not exceed 500 kg unless the bin is separated by a fire-resistant wall and the feed line can be firestopped.

Fire-resistant silos

No safety distances need be observed or fire-resistant barriers provided, either outdoors or indoors, if the silos are so constructed that any fire within a silo is confined to that silo. This entails the use of concrete or brickwork of the thickness required for compartment elements of structure for their walls, roofs, and floors.

Where such silos are outdoors, both they and ducts leading to them should be thermally insulated if there is any danger of condensation and formation of ice on the preexpanded beads. It should also be possible to heat the hopper of other discharge devices. It is advantageous to heat the inside of the silo in cold periods, since this assists drying and accelerates rates of diffusion of air and pentane through the polystyrene.

5 Avoiding ignition of flammable air-pentane mixtures

Good ventilation is needed in the neighbourhood of indoor silos, to avoid the formation and accumulation of flammable air-pentane mixtures. It is generally expedient to provide low-level exhaust intakes. The efficacy of the system should be checked regularly by means of an instrument measuring concentrations of hydrocarbons in air – e.g. from Mine Safety Appliances Co., Draeger Ltd, or the Gesellschaft für Gerätebau – , as described in TI 0-290 e, "Testing air for hydrocarbons".

Smoking and the use of naked flames must be prohibited. All electrical equipment within silos – especially in hoppers – must be flameproof. All metal parts must be bonded and earthed.

Essential welding work in the vicinity of silos may not be carried out until they have been completely emptied.

6 General safety precautions

Incipient fires may be fought with hand-held fire extinguishers. Water is effective in fighting more advanced fires. Silos that are not easily accessible are best provided with an automatic fire-protection installation.

All silos that are accessible from above must be secured in such a manner that no person or object can fall into them.

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** Compiled by the Fire Committee of the Industrial Insurers Association in collaboration with the Insurance Committee of Federal Association of German Industry.*

27043 April 1994

4 Processing

® = Registered trademark

Cleaning moulds for Styropor

During the production of Styropor mouldings, scale and polystyrene deposits are formed on the mould. Consequently, moulds must be cleaned from time to time to avoid breakdowns.

1 Removal of scale

Scale is inevitably formed if unsoftened water is used for cooling the moulds. It gradually chokes the steam nozzles and openings and thus impedes free entry of steam with an attendant high reject rate.

The cheapest method of cleaning a mould after it has been dismantled is to remove the scale with dilute hydrochloric acid at room temperature. Higher temperatures are inadvisable, because they allow the acid to attack the metal more strongly. When the mould is placed in the acid, the scale will dissolve after a certain period of time. A corrosion inhibitor should be added to the bath to prevent the metal surfaces of the mould from being attacked by the acid. A particularly effective inhibitor is Korantin® BH. The acid concentration should be about 5% and in no circumstances higher than 10%.

The recommended proportioning rates of Korantin BH Liquid are as follows:

Acid concentration	Addition rate of Korantin BH Liquid
5%	0.1 – 0.3%
10%	0.2 – 0.6%

Korantin BH is also available in solid form, in which case the proportioning rate is about one-quarter of that quoted for Korantin BH Liquid.

These conditions and observance of the manufacturer’s instructions will ensure that the metal is not attacked by the acid. A list of Korantin suppliers can be obtained from BASF subsidiaries and sales offices.

Even less likelihood of corrosion arises if the scale is removed by 10 –15% phosphoric acid instead of hydrochloric acid and Korantin BH. In this case, the bath temperature should be 50 – 60 °C. Room temperature is also feasible, but entails longer immersion periods. The moulds must not remain too long in the acid bath; on an average, about two hours will suffice.

2 Removal of polystyrene deposits

Polystyrene deposits are usually caused by superheated steam. In addition, minute expanded beads may be come lodged in the steam inlets and thus block them.

Flaming is the easiest and most effective means of removing these deposits from the mould after it has been dismantled. It also removes other organic contaminants. Any kind of burner can be used, but the flame temperature must not be so high that the material of the mould may be locally overheated or melted.

Solvents can be used in particularly stubborn cases. The most suitable is dichloromethane, because it is nonflammable, but combustible solvents, e.g. acetone and ethyl acetate, can also be used. It must be noted that high concentrations of solvent vapours are injurious to health and that the TLVs or MAK values* must be strictly observed.

Benzene and carbon tetrachloride are prohibited for cleaning. Grave dangers obviously arise if large amounts of combustible liquids are handled in closed, poorly ventilated rooms. It is thus evident that preference should be given to incombustible solvents. If none is available, it would be better to clean the mould by exposing it to a flame; but, in this case too, the requisite safety precautions must be observed.

3 Removal of colorants

Moulds may be stained by coloured Styropor, but these stains can also be removed by the solvents mentioned above.

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** The MAK values for the solvents mentioned are as follows:*

Dichloromethane	100 ppm (Vol)	≙	360 mg/m^3
Acetone	1000 ppm (Vol)	≙	2400 mg/m^3
Ethyl acetate	400 ppm (Vol)	≙	1400 mg/m^3

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Technical Information

Styropor®

012

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27033 April 1994

5 Building

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Insulation requirements, physical principles

In most countries there are statutory minimum standards for the insulation of habitable buildings that have to be heated for at least part of the year. There may also be regulations governing the insulation of other buildings occupied for long periods, such as schools, shops, and factories. The objects of such standards are to promote the health and comfort of the occupants and to keep energy losses at tolerable levels.

Insulation standards vary widely from country to country, since they are influenced by traditional methods of construction and heating, national habits, and climate. Statutory standards commonly relate to what may be termed *minimal insulation,* and seldom correspond to modern standards for *full insulation,* which is the generally accepted degree of insulation necessary for both comfort and moderate heating costs.

Thermal insulation of buildings is usually specified by giving either the *thermal transmittance U* or the *thermal resistance* $1/\Lambda$ for each element of construction (floor, roof, wall, *etc.*). For elements of uniform section these quantities are related by the equation

$$1/U = 1/A + R_{st},$$

where R_{st} is the sum of the inside and outside surface resistances $1/\alpha_i$ and $1/\alpha_o$. The rate of loss of heat through an element of area A and average transmittance U when the effective ambient temperatures inside and outside are ϑ_{ei} and ϑ_{eo} is

$$\Phi = UA\,(\vartheta_{ei} - \vartheta_{eo}).$$

The average transmittances of elements generally need to be lower when the *external design temperatures* are lower, but direct comparisons are possible only if the design temperature is always selected on the same basis. The criteria used for design temperatures in fact differ considerably from country to country, and it is advisable to choose a common criterion based on readily available data before comparing maximum transmittances specified in various countries. One such criterion is the average monthly minimum temperature in the coldest month, which has been tabulated for every major city in the world.*

Once one or more preliminary construction designs have been drawn up for a given building the calculated thermal transmittances for every enclosing or dividing element must be compared with the required transmittances. If the calculated transmittances exceed the maximum values permitted by law or decided on as part of the overall design, the construction design must be modified or additional insulation must be added. The calculation of thermal transmittances is discussed in detail in Technical Information leaflet TI 013 e, *Thermal transmittance (“U value”);* here it will be assumed that the results are available for the construction considered, and only the effects of added insulation need be worked out.

Suppose that a bungalow 10 m x 12 m is to be constructed on a coastal site; the design calls for a 35° tiled hipped roof with felt sarking and aluminum backed ceiling board on joists ($U = 1.6$ W/m$^2\cdot$K), a solid floor in contact with the earth ($U = 0.6$ W/m$^2\cdot$K), cavity walls with brick outer leaves and Styropor-concrete inner leaves ($U = 1.2$ W/m$^2\cdot$K), single-glazed windows with wood frames ($U = 5.0$ W/m$^2\cdot$K), and glazed doors with aluminum frames ($U = 6.7$ W/m$^2\cdot$K); the window area is to be 24 m^2, the door area 4 m^2, and the total wall area (including windows and doors) 125 m^2. What extra insulation is needed to meet the following limits?

* *Meteorological Office, Tables of Temperature, Refative Humidity, and Precipitation for the World. London: HMSO.*

Roof and ceiling	0.6 $W/m^2 \cdot K$
Floor	0.6 $W/m^2 \cdot K$
Any wall, excluding openings	1.0 $W/m^2 \cdot K$
Average of all walls, including openings	1.8 $W/m^2 \cdot K$

Roof & ceiling. The transmittance of the roof and ceiling must be reduced from 1.6 $W/m^2 \cdot K$ to less than 0.6 $W/m^2 \cdot K$, i.e. the total thermal resistance must be increased by about 1.1 m^2 K/W (from 1/1.6 $m^2 \cdot K/W$ to 1/0.6 m^2 K/W). Taking the resistivity of Styropor board as about 25 $m^2 \cdot K/W$, the required thickness is at least 44 mm, thus stock 50-mm Styropor board should be used. The transmittance of roof and ceiling with 50 mm Styropor board laid over the ceiling joists would be less than 0.55 $W/m^2 \cdot K$.

Floor. The addition of any normal floor covering would reduce the transmittance to below 0.6 $W/m^2 \cdot K$, so that no additional insulation is required.

Walls. The transmittance of the walls (excluding openings) must be reduced from 1.2 $W/m^2 \cdot K$ to less than 1.0 $W/m^2 \cdot K$, i.e. the total thermal resistance must be increased by about 0.2 $m^2 \cdot K/W$ (from 1/1 .2 $m^2 \cdot K/W$ to 1/1.0 $m^2 \cdot K/W$). Taking the resistivity of Styropor board as about 25 $m^2 \cdot K/W$, the required thickness is at least 8 mm, thus stock 15-mm Styropor board should be used. The transmittance of the walls with 15-mm Styropor board built into the cavity or applied to the inside faces as a laminate with gypsum plasterboard would be less than 0.84 $W/m^2 \cdot K$.

The average transmittance of all the walls (including openings) is found by summing the contributions of the walls themselves, the windows, and the doors, weighted in accordance with the corresponding areas. Thus if 15-mm Styropor board is used for insulation

$$U = \frac{(125-24-4) \times 0.84 + 24 \times 5.0 + 4 \times 6.7}{125} \; W/m^2 \cdot K \approx 1.83 \; W/m^2 \cdot K.$$

This value only just exceeds the limit of 1.8 $W/m^2 \cdot K$, and might be regarded as acceptable. However, in this example it would almost certainly be advantageous to substitute double-glazed for single-glazed windows; if the double-glazed windows had a transmittance of 2.7 $W/m^2 \cdot K$ the average transmittance of the walls would be

$$U = \frac{97 \times 0.84 + 24 \times 2.7 + 4 \times 6.7}{125} \; W/m^2 \cdot K \approx 1.4 \; W/m^2 \cdot K.$$

In deciding maximum thermal transmittances for given elements the principle criteria are comfort and economy. If the design is such that it is possible to maintain a comfortable environment in all weathers and costs are minimized, it is almost certain that any local regulations will be satisfied. Other factors to be considered are the avoidance of condensation and the reduction of pattern staining.

Ideally designs should be optimized for every building, but in practice it is more convient to use empirical values such as those given in Table 1, at least as an initial basis for planning. Table 1 has been compiled from values accepted in the colder parts of Germany for full insulation and values put forward in Britain as the basis for regulations intended to achieve similar insulation standards. It can be used as a guide in other countries with comparable climates (and heating costs); the external design temperatures ϑ_{do} quoted are based on average monthly minimum temperatures ϑ_{min} in the coldest months.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

Table 1 Suggested maximum thermal transmittance for dwellings

Element of construction	**U [$W\,m^{-2} \cdot K^{-1}$] for ϑ_{do} [°C]**	**−6[e]**	**−10[f]**	**−14[g]**
External enclosing elements				
Roof, or roof together with ceiling of story below roof[a]	average	0.6	0.6	0.5
(NB US spelling)	maximum[b]	1.1	1.0	1.0
External walls, excluding openings	maximum[b]	1.0	0.9	0.8
External walls, including glazed openings	average[c]	2.0	1.8	1.6
Floor exposed to the open air on the underside	average	0.6	0.4	0.3
	maximum[b]	0.9	0.8	0.7
Floor in contact with earth or suspended above it	maximum[b]	0.6	0.5	0.4
Internal dividing elements				
Wall between habitable room & unheated space (e.g. stair well)	maximum[b]	1.7	1.7	1.7
Wall between dwellings in building without central heating	maximum[b]	2.0	2.0	2.0
Wall between dwellings in building with central heating	maximum[b]	3.2	3.2	3.2
Floor of habitable room over unheated space (e.g. cellar, passage)	average	0.8	0.6	0.5
	maximum[b]	1.2	1.0	1.0
Floor between dwellings in building without central heating	maximum[b, d]	1.7	1.7	1.7
Floor between dwellings in building with central heating	maximum[b, d]	2.4	2.4	2.4

[a] *Excluding openings such as skylights*
[b] *Maximum at any point, including thermal bridges*
[c] *Average over all external walls of building*
[d] *For upward flow or heat*
[e] $-4\,°C > \vartheta_{min} \geq -8\,°C$
[f] $-8\,°C > \vartheta_{min} \geq -12\,°C$
[g] $-12\,°C > \vartheta_{min} \geq -16\,°C$

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5 Building

Impact sound: general introduction

Noise is sound that is unwanted by the recipient.[1] This simple definition explains why an important function of most buildings is to protect its occupants against extraneous sound. The need for such protection has not always been appreciated, and it is not yet appreciated everywhere, but noise is now widely recognized as a major pollutant of cities and even of smaller communities.

Noise is of course generated within buildings as well as outside them, and one of the aims of building design is to ensure that sound from a source in one part of a building does not cause annoyance to an occupant in another part. This aim may be only partially achieved by the usual division into compartments by floors and partitions, since there may still be transmission paths offering inadequate resistance to airborne or structure-borne sound. In particular, *impact sound* – sound produced by impacts delivered to the structure – can seldom be prevented from reaching adjacent rooms without special measures to reduce its transmission.

In the context of this Bulletin, and in architectural acoustics in general, impact sound is taken to be sound produced by impacts on floors, since this is the most common form of impact noise. In some countries the term “footstep sound” is used,[2] although the repertory of impact sounds produced in the typical household is by no means confined to footsteps.

One method of reducing the transmission of impact sound to the rooms below might be to increase the superficial mass of the floor, which also reduces the transmission of airborne sound. However, this method is essentially impracticable for all except the smallest buildings, because the increased weight would increase the cost of the load-bearing structure out of all proportion to the possible reduction in impactsound transmission.

The simplest method of reducing impact sound is to use soft flooring. Provided the flooring is soft enough and thick enough, this method can be effective, except at the lowest frequencies. However, it is expensive, impermanent, and not applicable to all rooms.

The third method is to use a *floating floor* separated from the structural floor by a layer of resilient material. Properly designed and constructed, the floating floor is the cheapest and most effective means of providing adequate impact-noise insulation over the whole of the relevant frequency range. In modern buildings with concrete floors the floating floor generally consists of a cement or anhydrite screed, about 40 mm thick, laid over insulating material covered with corrugated board, polyethylene film, or building paper (cf. Fig. 1). However, wooden constructions are practical alternatives, and may even be preferable for specific applications. In all floating-floor constructions there must be no direct contact with other parts of the structure, including walls, and insulation should be carried up over the edges.

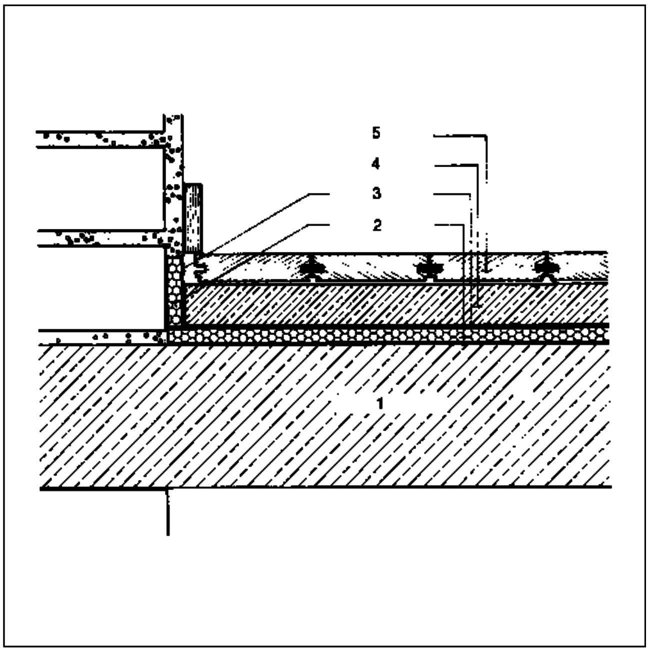

Fig 1. Typical floating floor: 1, reinforced concrete; 2, Styropor sound-insulation board; 3, oiled paper; 4, screed; 5, parquet flooring.

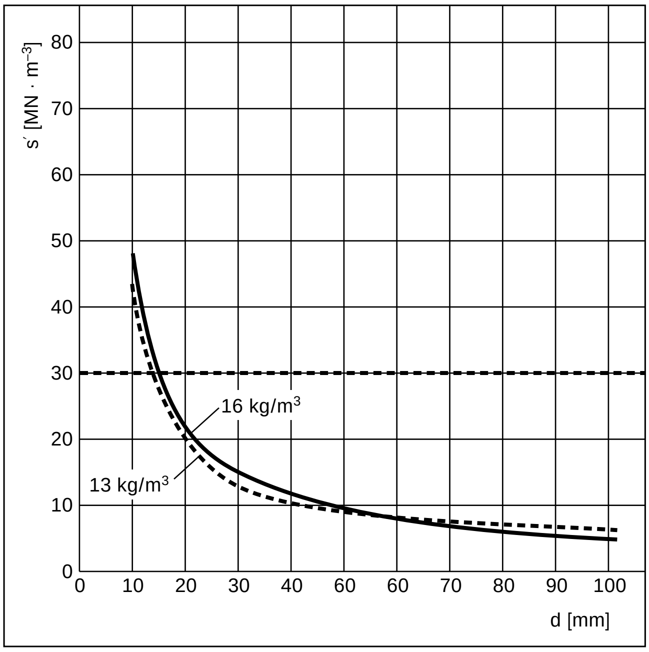

Fig 2. Superficial dynamic stiffness (s′) v. thickness (d) for pre-compressed Styropor board.

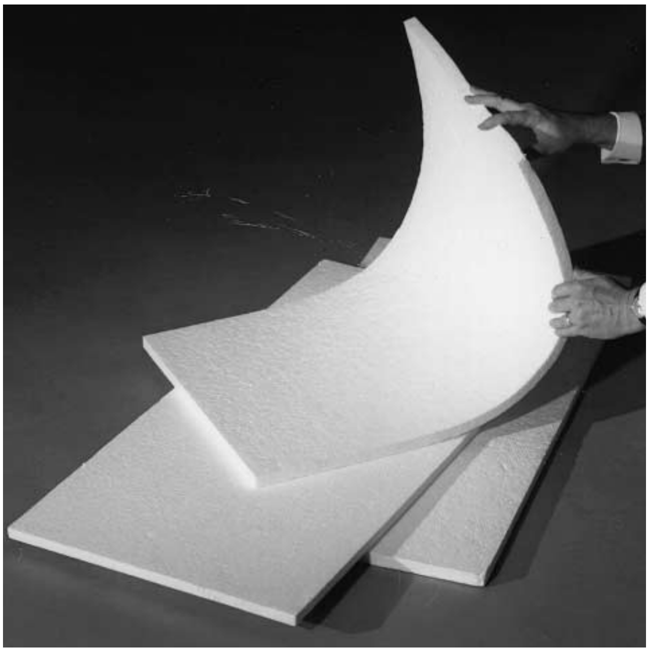

Fig. 3 Precompressed Styropor board

Fig. 4 Ribbed Styropor board

Design principles

A rigid slab of superficial mass *m* resting on a layer of material of superficial dynamic stiffness *s′* can be treated as a simple oscillator whose natural frequency (without damping) is given by

$$2\pi f_o = (s'/m)^{1/2}. \qquad (1)$$

A periodic force, such as that, produced by sound pressure, can force the slab to vibrate vertically with the frequency *f* of the force. The transmitted pressure p_t is then less than the incident pressure p_i, the predicted relationship being

$$(p_i/p_t)2 \approx (f/f_o)^4.$$

The reduction in impact sound pressure level caused by the reduction in the transmitted pressure is

$$\Delta L = lg\, p_i^2 - lgp_t^2,$$

hence

$$\Delta L \approx 40\ lg\ (f/f_o)\ dB. \qquad (2)$$

Although Eqn. 2 is based on a number of simplifying assumptions, it gives results that agree quite well with experiment, provided *f* is greater than f_o and does not approach it too closely, and the system is very lightly damped. The latter condition is met by most suitable insulating materials; the former condition must be satisfied by proper design.

Sound of frequencies much below 100 Hz is not generally considered in architectural acoustics, since although it is detectable by the human ear it is not perceived as loud unless it is unusually intense. Thus the natural frequency of a floating floor can be about 100 Hz, corresponding to (cf. Eqn. 1)

$$s'/m \approx 0.4 \times 10^6\ s^{-2}.$$

The value of *m* is largely determined by the materials and construction used for the floating floor. For instance, if a cement screed is used it must be about 35 mm thick to provide the necessary strength, on the other hand it is unlikely to be more than about 50 mm thick to avoid unnecessary weight on the loadbearing structure; thus *m* is 70 – 110 kg/m², and s′ should be 28 – 44 MN/m³.

Dynamic stiffness of Styropor board

Stiffness is restoring force per unit displacement, but in architectural acoustics the same term and symbol are often used for the restoring stress per unit displacement, i. e. for superficial stiffness. In connexion with static compression of Styropor board the superficial stiffness is given by

$$s = E/d,$$

where E is Young's modulus and d is the thickness. At high rates of strain the dynamic modulus of elasticity E' must be substituted for Young's modulus, giving the frequency-dependent superficial dynamic stiffness s', where

$$s' = E/d, \qquad (3)$$

For Styropor, as for all insulating materials, E' is greater than E over the entire range of audible frequencies.

In practice Eqn. 3 may not give the effective stiffness of Styropor board used for a floating floor, since neither the board nor the floor on which it rests have perfectly plane surfaces. There is a contact zone whose compliance $1/s'_k$ may be comparable with the compliance $1/s'_m$ of the material itself, and the effective compliance is given by

$$1/s' = 1/s'\ m + 1/s'_k. \qquad (4)$$

Eqn. 4 indicates two possible ways of reducing the stiffness – i. e. of increasing the compliance – of Styropor board: reducing the material stiffness or reducing the contact stiffness.

The material stiffness of expanded Styropor board can be reduced by passing it through a pair of rolls or by cutting it from block previously subjected to the same compression (60 %) in a press. Although the material almost recovers its original thickness the effect of crushing the cell walls is to substantially reduce the dynamic elastic modulus, without excessively reducing the static modulus. The superficial dynamic stiffness at low frequencies of board treated in this way is shown in Fig. 2.

The contact stiffness of ordinary Styropor board can be reduced by roughening its surface or even giving it a ribbed finish. Both measures reduce the contact area and increase the thickness of the contact zone, thus increasing its compliance.

Requirements for impact-sound insulation material

Insulation material for floating floors intended to reduce transmission at frequencies down to 100 Hz should have a superficial dynamic stiffness of not more than 30 MN/m^3; as was shown above, this maximum value corresponds to that required with a 35-mm cement screed. Sometimes however it is not essential to reduce transmission at the lower frequencies, because the load-bearing structure does not transmit impact-sound or airborne sound excessively. This may be the case when the structural floor consists of a concrete slab of superficial mass greater than about 350 kg/m^2, which gives considerable protection against airborne noise over most of the audible frequency range and adequate protection against impact noise at the lower end of the range. In such cases it is reasonable to set a higher limit for the stiffness of the insulation material, for instance a limit such that the expected reduction in sound pressure level is about 10 dB less than that given with material of lower stiffness. If the lower limit of stiffnes is s'_1 and the higher limit is s'_2, then from Eqns. 1 and 2

$$\Delta L_1 - \Delta L_2 \approx 20 \lg (s'_2/S'_1) \text{ dB}.$$

If $(\Delta L_1 - \Delta L_2)$ is to be less than 10 dB, lg (s'_2/s'_1) must be less than 0.5; this is the case if $s'_2 \leq 3s'_1$, hence if s'_1 is 30 MN/m^3, s'_2 should be 90 MN/m^3.

The stiffness limits 30 MN/m^3 and 90 MN/m^3 are already specified in some countries for cellular plastics intended for impact-sound insulation.[3]

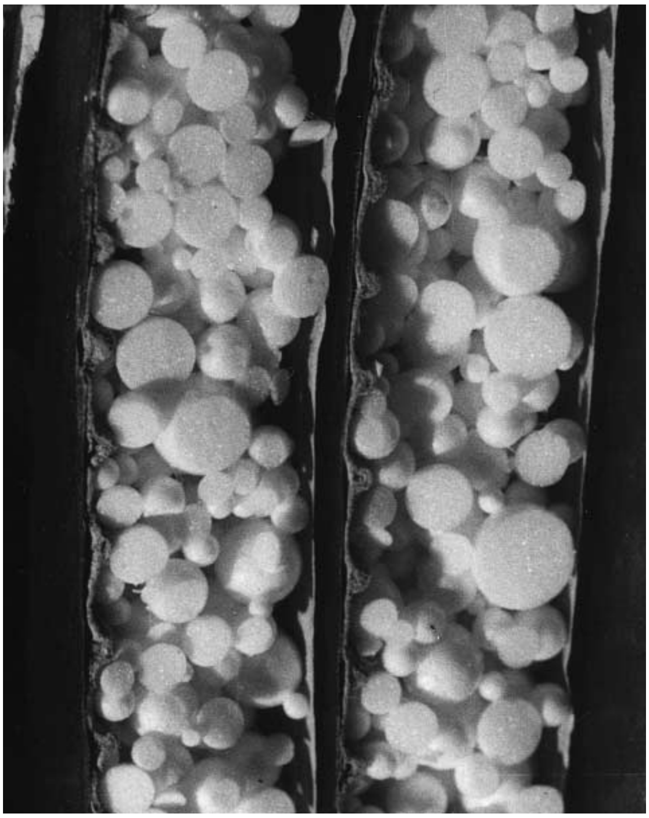

Fig. 5 Insulation board made from dispersion-bound expanded Styropor beads

Fig. 6 ISO standard tapping machine

The thickness of impact-sound insulation material must be such that specified stiffness limits are not exceeded, but should add as little as possible to the overall thickness of the construction. Precompressed Styropor board intended for impact-sound insulation should be about 20 – 25 mm thick for Class I insulation ($s' < 30$ MN/m^3) or 10 –15 mm thick for Class II insulation (30 MN/m^3 < s' < 90 MN/m^3).

Normal untreated Styropor board 25 mm thick *may* satisfy the requirement for Class II insulation, but because of the inevitable fluctuations in the dynamic stiffness of expanded Styropor it is advisable to use only treated board for impact-sound insulation.

Commercial materials

Precompressed Styropor board (Fig. 3) is inherently more compliant than normal board because of the effects of crushing the cell walls; it is available under designations such as “ISD – Impact-sound duty”. Ribbed Styropor board (Fig. 4) is also more compliant than normal board; in this case the contact area is reduced and the depth of the contact zone is increased. A third type of insulation material is made from expanded Styropor beads bound by means of a polymer dispersion (Fig. 5); this has very low dynamic stiffness.

Rating of impact-sound insulation

Impact-sound transmission is usually measured by internationally agreed methods.[4] A standard tapping machine with five 500-g hammers delivers blows on the floor at intervals of 0.1 s, each hammer dropping freely from a height of 40 mm (Fig. 6). The sound pressure levels in the room below are measured at third-octave intervals over the frequency range 100 – 3150 Hz by means of a microphone and a sound analyser. These levels are normalized with reference to an equivalent absorption of 10 m^2 by adding lg [A/(10 m^2)] to each value, where *A* is the equivalent absorption calculated from the volume V and the reverberation time *T* of the room by means of Sabin’s formula

$A = (0.163\ s/m)V/T.$

The reverberation time is measured by standard methods;[5] it is the time required for the sound pressure level in a given frequency band to decrease by 60 dB after the source is stopped, and varies with frequency. The loudspeaker used as the source in measuring the reverberation time can be seen in Fig. 8.

The normalized impact-sound transmission levels L_n are converted to octave-band levels by adding[5] dB (1/1octave-band and 1/*n*-octave-band levels differ by lg *n*) and compared with those represented by the ISO standard reference curve[6] shown in Fig. 7. The differences between the measured and the reference levels give the ISO *impact protection margin,* M_i. This is the largest integral increment that can be added to each measured level without exceeding any corresponding reference level by more than 8 dB and without raising the total of the positive deviations to more than 2*n* dB, where *n* is the number of levels measured. In the example shown in Fig. 7 M_i is 4 dB.

The impact protection margin gives a single-value rating that is used in many countries for specifying the degree of impact-sound insulation required for floors. In some countries the ISO *impact-sound index* L_i is used as a single-value rating. Like the impact protection margin M_i it is based on the relation of measured impact-sound levels to the levels represented by the ISO standard reference curve, and can be derived from M_i.

The degree of impact-sound insulation required for floors between various types of rooms in a building serving various purposes is discussed in TI 1041 e, which also gives examples of suitable constructions.

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1. BS 661: 1969, *Glossary of acoustical terms*.
2. DIN 4109 Bl. 1, September 1962, *Schallschutz im Hochbau; Begriffe.*
3. DIN 18164 Bl. 2, December 1972, *Schaumkunststoffe als Dämmstoffe für das Bauwesen; Dämmstoffe für die Trittschalldämmung.*
4. ISO/R 140 –1960 (E), *Field and Laboratory measurements of airborne and impact sound transmission.*
5. ISO/R 354 –1963 (E), *Measurement of sound absorption coefficients in a reverberation room.*
6. ISO/R 717–1968 (E), *Rating of sound insulation for dwellings*.

Note

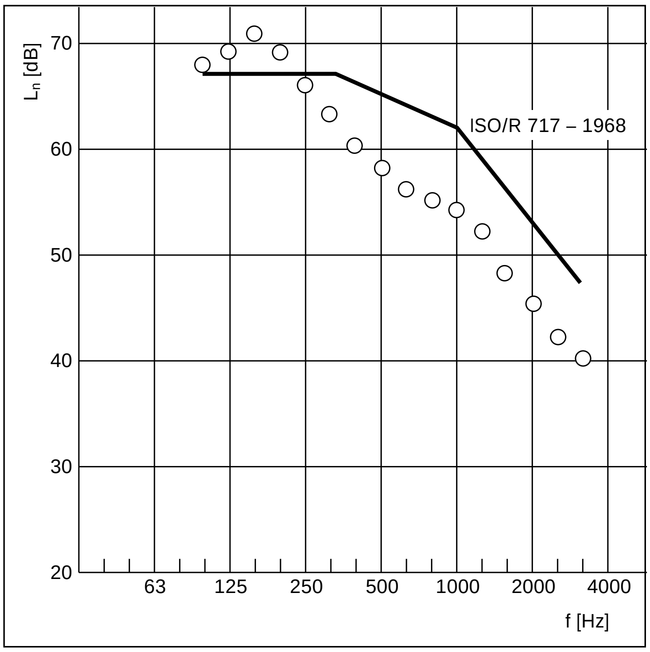

Fig. 7 Impact-sound level (L_n) v. frequency (f) for an insulated floor

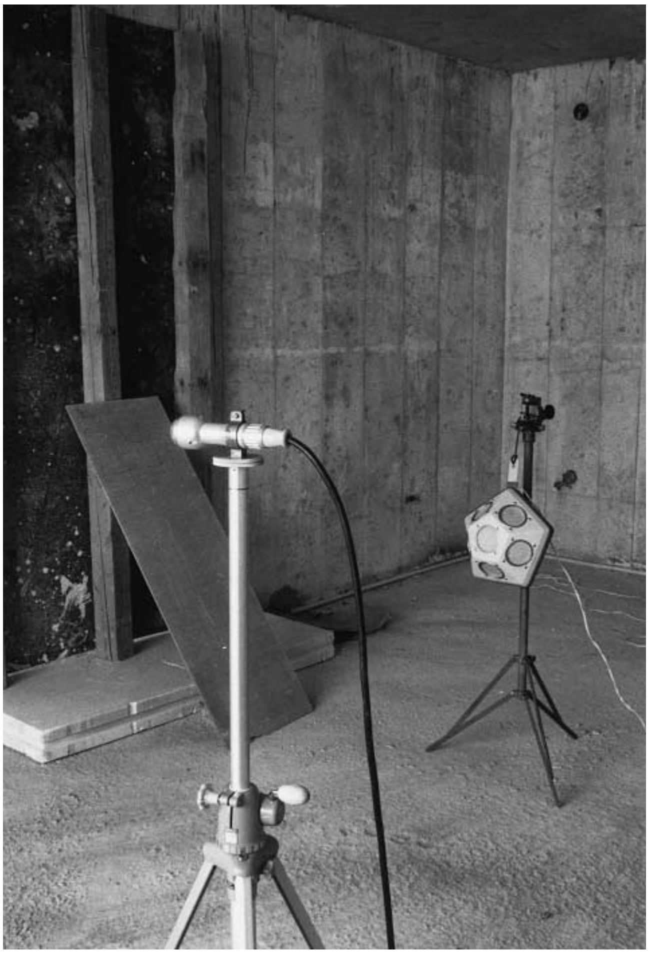

Fig. 8 Microphone for receiving impact noise generated in the room above and loudspeaker as source for reverberation-time measurements.

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21920 January 1998

5 Building

Long-term performance, reliability under practice conditions in the construccion industrie

Styropor foam does not rot; and, if our instructions are observed, it is resistant to aging. These are facts that have been confirmed by independent experts and scientific institutes over many years of observation in all feasible applications that arise in the building trade.

Some of the terms that are encountered in this connection are defined below.

Aging

A material is said to age if its properties change under given natural ambient conditions despite the fact that the conditions of use lay within its performance limits. In this particular case, expectations with regard to performance and service life relate solely to the building trade. As a rule, aging becomes evident by failure or even by subsequent decomposition.

The reasons for these changes are the effects of ambient conditions, e.g. atmospheric oxygen, water, heat and light. The condition having greatest effect is radiation at the ultraviolet end of the spectrum. Many plastics may become brittle on exposure to ultraviolet radiation if they are not stabilized or protected from it. The method usually adopted for protecting insulation is to cover it with other materials when it is installed.

Aging and its consequences must be distinguished from premature damage or even destruction of a material by improper use, i.e. by exceeding its performance limits. An example is processing a material together with other substances that attack it (cf. “Performance limits”).

Rotting

Natural organic substances, e.g. rubber, wood, leather and textiles, may rot when exposed to moisture and atmospheric oxygen. However, synthetic organic materials, e.g. plastics, do not rot.

Styropor foam is immune to rot.

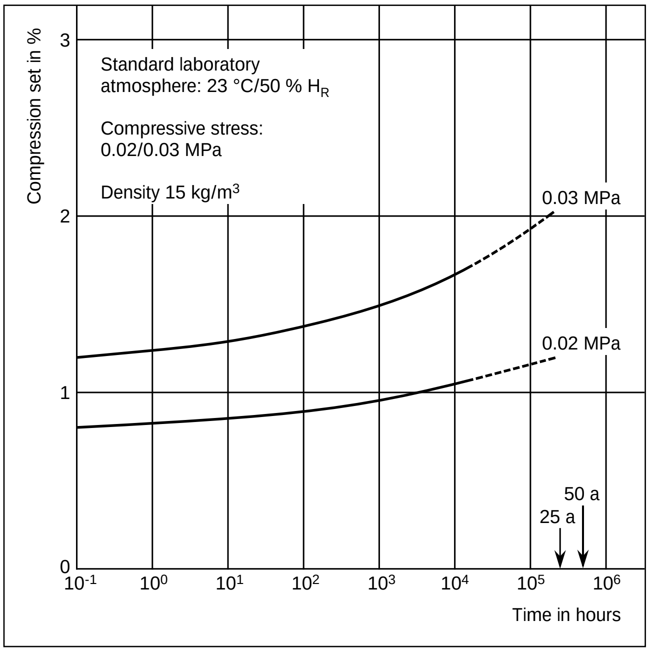
Fatigue

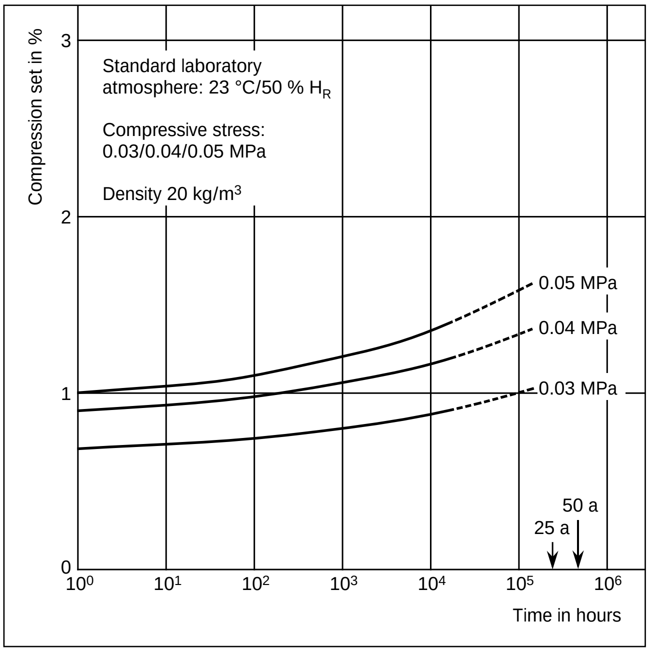
Fatigue is the failure of materials subjected to repeated cyclic loads. If rapidly alternating stresses are applied over long periods, an idea can be obtained of a material’s life under given conditions. Alternatively, it can be forecast whether a factor of safety is high enough for an intended application.

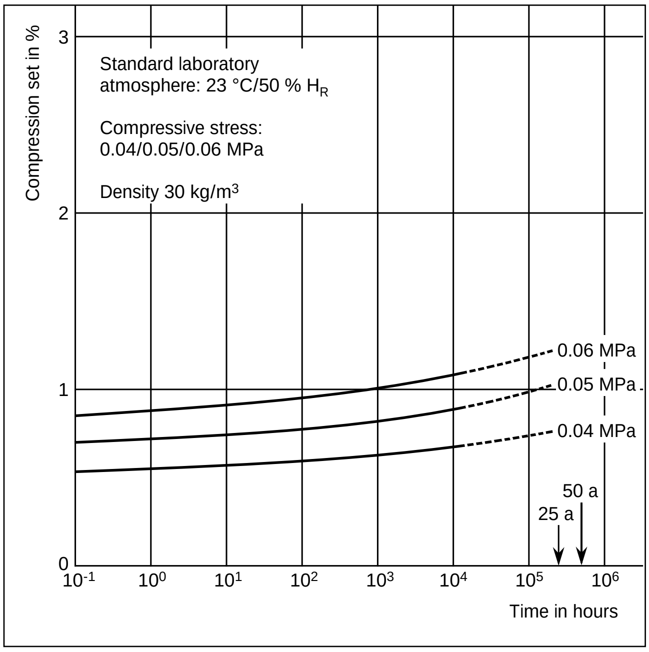
Wöhler tests under practical conditions on Styropor panels have revealed that fatigue does not occur under the normal conditions encountered in buildings, e.g. the stresses to which footfall-sound insulation is subjected.

The draft European standard “Thermal insulation for the building trade” describes a method for determining the compressive creep strength of insulating materials. It can be applied to estimate permissible loads in practice and/or to check the long-term performance of certain products subjected to compressive loads.

The calculation is based on the Findley equation. Thus the compressive set under defined conditions for any given length of time can be determined, but extrapolation is allowed only for a period not exceeding the duration of the test by a factor of more than 30 (cf. Diagrams 1– 3).







Diagrams 1 – 3 Creep curves for expanded polystyrene

Performance limits

The performance limits of a material are governed by its chemical and physical properties. The main factors concern its resistance to mechanical loads, heat, and chemicals. The corresponding properties of Styropor foam are described in detail in the Technical Information Bulletin TI 1-101.

Cement, lime, gypsum, anhydrite, and mortar modified by plastic dispersions do not have any effect on Styropor foam. As a consequence, Styropor can be installed together with all the conventional types of mortar, plaster and concrete encountered in the building trade, with the exception of mastic asphalt.

Styropor foam must be protected from protracted exposure to solar radiation. Empty spaces in which Styropor foam is exposed, e.g. behind cladding or in ventilated flat roofs, must be sealed to exclude the entry of mice and other rodents.

Styropor foam must not be exposed for long periods to temperatures higher than 95 °C and must not be allowed to come into contact with certain products that contain solvents. For instance, it is attacked by solvent-based cold bitumen, many surface coatings, paint thinners and their vapors, oily wood preservatives, and tar products (but not by bitumen). A particularly suitable adhesive in many applications, e.g. roofs and cold stores, is hot bitumen. It entails short-term exposure to temperatures above 100 °C, but this has practically no effect on the dimensional stability of the insulating material.

Evidence of resistance to aging

Practical trials performed by BASF

Laboratory studies often do not allow a definite conclusion to be drawn as to the long-term performance of materials under practical conditions that occur simultaneously but often cannot be simulated in the laboratory. For this reason, BASF have been running technical performance trials for several years under actual conditions in the field.

Numerous studies along these lines have been carried out on the application of Styropor foam in the building trade. The numerous buildings with flat roofs on the BASF production site provided the initial basis for these thermal insulation trials. Despite the severe exposure conditions, the insulation on all these roofs gave no grounds for complaint. No cases arose in which the Styropor foam failed or exhibited effects of aging.

Report on flat roof insulation after 31 years' service

One of the oldest applications of Styropor foam in buildings is the thermal insulation for a flat roof on a BASF Aktiengesellschaft factory building. The panels were laid in 1955 and were dismantled for inspection on 20 June, 1986, in the presence of an authenticated specialist at the request of the *Industrieverband Hartschaum e.V., Heidelberg* (German industrial association for rigid foam).

Visual inspection revealed that the joints between the individual insulating panels were still tightly sealed. No irreversible changes in dimensions were observed that could

Fig. 1 *Removing the roof covering to inspect Styropor foam panels that had been installed 31 years before. The joints between the panels were still sealed.*

Fig. 2 *Specimen taken from flat roof as shown in Fig. 1. No changes can be discerned in the Styropor*

have been caused by shrinkage or contraction. Likewise, there were no signs of any deformation or buckling that may have been caused by exposure to heat. The unreserved verdict given in the visual examination was that the Styropor foam panels were still in excellent condition.

Many samples of the thermal insulation taken during the course of the inspection were sent to a research institute in Munich (Forschungsinstitut für Wärmeschutz e.V. [Research institute for thermal insulation]) for determination of:
1. thermal conductivity
2. moisture content.

Results

1. The thermal conductivity, as determined by the DIN 52612 method, for a panel having a density of 17.4 kg/m^3 was 0.0345 W/mK (Test report F.2-351/86 dated 16 October 1986). This figure conforms to the German standard on thermal insulation in buildings (DIN 4108), in which the calculated value is 0.04 W/mK.

2. The volume fraction of water in panels of 20 kg/m^3 density was 0.02%.

The results of other tests also verified that the performance of Styropor foam panels remained absolutely unimpaired after 31 years of service and still satisfied the requirements laid down in the German standard on “Foamed plastics as insulating building materials” (DIN 18164, Part 1).

Studies by officially recognized test institutes

The practical experience gained on buildings in the BASF production site was supplemented by the results of studies on numerous other buildings in which Styropor foam panels had been installed many years before. In all cases, the test institutes and consultants entrusted with the studies verified that the condition of Styropor foam panels did not undergo any percep-

Fig. 3 *Taking a sample of Styropor from an outdoor composite insulating system consisting of Styropor and a fabric-reinforced textured finish.*

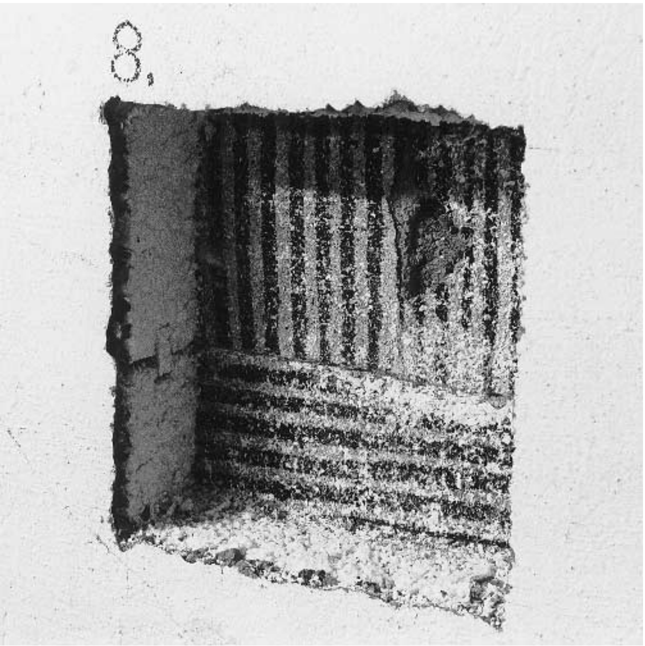


Fig. 4 *Styropor foam panels in the outer wall of a fruit warehouse*

Length of exposure	*10 years*
Density	*14.9 kg/m^3*
Moisture content	*0.021 vol.-%*

Make-up of wall from the inside to the outside:

Cement mortar plaster	*1 : 3*
Styropor P foam	*100 mm*
Normal concrete	*400 mm*

tible change nor did the property suffer any deterioration even after more than 20 years of service. The panels still conformed to the requirements of DIN 18164 Part 1 after this period of time (Fig. 5). The moisture content of the foamed plastic insulation in all the structures tested in residential and factory buildings was less than the value considered to be acceptable in practice, viz. 0.1% expressed in terms of volume.

A particularly interesting comprehensive study concerned outdoor composite insulation systems containing Styropor panels. It was carried out by the Holzkirchen branch of the Fraunhofer Institute of Physics. The long-term performance of thermal insulation was determined in 93 buildings that were selected from a list of manufacturers.

The criteria adopted in selecting the 93 buildings were the conditions to which the insulating systems were exposed and which arose from the geographical location, the altitude, the type of building, and differences in age. At the time of the study, i.e. 1974 –1976, the most frequent age of the outdoor composite insulating system was 3 – 4 years, but some were as many as 16 years old. Almost all the buildings were undamaged. Specific instances of damage were observed in only three of the 93 cases investigated. However, these were ascribed to errors in laying and not to the insulating system itself. In all cases, the Styropor foam panels remained dimensionally stable and completely retained their functions. In some of the random samples taken the moisture content was very low, i.e. less than 0.05% by volume.

In 1983, a further study was carried on the same buildings by the same institute. The aim was to gain information further to that obtained in the previous tests on the long-term performance of the outdoor composite insulating system containing Styropor foam.

It was possible to determine the effect of a further eight years of outdoor exposure on the insulating material and the protective layer of fabric-reinforced textured finish.

In the institute's report, it was stated that only 20% of the buildings investigated had been renovated but that the work concerned was confined almost exclusively to renewing the coats of textured finish for aesthetic reasons. The average age of the composite systems before these fresh coats of textured finish were applied was 11 years. It is thus safe to assume that the time that elapses before renewal work is required is comparable to that required in renewing a mineral plaster and paint, viz. 10 – 25 years*.

The report stated that the moisture content of the expanded polystyrene insulating board was subcritical, i.e. 0.06 vol.-% at most. Thus the results obtained after a further eight years' exposure confirm the evaluation given in the previous study to the effect that composite thermal insulating systems consisting of Styropor panels and textured finishes represent a practicable and reliable means for the efficient thermal insulation of outdoor walls.

Practical experience gained with Styropor foam in earthworks and foundations

The features of closed-cell Styropor foam are great stability and durability, immunity to moisture and soil organisms, and biological neutrality, i.e. no threat to groundwater. They have been convincingly verified by the experience gained in earthworks and foundations.

Since the mid-1960s, Styropor foam has provided excellent frost protection in foundations, pipeline systems, and the substructures of roads and railroads (Fig. 6). The relevant construction techniques are standard practice in Scandinavian countries with severe winters and deep ground frost. The experience gained gave rise to a new construction method that was developed in Norway in 1972 and has since been successfully adopted in other countries.

Substructures consisting of Styropor blockware allow loads to be evenly distributed under causeways and bridges in regions with poor load-bearing soil (Fig. 7). The height to which the Styropor blocks are stacked may be as much as eight meters, and their permanent compressive strength permits pressure to be evenly distributed over marshy soils. A lightweight embankment of this nature prevents the road structure from subsiding and forming potholes, particularly in critical access zones at structures with deep foundations, e.g. bridges (cf. Technical Information Bulletin TI 800).

The many years of positive experience represent a reliable source of information on the resistance to aging and long-term performance of Styropor foam and formed the basis upon which many countries accepted and adopted this road construction technique.

Langzeitbewährung von Styropor

Sonderdruck aus „DBZ", Juni 1976

Überprüfung von Außendämmsystemen mit 'Styropor-Hartschaumpl

Styropor-Kerndämmplatt für zweischaliges Mauerwerk ohne Luftschicht

GUTACHTEN

STYROPOR

Fig. 5 *Test reports on the long-term performance of Styropor foam in various applications in the building trade.*

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* *Figures submitted by Professor Künzel, Institut für Bauphysik der Fraunhofer Gesellschaft e.V.*

Fig. 6 Styropor foam board for frost protection in road construction. Samples taken 11 years after installation. The Styropor foam panels were in the same condition as when installed.

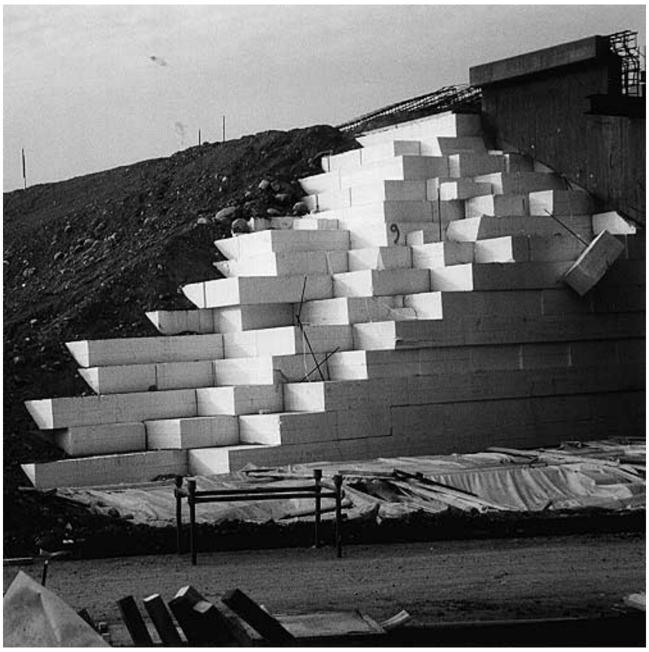

Fig. 7 Styropor blockware in the construction of causeways and bridge ramps in regions with poor load-bearing soils (European Highway E6, Ljungskile, Sweden).

Resistance to aging of low-flammability Styropor foam panels

The sustained effectiveness of the flame retardant system in Styropor F foam has been verified by fire tests performed by the official German center for materials testing*. The test certificate states that the flame retardance of Styropor F specimens did not deteriorate after 7 1/2 years (about 4 years in a standard laboratory atmosphere of 20 °C and 65 % relative humidity, as defined in DIN 50014, followed by about 3 1/2 years under a roof but exposed to outdoor conditions). The summary of the results given in Table 5 of the certificate demonstrates that the foamed plastic conforms to the demands imposed on poorly combustible (low flame spread) building materials. A copy of the test certificate BAM No. 2.41/14271 will be sent on request.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Styropor®

28750 October 1994

5 Building

Fruit stores

Insulating fruit stores with rigid cellular material made from Styropor

Geographically enlarged markets and the changing shopping habits of consumers necessarily present new problems, and these also affect the storage of fruit.

Fruit stores hold the new crop from the time it is harvested to the time it is marketed, keeping it fresh under appropriate conditions so that it can be sold in or out of season. For instance, locally grown apples can easily be kept until the next harvest.

The effort that has to be put into storage depends on how long the fruit is to be kept. In the northern hemisphere, the traditional large demand for fruit at Christmastide can be met largely by storage at reduced temperature but in a normal atmosphere, whereas fruit to be sold in spring and summer needs to be kept in a special, artificially maintained atmosphere.

1 Storage buildings

The overall concept of the building design depends on the quantity and kind of fruit to be stored, how things are to be run, and the storage conditions.

The quantity of fruit largely determines the size of the store, but at the planning stage it is necessary to consider too what changes may take place over the years. Controlled-atmosphere (CA) storage in particular necessitates individual cells, and the sizes of these depend on how much fruit can be placed on the market at a time, since once a CA cell is opened it must be cleared as quickly as possible.

Cells holding 100 – 400 tons of fruit are usual, but some stores have cells with a capacity of 1000 tons or more. At the other end of the scale, the minimum economic capacity is 10 000 kg (10 tons).

In their own stores, producers commonly stack fruit boxes up to 5 m high, without palletizing them. Other organizations place the 20-kg boxes on 1.2-m^2 pallets, 24 or preferably 30 to a pallet, and stack the pallets up to five high. An additional 1-m headroom is needed for the cooling units and air circulation.

Doors are dimensioned to allow the passage of fork-lift trucks, and the gangways must be too, with additional space for working. A 100-ton store might have 67 m^2 for storage and 18 m^2 for movement; for a 400-ton store only 160 m^2 might be needed for storage, but another 40 m^2 or so would have to be allowed for movement.

Where fruit has to be prepared and sorted, this should be done in a well-lit area accessible from outside and adjacent to the storage areas. A practical arrangement used for many purpose-built stores has a preparation and sorting room against an outside wall, with climatized storage cells on either side of it (as in Fig. 1) or behind (as in Fig. 5).

All types of fruit store require air conditioning, which is generally fully automatic. The necessary cooling and humidifying units and fans are suspended below the ceiling and are arranged to ensure uniform conditions throughout the room. The compressors, air-treatment equipment, etc. are located in a separate machine room.

The orientation of the building is of minor importance as far as climatization is concerned, since the effects of even prolonged sunshine can be countered without much expense, for instance by slightly increasing the thickness of the insulation.

To avoid pressure differences of more than about 1 hPa between CA storage cells and the outdoor atmosphere, these cells are provided with both air inlets and vents that are normally closed by water traps or loaded flaps. If this were not done, there would be a considerable reduction in inside pressure on cooling the sealed cell.

Small stores used by growers can often be installed in existing farm buildings; barns in particular usually afford the headroom desired. Large stores, particularly those employing controlled atmospheres, need to be designed and built for the purpose.

2 Types of storage

The two main types of storage differ in the composition of the atmosphere maintained in them: normal or artificially controlled. Controlled-atmosphere (CA) stores are of one of two sub-types:

- carbon dioxide stores
- scrubber stores.

In all stores the aim is improve keeping by slowing down post-harvest ripening. The fruit is cooled, according to a preset program, from ambient temperature (perhaps in the region of 25 °C) to the best storage temperature, which is between –1 °C and 6 °C, depending on the cultivar concerned. The relative humidity must be controlled at a value between 85 % and 96 %, to prevent condensation while avoiding evaporation (apples and pears shrivel visibly if they lose only 4 % of their mass).

Normal-atmosphere storage

Normal-atmosphere storage is simplest. North of the equator it is used for keeping apples to be sold at any time until Christmas. The apples are cooled to a temperature of 0 – 2.5 °C over a period of 2 – 6 weeks, relative humidity being kept at 90 – 93 %. In this way they keep for up to 5 – 6 months.

Since a normal-atmosphere store may be opened intermittently, just part of its contents can be withdrawn at a time. Provided fresh air is admitted, and temperature and humidity are controlled, the fruit keeps well enough.

Controlled-atmosphere storage

In CA stores, the composition of the atmosphere is regulated as well as temperature and relative humidity. Fruit of the right varieties can be kept in them until the next season. They have to be made practically gastight, to allow keeping the gas composition different from that of air (more carbon dioxide, less oxygen), so provision must be made for pressure equilibration while the cell is being cooled, otherwise the pressure drop would be considerable.

It is not practicable to remove just part of the fruit from a CA cell, on the grounds of both the cost of restoring the atmosphere and of loss in quality of the remaining fruit: once the cell is opened, it must be cleared of its contents.

Carbon dioxide stores

Even after fruit has been harvested, metabolic processes continue. These entail consumption of oxygen and emission of carbon dioxide. In an airtight cell filled to capacity, the volume fraction of carbon dioxide in the air increases to 3 – 4 % within three or four days, and the volume fraction of oxygen decreases accordingly. Since the volume of carbon dioxide formed is the same as that of the oxygen consumed, the volume fraction of the two gases together remains at its normal value, 21 %.

The carbon dioxide content is not allowed to increase beyond 8 %: over the remainder of the storage period, which may be as much as 7 – 8 months for some varieties of fruit, air is admitted in controlled quantities.

Some varieties of apple in particular cannot tolerate very high concentrations of carbon dioxide. For keeping such sensitive fruit, scrubber stores are used.

Scrubber stores

The scrubber is the apparatus in which carbon dioxide is stripped from the air by chemical absorption. How and why it is used is explained below.

Although cooling reduces the rate of metabolic changes in fruit, and an atmospheric carbon dioxide content higher than normal reduces it somewhat more, a further reduction can be obtained only by lowering the oxygen content substantially. In a carbon dioxide store, increasing the carbon dioxide content to 7 % still leaves an oxygen content of 14 %. In a scrubber store, the aim is to increase the volume fraction of carbon dioxide to 3 – 3.5 % and to reduce that of oxygen to 1.5 – 3 %. There is then just enough oxygen to maintain maturing processes, while the carbon dioxide concentration is not high enough to affect less tolerant varieties of fruit adversely. Apples can be kept for about four weeks longer than in a carbon dioxide store.

Producing and maintaining the right gas mix in a scrubber store entails the use of more or less elaborate techniques to remove the excess carbon dioxide:

- chemical absorption by potassium carbonate standing in the store;
- chemical absorption by scrubbing with potassium carbonate solution (which can be regenerated);
- selective adsorption by passing the air over active charcoal (which can be regenerated);
- selective permeation through thin plastics membranes – carbon dioxide passes through faster.

Each of these methods has its merits, which must be weighed from case to case.

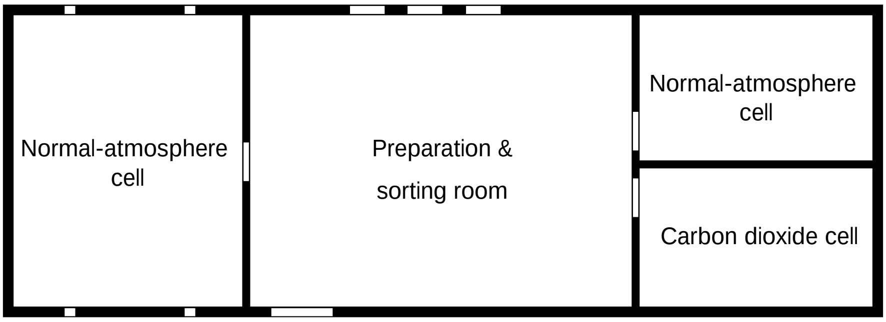

Fig. 1 Suggested layout for fruit stores

In both carbon dioxide and scrubber stores it is desirable to establish the required atmosphere and temperature as soon as possible after the fruit has been brought in. The rate of cooling is restricted, since the capacity of the refrigerating plant is necessarily modest, but both enrichment with carbon dioxide and depletion of oxygen can be accelerated initially. How effectively this is done depends to a great extent on the gastightness of the cell.

Mobile deoxygenators remove oxygen from the air by catalytic oxidation of a hydrocarbon. The exhaust gas, in which much of the oxygen is replaced by carbon dioxide and water, is filtered, humidified, and either discharged direct (in a carbon dioxide cell) or after scrubbing to remove carbon dioxide (in a scrubber cell). These deoxygenators are run until the required conditions are established.

If the capacity of the storage cell is 800 tons or more, it may be economic to flush with nitrogen from cylinders to reduce the oxygen content. Since the nitrogen may be assumed to mix with the air, the volume required is about twice the cell volume.

Carbon dioxide and oxygen contents can be determined with Orsat apparatus for volumetric gas analysis, but process analysers that can be used for control purposes are available for both compounds. These can be used to regulate the operation of deoxygenators, carbon dioxide scrubbers, etc.

3 Thermal insulation

To keep a fruit store at a temperature between –1 °C and 6 °C, refrigeration is needed. Since removing heat costs several times as much as producing it, effective thermal insulation is essential. The values of the thermal transmittance, U, should not be appreciably greater than 0.45 $W \cdot m^{-2} \cdot K^{-1}$ for outside walls, 0.35 $W \cdot m^{-2} \cdot K^{-1}$ for the ceiling, and 0.80 $W \cdot m^{-2} \cdot K^{-1}$ for the floor.

Table 1 gives a number of wall constructions that satisfy or exceed the minimum requirement when Styropor board is used for insulation. The thermal resistance and transmittance values shown are based on design values of 40 $mW \cdot m^{-1} \cdot K^{-1}$ for the thermal conductivity of Styropor board and 0.16 $m^2 \cdot K \cdot W^{-1}$ for the sum of the internal and external surface resistances.

The diffusion of water vapour through the enclosing elements of fruit stores – particularly walls and ceilings – must of course be considered.

Normal-atmosphere cells offer the least difficulty, since there the risk of condensation in the structure is comparatively slight, for several reasons:

– the storage period commonly extends from just after a warm period to a cooler one (e.g. from early autumn to December in northern Europe), when there are no extreme differences between outside and inside temperatures;
– during this time the direction of the vapour-pressure gradient (which depends on both the temperatures and relative humidities outside and inside) tends to change a number of times;
– moisture that may accumulate during the summer months, while the store is not in use, will certainly evaporate.

For these reasons, normal-atmosphere cells are not surrounded by vapour barriers. On the contrary: it is desirable to use construction materials that offer little resistance to the passage of water vapour.

CA cells, which have to have effective barriers to the passage of gases, are another matter. The gas barrier, consisting of sheet aluminium, aluminium foil laminated to polyethylene, polyester sheet, or even a special sprayed coating, is normally placed on the inside. But during warmer weather, when a CA cell is likely to be in use, the potential movement of water vapour is from the outside, where an additional barrier against water vapour must be provided. Both the inside and the outside barriers must prevent the passage of water vapour very effectively, otherwise water can condense in the insulation.

An alternative arrangement has proved effective in practice. A single barrier that is impermeable to both water vapour and permanent gases is placed outside the insulation. Water vapour can diffuse into the insulation from inside, but since the temperature gradient is unlikely to be such as to promote this (i.e. fall from inside to outside), only small quantities of moisture can be involved, and these can evaporate when the cell is opened.

Because storage cells need to be gastight, conditions are more complicated than in cold stores, although there the temperature differences are much more extreme.

Cold stores usually have ventilated roofs (cold roofs) of lightweight construction. The current of air between the insulated ceiling and roofing above it removes any moisture that diffuses out through the insulation of normal-atmosphere cells. If adequate openings are left at the eaves and formed near the ridge, convection usually provides sufficient air flow, but it is helpful to site the building so that its ridge lies across the direction of the prevailing wind.

The ceiling joists are unlikely to be even enough to allow the Styropor board to be fastened to them direct, so crosswise battens are nailed underneath, at distances to suit the size of the board. The total thickness of insulation needs to be about 120 mm, but this may be made up of two layers of Styropor board arranged to break joint. The upper layer, which should be no thicker than 50 mm, is fixed to the battens, which are previously coated with adhesive, with felt nails.

For suspended ceilings, the usual commercial metal hangers and runners may be used. Two layers of Styropor board can be used, in which case the upper layer is fixed to the runners and the lower layer is bonded to it with adhesive.

Wherever the surfaces of insulation are exposed, it is advisable to protect them from rodents by a covering of expanded metal or 5-mm woven wire mesh.

4 Styropor insulation

Description

Expanded Styropor is an extremely good thermal insulant, ideally suited to the insulation of fruit stores. The thermal conductivity of the Styropor board used for building insulation is 30 – 37 $mW \cdot m^{-1} \cdot K^{-1}$, but BASF usually quotes the design values of 40 $mW \cdot m^{-1} \cdot K^{-1}$ or 35 $mW \cdot m^{-1} \cdot K^{-1}$ (depending on the grade) currently given in DIN 4108 Part 4. The higher design values provide an ample safety margin.

Values summarizing some of the physical properties of Styropor board are given in Table 2. More generally, it is a material unaffected by most of the substances encountered in building, including Portland cement, lime, gypsum, polymer dispersions, and mortars made out of any combination of these. It can even be laid in hot bitumen.

Styropor board cannot rot, and when properly used it is not subject to aging; its long service life is well established through many years of use as an insulant for floors, walls, and roofs. Styropor board is a particularly convenient material to use, being exceptionally light, easy to cut and shape with simple tools, and non-irritant. It is also one of the most cost-effective insulants available.

For both cold stores and fruit stores, self-extinguishing Styropor board of density 15 kg/m^3 or 20 kg/m^3 is most commonly used.

Application

Styropor board can be fixed with felt nails, adhesives, or beading, depending on the background. It bonds to fresh concrete if is placed in the form, but additional fixing with plastic spikes having extra broad heads and barbed shanks is advisable. On flat absorbent surfaces Styropor board can be fixed with cold-curing adhesives based on polymer dispersions. For rougher surfaces, such as brickwork, a trowelling adhesive based on fine Portland cement and a polymer dispersion should be used.

Typical constructions for fruit stores in which Styropor board is used for thermal insulation are shown in Fig. 2 – 4.

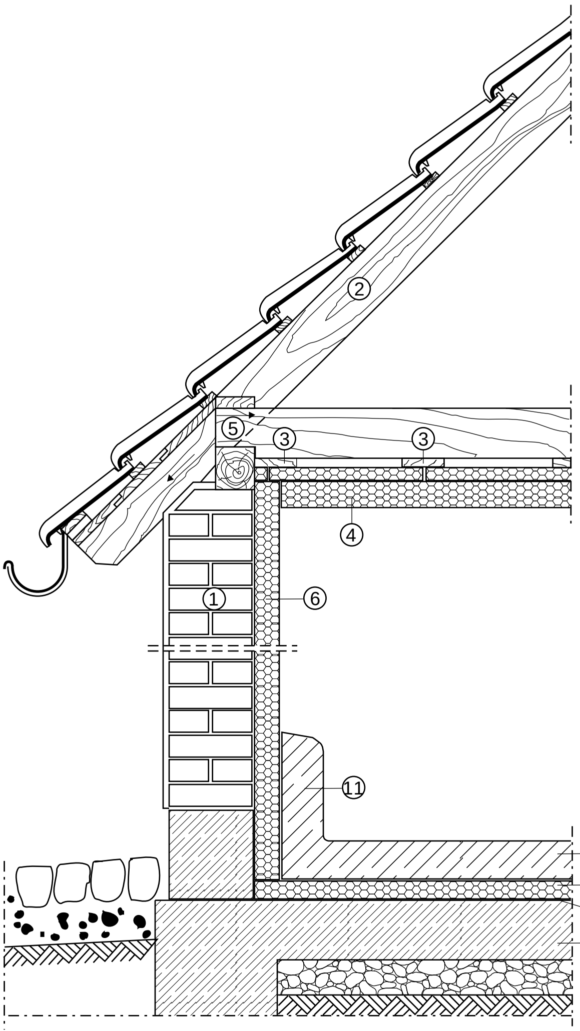

Fig. 2 Insulated store: conventional construction

1 Brickwork
2 Tiled roof
3 Battens
4 Styropor F panels of type PS 20 SE (flameproof, two layers)
5 Fine wire mesh to exclude vermin
6 Styropor F panels of type PS 20 SE (flameproof)
7 Concrete raft foundation
8 Damp-proof membrane
9 Styropor board covered with plastic sheet
10 Concrete screed
11 Concrete skirting

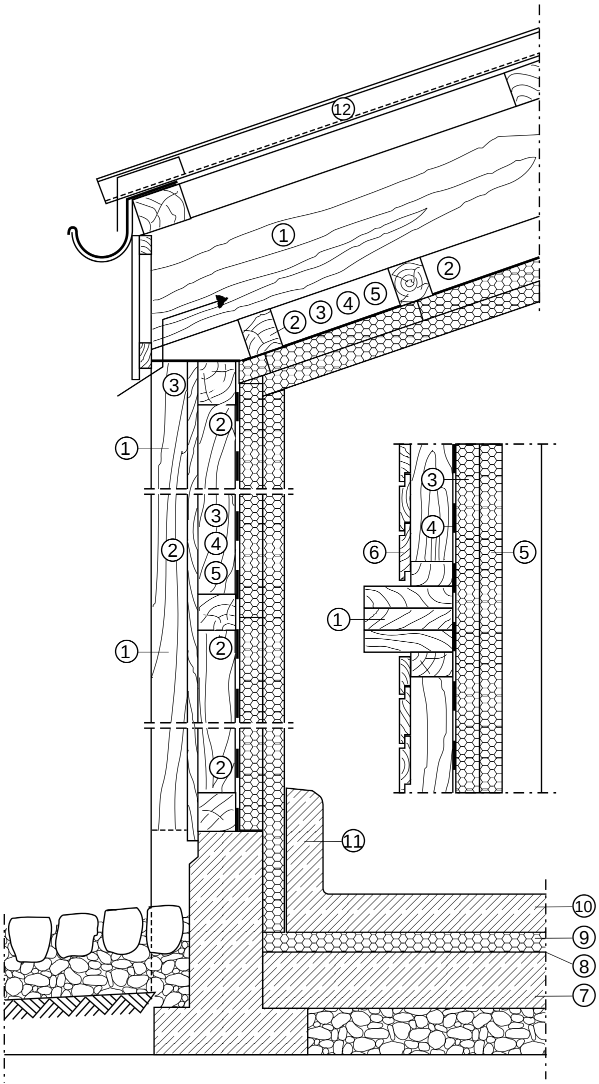

Fig. 3 Insulated store: prefabricated construction

1 Wooden trusses with ventilation cavity
2 Timber cross-pieces
3 Fine wire mesh to exclude vermin
4 Vapor barrier
5 Styropor F panels of type PS 15 SE (flameproof, two layers)
6 Boarding
7 Concrete foundation
8 Combined damp-proof membrane & vapor barrier
9 Styropor board covered with plastic sheet
10 Concrete screed
11 Concrete skirting
12 Corrugated asbestos cement

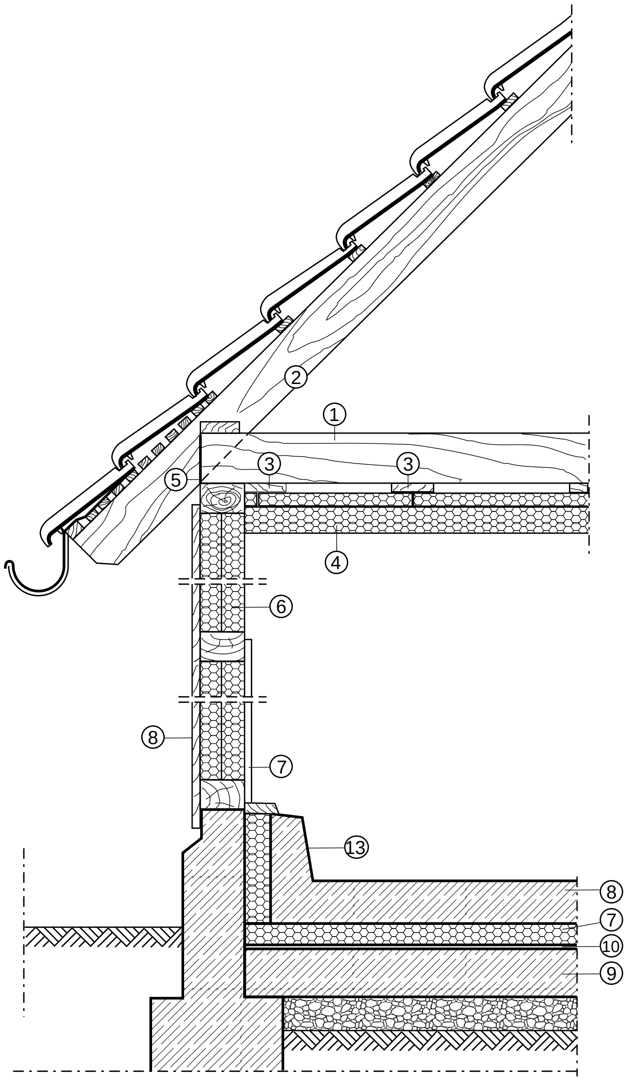

Fig. 4 Insulated store: simple timber construction

1 *Ceiling joist*
2 *Tiled proof*
3 *Battens*
4 *Styropor F panels of type 15 SE (flameproof, two layers)*
5 *Fine wire mesh to exclude vermin*
6 *Styropor F panels of type 15 SE (flameproof, two layers, filling frame)*
7 *Hardboard wall lining*
8 *Boarding*
9 *Concrete foundation*
10 *Damp-proof membrane*
11 *Styropor board covered with plastic sheet*
12 *Concrete screed*
13 *Concrete skirting*

Table 1 Thermal resistance *R* and thermal transmittance *U* of common wall constructions (thermal conductivity of Styropor board 40 $\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$; total surface resistance 0.16 $\mathrm{m^2 \cdot K \cdot W^{-1}}$)

Ser.	Construction	*d*/mm	*R*/$\mathrm{m^2 \cdot K \cdot W^{-1}}$	*U*/$\mathrm{W \cdot m^{-2} \cdot K^{-1}}$
1	240-mm brickwork (solid fired-clay, 1800 kg/m^3), plastered & rendered; Styropor board, thickness *d*	0 70 100	0.34 2.09 2.84	2.00 0.44 0.33
2	115-mm brickwork (solid fired-clay, 1200 kg/m^3), plastered & rendered; Styropor board, thickness *d*	0 70 90	0.26 2.01 2.51	2.38 0.46 0.37
3	240-mm solid blockwork (lightweight concrete, 1400 kg/m^3), plastered & rendered; Styropor board, thickness *d*	0 70 100	0.42 2.17 2.92	1.72 0.43 0.32
4	240-mm brickwork (solid sand-lime, 1800 kg/m^3), plastered & rendered; Styropor board, thickness *d*	0 70 100	0.28 2.03 2.78	2.27 0.46 0.34
5	240-mm dense concrete (2400 kg/m^3) rendered externally; Styropor board, thickness *d*	0 80 100	0.15 2.15 2.65	3.22 0.43 0.36
6	115-mm dense concrete (2400 kg/m^3), rendered externally; Styropor board, thickness *d*	0 80 100	0.09 2.09 2.59	4.00 0.44 0.36
7	Wood framing, outside boarding; Styropor board (infill), thickness *d*	0 120	0.17 3.17	3.03 0.30

Table 1 Physical data for foams made from Styropor for construccion

Properties[1)]	Test standard	Unit	Test result		
Quality assured types	GSH quality conditions		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18 164, Part 1		W	WD	WD + WS
Minimum bulk density	EN ISO 845	kg/m^3	15	20	30
Building material class	DIN 4102		Poorly B 1 flammable	Poorly B 1 flammable	Poorly flammable
Thermal conductivity					
Measured value at + 10 °C	DIN 52 612	mW/(m · K)	36–38	33–35	31–34
Calculated value according to	DIN 4108	mW/(m · K)	40	40	35
Compressive stress at 10 % compressive strain	EN 826	kPa	65–100	110–140	200–250
Resistance to sustained compressive loads at < 2% strain after 50 years	ISO 785	kPa	20–30	35–50	70–90
Flexural strength	EN 12 089	kPa	150–230	250–310	430–490
Shear strength	DIN 53 427	kPa	80–130	120–170	210–260
Tensile strength	DIN 53 430	kPa	160–260	230–330	380–480
Modulus of elasticity (compressive test)	EN 826	MPa	1.0–4.0	3.5–4.5	7.5–11.0
Heat deformation temperature					
short-term	based on DIN 53 424	°C	100	100	100
long-term at 50 kPa		°C	75	80	80
long-term at 20 kPa		°C	75	80	80
Coefficient of linear expansion		1/K	$5–7 \cdot 10^{-5}$	$5–7 \cdot 10^{-5}$	$5–7 \cdot 10^{-5}$
Specific heat capacity	DIN 53 765	J/(kg · K)	1210	1210	1210
Water absorption when submerged (by volume)					
after 7 days	DIN 53 434	Vol. %	0.5–1.2	0.5–1.5	0.5–1.5
after 28 days		Vol. %	1.0–3.0	1.0–3.0	1.0–3.0
Water vapor diffusion rate	DIN 52 615	g/(m^2 · d)	40	35	20
Water vapor diffusion resistance factor	Calculated according to DIN 4108, Part 4	1	20/50	30/70	40/100

** 1 N/mm² ≙ 1 MPa*

[1)] Corresponding to Testnorm

Fig. 5 A normal-atmosphere store built from prefabricated units

Fig. 6 Cooled normal-atmosphere storage cell

Fig. 7 Sorting and preparation area

Fig. 8 Stacking fruit by hand in a cooled cell

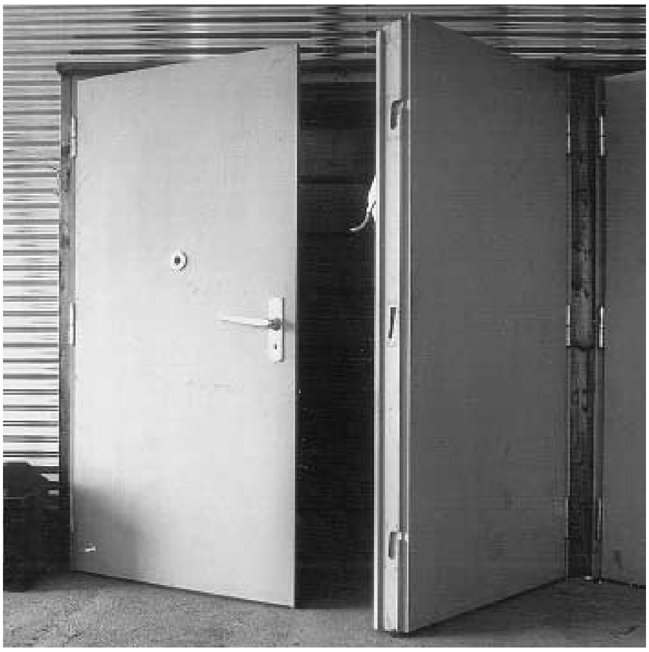

Fig. 9 Airtight doors of a CA cell, filled with expanded Styropor

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46439 July 1991

5 Building

Cold storage cells

Cold stores have become indispensable for storing foodstuffs. By the use of refrigerating systems stores can be maintained at constant temperatures, even when outside temperatures are very much higher, allowing food to be kept in prime condition for long periods. Larger stores are generally in buildings constructed for the purpose, but the much smaller stores required by caterers, retail grocers, butchers, etc. can be more economically incorporated in existing buildings. For these smaller stores it is frequently convenient to use cold cells, which are sectional or portable cold rooms largely assembled from factory-made units.

The refrigerating duty of plant used for any cold store is the sum of the maximum product load and the maximum service load. The product load is the rate at which heat must be removed from the stored goods, and is determined by the temperature of the store, the temperature of the product on entry, and the thermal capacity of the product entering. The service load is the rate at which heat resulting from normal use of the store must be removed. Common predictable contributors to the service load are fans and heaters for defrosting; intermittent sources for which an arbitrary allowance (usually 15 – 20 %) must be made include lighting, air admitted when the doors are open, mechanical-handling equipment, and body heat from people employed in the store. The third type of heat source is that which flows through the fabric of the store from the outside; it is always the largest contributor to the total load.

The entry of heat through the fabric can be slowed by the use of an insulant with high resistivity, such as expanded Styropor. This material

Temperature inside the cold store °C	Thickness of the insulating material in cm +10 °C*	For an ambient temperature of +20 °C**
+ 5	10	14
0	12	16
– 5	14	18
– 10	16	20
– 15	18	22
– 20	20	24
– 25	22	26
– 30	24	28

** Central European outdoor annual average.*

*** Annual average ambient temperature in hotter climates or where rooms adjacent to the coldstore are heated during the colder months of the year.*

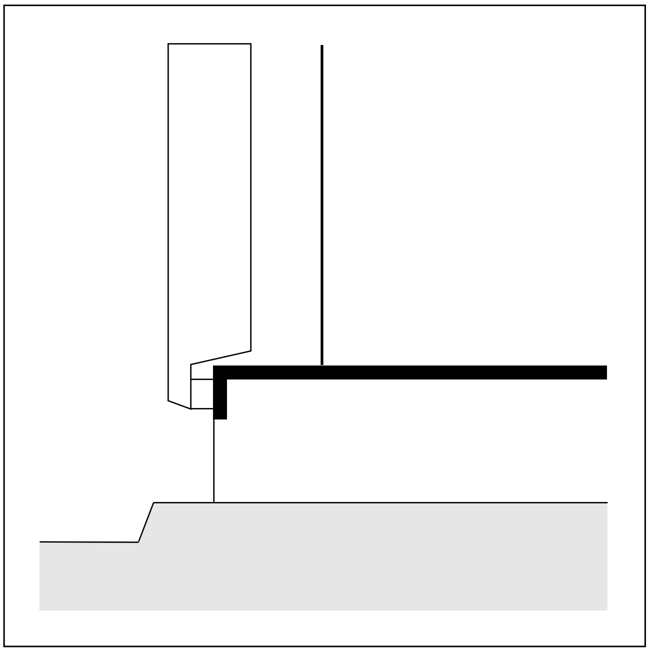

Fig. 1 Cold cell on raised base

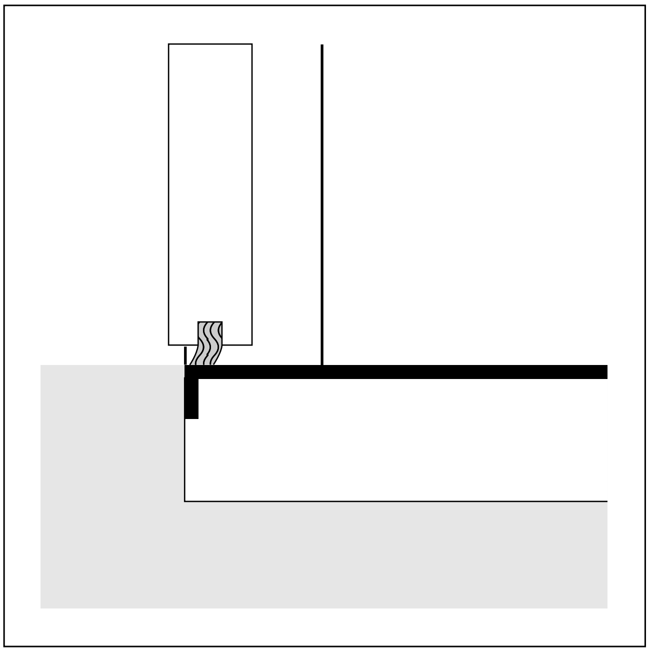

Fig. 2 Cold cell on sunken base

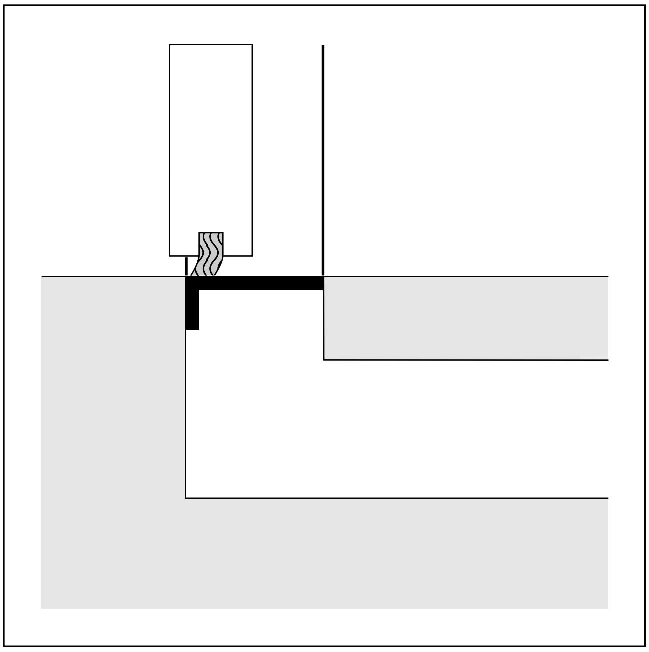

Fig. 3 Cold cell with flush concrete-slab floor

Fig. 4 A typical cold cell in use

has proved its value over many years, and is used in cold stores for insulating both the fabric and the lines for the cooling medium. It has been found that the thickness of expanded Styropor required for insulating the fabric of the store is given by

$$d = (4\ \mathrm{mm/K})\ ([\vartheta_o] + 20\ \mathrm{K} - \vartheta_i),$$

where $[\vartheta_o]$ is the annual mean Celsius temperature outside the store and ϑ_i is the operating temperature within the store. This empirical equation is based on the assumptions that the rate of entry of heat through the fabric should not exceed 9 W/m^2, the thermal conductivity of expanded Styropor at the highest temperatures is not more than 36 mW/m·K, and that the outside temperature will seldom exceed the annual mean by more than 20 K. The last assumption is valid for conditions in central Europe (annual mean ~10 °C), and is adequate for many other parts of the world, but there are also many places where summer temperatures frequently exceed the annual mean by more than 30 K (e.g. Winnipeg) or seldom exceed it by 10 K (e.g. Port Darwin).

Cold cells are normally used for intermediate storage, and they must be designed to facilitate frequent

Fig. 5

access and allow easy cleaning. They should be readily constructed in a variety of sizes, which is possible if modular sections are used. Fig.1 illustrates a typical cold cell in use, and Fig. 2 shows some of the details of sectional cells. The sections can be made from expanded Styropor faced with glass-fibre-reinforced polyester sheet, sheet metal, or other material; they are fitted together by means of special fastenings that ensure tight joints. The thickness of the expanded Styropor cores can be adjusted to meet any insulation requirements. Doors and hatches can be built in as required.

Cold cells are constructed on a prepared base whose form is determined largely by the way in which goods are transported into and out of the cell. Fig. 3 shows the least convenient form of base as far as access is concerned, but it may be impossible to form a sunken base in the floor of the building. Fig. 4 shows a construction allowing the door sill of the cell to be flush with the floor of the building. Cold cells are commonly provided with rigid aluminium floors, but other floors or flooring can be used. Fig. 5 shows a construction which provides for a concrete floor slab over the insulation, allowing the use of heavy mechanical handling equipment.

Cold cells should not be placed next to rooms with unusually high temperatures, e.g. bakehouses or drying rooms. Areas with very high absolute humidity should also be avoided. If the building containing the cold cell is heated for much of the year it is advisable to increase the insulation thickness to reduce average running costs. It has been found generally satisfactory to use the insulation thickness corresponding to a mean annual outside temperature of 20 °C, i.e.

$d = (4\ \text{mm/K})\ (40\ °\text{C} - \vartheta_i)$.

Note

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BASF

28209 July 1994

5 Building

Reinforced concrete bulk-storage units

Modern day rates of production and consumption make it necessary to store all types of raw materials in bulk. However, warehouse storage of large quantities of liquid or dry-bulk materials is uneconomical. The optimum solution is to use large silos able to support the weight of the contents, and which provide for efficient filling and discharge. These silos are usually built of reinforced concrete.

Silos where sensitive goods are stored must be able to maintain a constant temperature and humidity to prevent damage to the contents. This is achieved by providing the silos with additional thermal insulation. The insulation should be applied to the outside of the silo to simplify the design and avoid the problem of compressive forces exerted on the insulation by the contents. Over the years Styropor foam insulating board covered with a fabric-reinforced dispersion-based rendering has established an outstanding performance record. What follows are a few typical examples of many that show how Styropor can be employed in silo/bulk-storage construction.

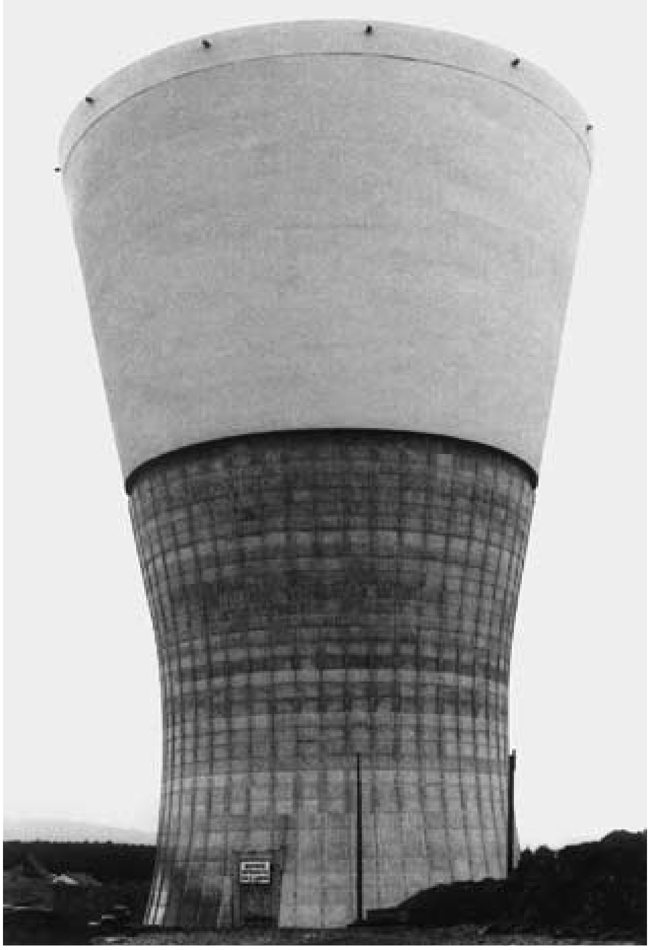

Fig. 1: Not a silo, but a 2.4 million litre capacity water tower. The reservoir section of the tower has been insulated with 100-mm-thick Styropor foam board.

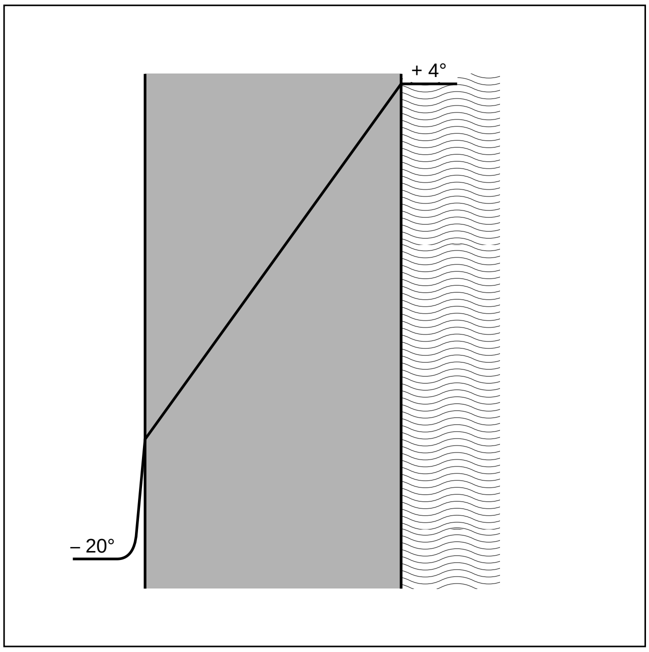

Fig. 2 : Temperature profile in the wall of an uninsulated water tower. The mean temperature of the concrete wall falls as low as –5 °C.

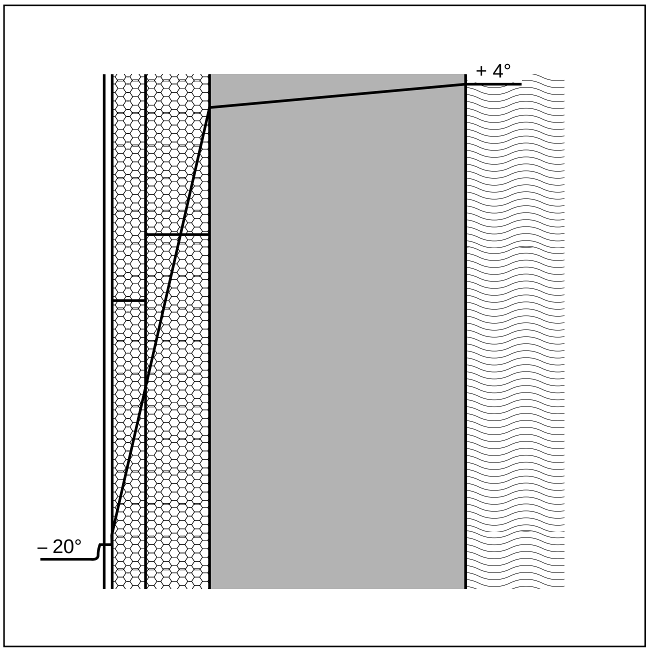

Fig. 3 : Temperature profile in the wall of a water tower insulated with Styropor foam. The mean temperature is some 8 °C higher than in the uninsulated design.

Water tower

The open-top water tower shown in figure 1 is 30 metres tall and has a capacity of 2.4 million litres. The walls are constructed from 250-mm-thick reinforced concrete. The water temperature of 4 °C must not fall below 3 °C within 24 hours when the outside temperature is – 20 °C (see figure 2).

An uninsulated tower has the following heat loss:

201 m^2 water surface = 9.7 GJ/24 h
616 m^2 tank walls = 7.7 GJ/24 h
113 m^2 tank base = 0.3 GJ/24 h
Total heat loss = 17.7 GJ/24 h

This heat loss means that the temperature water falls from 4 °C to 2.2 °C within 24 hours and so the required discharge temperature of 3 °C cannot be maintained.

Additional insulation is therefore necessary. Two layers of Styropor foam board are applied to the outer concrete surfaces with construction adhesive. The first layer is 65 mm thick; the second 35 mm thick. The boards of the second layer are made to overlap the gaps in the first. Finally the Styropor is covered with a layer of fabric-reinforced rendering. The insulating layer, which has an overall thickness of 100 mm, results in a significant reduction in heat loss (see figure 3).

201 m^2 water surface
(not insulated) = 9.7 GJ/24 h
616 m^2 tank wall
with insulation = 0.4 GJ/24 h
113 m^2 tank base
with insulation = 0.2 GJ/24 h
Total heat loss = 10.3 GJ/24 h

The reduced heat loss prevents the required water discharge temperature from falling below 3 °C within 24 hours.

Fig. 4 : Concrete sugar-storage silos; left: completed, right: under construction.

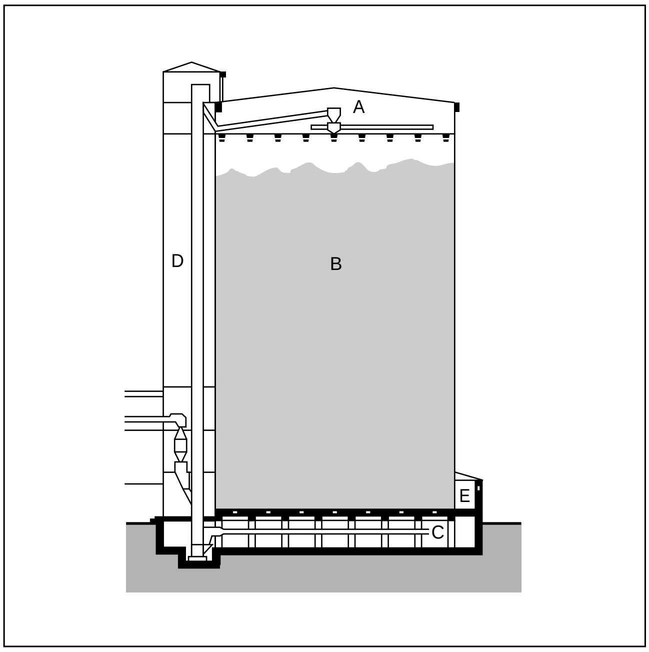

Fig. 5 : Cross-section through a sugar storage silo: A = silo filling platform, B = storage space, C = discharge room, D = elevator tower, E = air conditioning system.

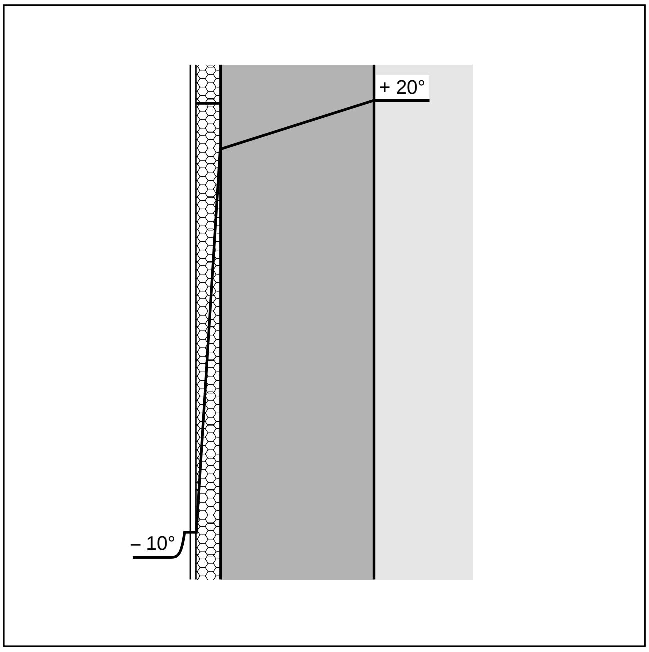

Fig. 6 : Temperature profile through the insulated silo wall

Sugar storage silos

The facility comprises silos 34 m in height, 22 m in diameter, and with a capacity of 10 000 t each. The sugar must be maintained at a temperature of 20 °C, since a drop in temperature can lead to condensation that will cause the sugar to cake.

The silos are filled from above through an elevator tower and emptied from below. The air in the discharge room, elevator tower, and space above the sugar is maintained at a uniform temperature by an air conditioning system (see figure 5).

Cooling, therefore, occurs only through the outside wall. With a diameter of 22 m and a fill height of 24 m, the surface subject to cooling is 2350 m^2. If the silo was not insulated, the temperature would drop by 6.9 °C within 24 hours. This would make it necessary in the cold months of the year to have a high turnover to prevent the sugar caking. By installing 25-mm-thick Styropor foam board, the thermal resistance can be increased considerably: from 0.095 m^2 K/W to 0.714 m^2 K/W (see figure 6). Styropor insulation reduces the heat loss, which is equivalent to a 1.3 °C drop in temperature; this is compensated for by the air conditioning system.

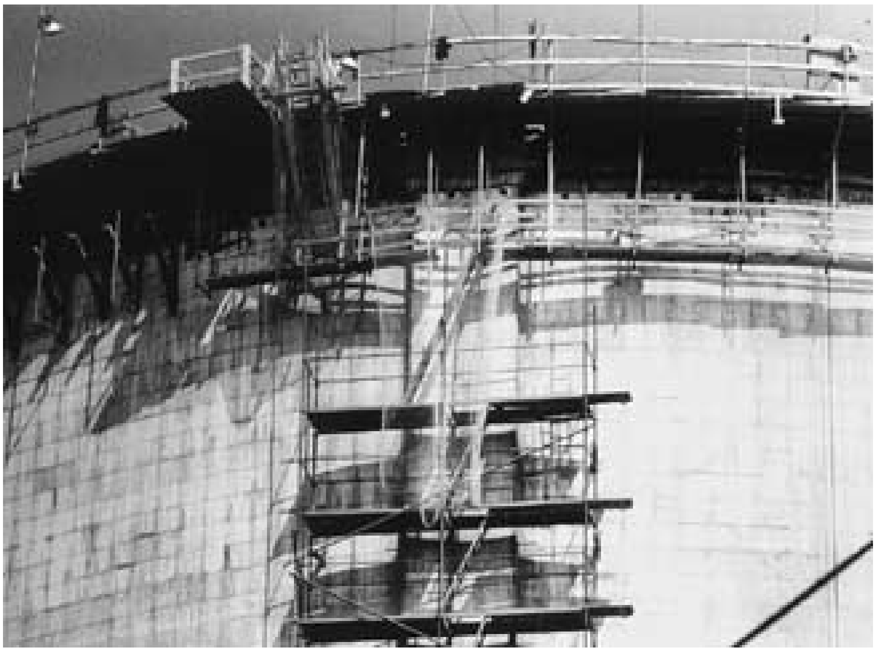

Fig. 7 : Sugar silo under construction

It is worth mentioning the ease with which the Styropor boards are installed. Before the concrete is placed, the Styropor boards are inserted into a sliding form, where they act as permanent shuttering. They become firmly bonded to the wall of the silo as the concrete hardens (see figure 7). Finally the silo wall is weatherproofed with a layer of fabric-reinforced rendering.

Flour silo

The rectangular silo shown in figure 9 is 50 m high and stores flour in vertical compartments. It can hold 5000 tonnes of flour at a storage temperature of 20 °C.

The silo must be thermally insulated to prevent the moisture-sensitive flour from caking during the cold winter months. The 150-mm-thick reinforced-concrete walls have a thermal resistance of 0.074 m^2 K/W, which produces appreciable cooling of the silo’s contents.

The thermal insulation, which comprises 25-mm-thick Styropor foam board covered with a fabric-reinforced rendering, raises the thermal resistance to 0.688 m^2 K/W. The small drop in temperature can be made up for by heating the air in the space above the flour.

Fig. 8 : Flour storage silo near Aalen, Germany (photo: Dryvit).

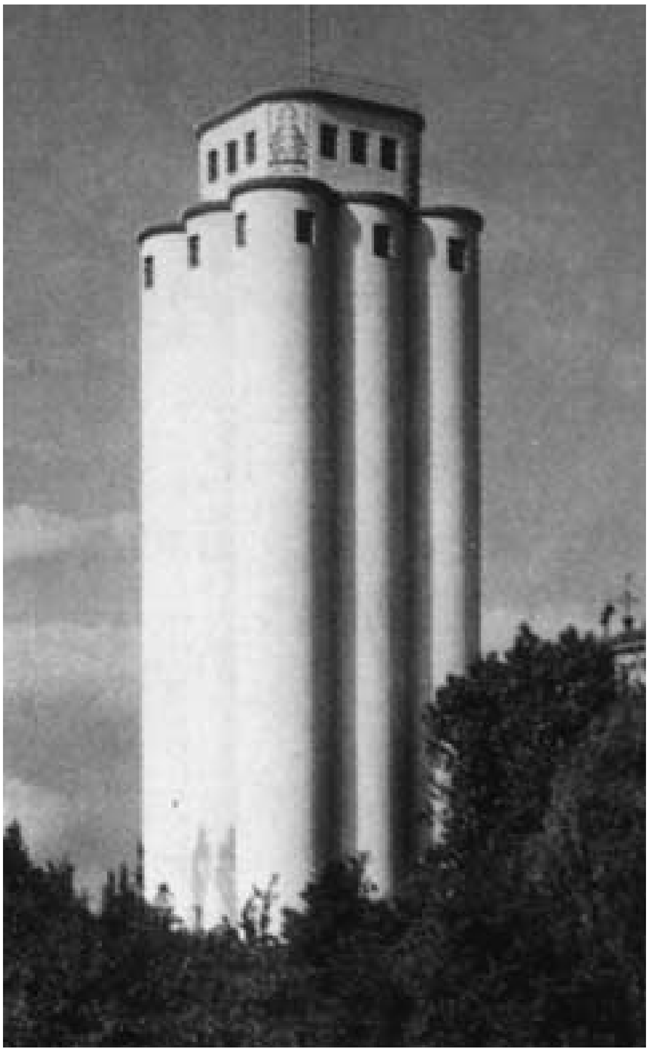

Fig. 9 : Renovated grain silo near Assenheim, Germany.

Renovation of a grain silo

The concrete silo pictured in figure 9 was built in 1937 to store wheat. Because of cracks in the 150-mm-thick reinforced-concrete wall, and the absence of thermal insulation, dry storage of the grain could no longer be guaranteed. The wall of the silo was in need of renovation. The cracks in the concrete were filled with an elastomeric sealing compound and the wall clad with 20 mm Styropor foam board. The final covering comprises a fabric-reinforced rendering.

The examples just given demonstrate that Styropor foam insulation is a cost-effective solution to some of the problems of bulk-storage. Technical details about the use of fabric-reinforced dispersion-based renderings are given in our Technical Information 302.

Note

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Technical Information

Styropor®

280

BASF Plastics

47293 December 1991

5 Building

Pipe insulations

Thermal insulation of pipelines

From the engineering and economic aspects, it is often advisable or even essential to protect pipelines from heat losses and condensation. Particularly effective protection is offered by expanded Styropor split lagging and segments. If the pipes are of very great diameter, good results can be obtained by Styropor sheet wrapped in several layers with staggered joints.

Fields of application

Heating, plumbing, and ventilation systems operating at temperatures up to 80 °C

Insulated equipment

Pipes for hot-water and central heating systems (to prevent heat losses)

Pipes for cold-water systems (to prevent condensation and to protect against freezing)

Ducts in ventilation and air-conditioning systems (to suppress fluctuations in temperature)

Pipes for refrigerants (to prevent refrigeration losses and condensation)

Examples are refrigeration units in cold stores, chemical factories, textile and paper mills, ice factories, dairies and breweries.

Pipes for liquefied gases in the cryogenic range down to –180 °C (to prevent frost build-up)

Physical form of the insulation and technical data

The following design values apply for the thermal conductivity of rigid expanded Styropor with a density of 25 – 30 kg/m^3 to be used as thermal insulation in refrigeration.

Mean temperature	λ (W/m K)
20 °C	0.030
0 °C	0.028
– 20 °C	0.026
– 40 °C	0.024
– 60 °C	0.023
– 80 °C	0.021
–100 °C	0.019
–120 °C	0.017
–140 °C	0.015
–160 °C	0.013

They differ from those laid down for thermal insulation to be used in building.

On request, moulded lagging and segments of 20 – 30 kg/m^3 density can also be supplied in self-extinguishing material. Rigid Styropor split lagging is moulded in lengths of 0.05 and 1.00 m and wall thicknesses of 15, 25, 40 and 50 mm for all standard pipes with outer diameters ranging from 17 to 419 mm. The ends and longitudinal edges may be rebated or square. Moulded

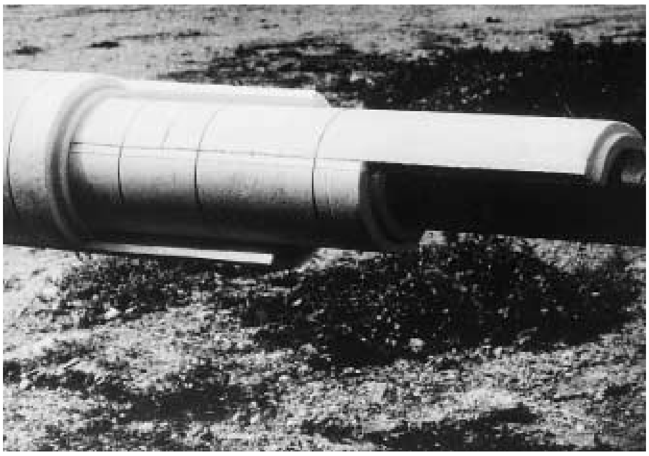

Fig. 1

quarter-circular lagging is supplied in lengths of 0.50 m and thicknesses of 25, 40 and 50 mm for pipes of 500, 600, 700, 800, 900 and 1000 mm outer diameter (cf. Fig. 1).

Rotary-cut expanded Styropor sheet of up to 12 mm thickness is supplied in rolls of up to 1 m width.

Depending on the application, the segments are fixed without an adhesive on hot-water pipes, but with an adhesive on pipes for refrigeration systems. Since the thickness of the bonds varies, segments of different internal diameter are required for pipes of the same outer diameter. Consequently, the inner diameter of the segments must be accurately determined. The thickness of the adhesive can be regarded as the tolerance.

Pipe with a rated inner diameter of 80 mm	
Outer diameter of pipe	89 mm
Thickness of adhesive 1.5 mm x 2	3 mm
	92 mm

Thickness of insulation = 40 mm

The figure quoted in orders for these segments are 40/92 mm (cf. Figs. 2 and 3).

Fitting insulation to pipes

Without an adhesive

The lagging can be fixed without an adhesive on pipes for hot-water or heating systems at temperatures of 80 °C or less. As a rule, it is also fitted without an adhesive on cold-water pipes in households. The lengths of lagging are generally butt-jointed, but thermal bridges can be avoided by rebates on the ends and sides. The moulded segments are secured with adhesive tape, galvanized iron wire, steel tape or clamps (cf. Fig. 4).

With adhesives

If the temperature of the pipe is less than 8 °C or if a refrigerant flows through the pipe, the lagging must be fitted with a special bitumen adhesive, as otherwise water of condensation or ice may form in the joints. The hot-melt bitumen-rubber adhesives used for the purpose remain elastic over a wide range of temperatures and are still sufficiently tacky if they are applied at low temperatures.

The segments for securing pipes in refrigerated systems should be made of hardwood to avoid thermal losses. The manner in which they are attached depends on whether the pipeline is suspended or rests on supports.

Before low-temperature pipes are insulated by expanded Styropor lagging, they must be thoroughly derusted and descaled. They should then be primed with two blister-free coats of a bituminous paint. If they pass through food storage space, a special odourless paint must be used. The lengths of lagging are rubbed into the hot adhesive and then bound tightly with galvanized iron wire or steel tape. The excess adhesive that is thus pressed out of the joints is removed with a trowel, and all the joints are subsequently sealed. The moulded expanded Styropor segments can be easily cut to shape for lagging bends, flanges, valves, branches, etc. Particular care is required in insulating flanges and valves. For instance, only the handwheel and stuffing box of valves should be left exposed (cf. Fig. 7).

The thickness of insulation required to avoid condensation may be greater than that of moulded segments. The insulation in this case may consist of several layers of expanded Styropor strips, which are carefully bonded together by an adhesive. It is particularly important to ensure that the longitudinal and butt joints are staggered. Ice may be formed in any gaps caused by careless workmanship and, in extreme cases, could burst the insulation and thus give rise to rust or damage.

If the temperature difference or the atmospheric humidity is high, a vapour barrier is required on the

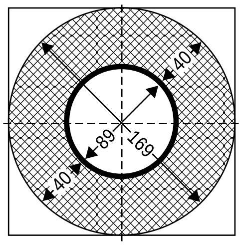

Fig. 2 (without adhesive) The inner diameter of the lagging is exactly the same as the outer diameter of the pipe to be insulated.

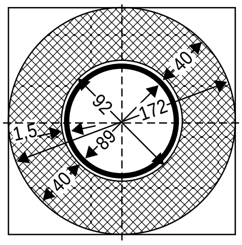

Fig. 3 (without adhesive). The inner diameter of the lagging is 3 mm greater than the outer diameter of the pipe to be insulated.

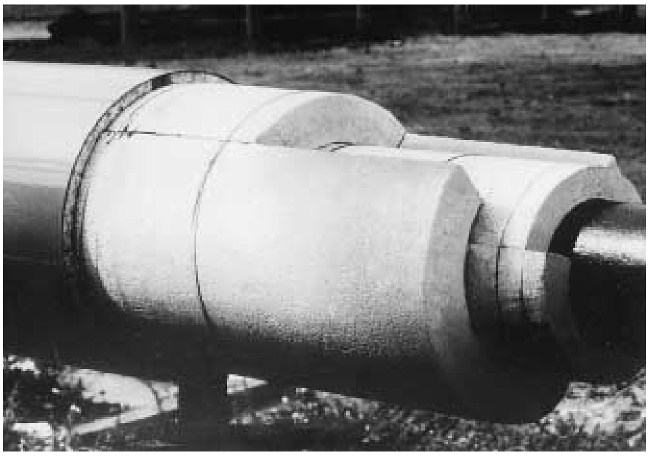

Fig. 5

Fig. 4

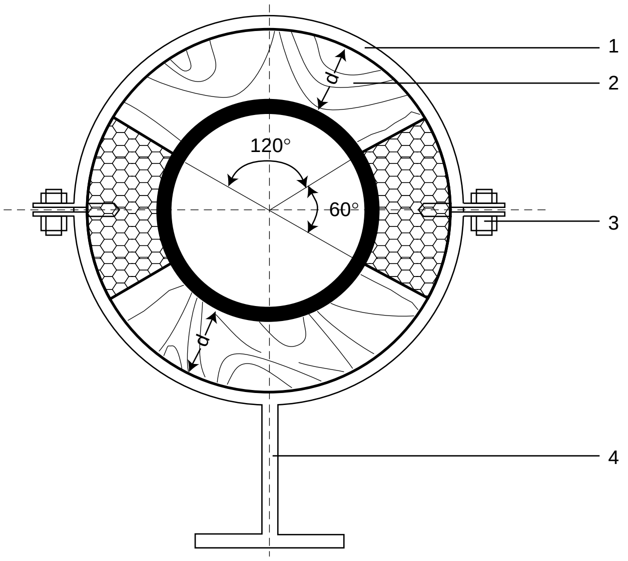

Fig. 6

1 Iron strap
2 Wooden segments
3 Bolts to secure iron strap
4 Pipe support or suspension
Thickness of hardwood d = 20 mm for insulation of 25 mm thickness
Thickness of hardwood d = 35 mm for insulation of 40 mm thickness
or for several layers of insulation

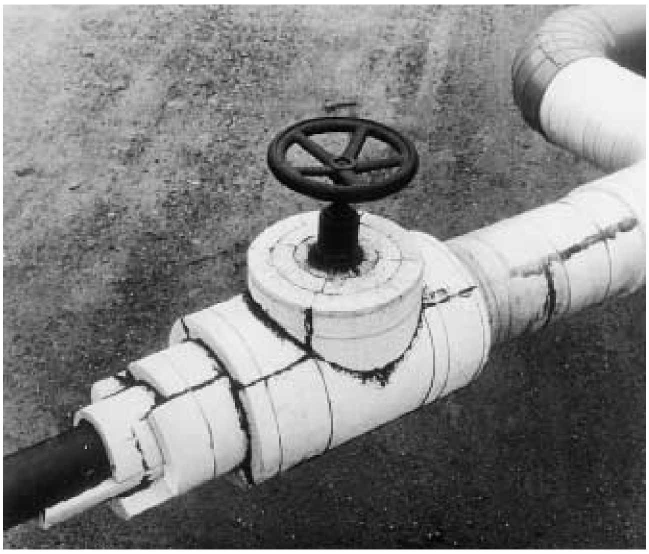

Fig. 7

warm side of the insulation. It may assume the form of a bitumen coating (if necessary reinforced with a woven glass fabric), wrapped plastic tapes, lapped and sealed bitumen felt, bitumen-coated aluminium foil, etc. Care should be taken with coloured adhesive plastic tapes, which may contain substances that damage rigid expanded Styropor.

No restrictions are imposed on the types of conventional sheaths that may be fitted to protect the expanded Styropor lagging, e.g. gypsum, cement, scrim soaked in a polymer dispersion, and plastics film. If metal sheaths are fitted, care must be taken to ensure that the self-tapping screws do not damage the vapour barrier.

Determination of the thickness of pipe insulation

(cf. table overleaf)

The point to observe in designing the thickness of expanded Styropor lagging is that no water of condensation may be formed. The factors concerned are the ambient temperature, the relative humidity, the pipe temperature, and the pipe diameter. Under otherwise identical conditions, pipes of large diameter require thicker layers of insulation, because their surfaces are cooled by the greater volume of liquid concerned (cf. Figs. 8 and 9).

Fig. 8

Fig. 9

Ducts for heater pipes

If pipes cannot be lagged, the ducts in which they lie can be lined with expanded Styropor board to avoid excessive heat losses.

Since the walls of the ducts are usually concrete or a similar porous building material, the insulating board can be secured by conventional dispersion-type adhesives. If the duct is lined with bitumen felt as protection against rising damp, a special adhesive must be used.

Expanded Styropor insulation must not be exposed to sustained temperatures higher than 85 °C. This figure is not exceeded in hot-water heating systems. Brief exposure to temperatures as high as 100 °C does not harm expanded Styropor. If hot-water and cold-water pipes run side by side in the one duct, they can be insulated from one another by expanded Styropor beads used as loose fill.

Thickness (in mm) of expanded Styropor lagging required to prevent condensation on pipes

(compiled by J. S. Cammerer)

		Relative humidity %											
		90			80			70			60		
		Ambient temperature °C											
Pipe diameter mm	Pipe temperature °C	10	20	40	10	20	40	10	20	40	10	20	40
25/33.7	– 20	65	60	100	35	45	55	20	30	40	15	15	25
	0	25	45	75	15	25	45	15	15	25	15	15	20
	+10	–	25	60	–	15	30	–	15	20	–	–	15
50/75	– 20	75	90	120	40	50	60	25	30	45	15	20	30
	0	30	50	85	15	25	60	15	15	30	15	15	25
	+10	–	30	70	–	15	35	–	15	20	–	15	15
100/108	– 20	85	100	140	45	55	70	25	35	50	15	25	35
	0	35	55	100	15	25	55	15	15	35	15	15	15
	+10	–	35	80	–	15	40	–	15	25	–	15	15
200/216	– 20	100	115	150	50	60	80	30	40	55	15	25	35
	0	35	60	110	25	30	60	15	20	35	15	15	20
	+10	–	35	90	–	15	40	–	15	30	–	15	15
400/419	– 20	110	130	180	55	70	90	30	45	60	20	30	40
	0	40	70	125	25	30	70	15	20	40	15	15	30
	+10	–	40	100	–	20	45	–	15	30	–	15	20

Note

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5 Building

Interior insulation; composite board

Composite board of room height has proved to be one of the most economical means of insulating a wall from the inside or a ceiling from below. It consists of expanded Styropor faced with gypsum plasterboard, mineral fibre board, wood particle board, etc. Composites may also be formed from Styropor together with other plastics, ceramics, dispersion-modified concrete, and other materials. These are primarily intended for outdoor insulation, and the dimensions of the largest board are 1.25 m x 4.50 m.

Specifications on the thermal insulation of the composite board can be met by appropriate selection of the thickness of the expanded Styropor.

It is common practice to use gypsum plasterboard of 9.5 mm thickness instead of premixed plaster. This thickness is sufficient to ensure the stability required in residential buildings.

The composite board allows walls and ceilings to be lined very economically, e.g. an area of 5.6 m^2 can be covered with insulation and plaster in the one operation. In addition, greater reliability is offered in obviating cold bridges.

The large composite panels can be easily laid under clean and almost dry conditions, with the result that the room in which they have been laid can be occupied very soon afterwards. The remoistening that was otherwise unavoidable in finishing can be dispensed with. The walls and ceilings can be decorated soon after the few joints and seals have been filled.

Lining walls with composite board

It is advisable to lay the composite board on the walls **after** the ceiling has been finished and **before** the floor screed or floating floor is laid.

The first step is to cut the composite board to the required length, corresponding to the height of the room, with normal woodworking tools, e.g. a handsaw (Fig. 1).

Fig. 1

Fig. 2

The composite panels are laid face down on two or three battens, and an adhesive is applied to the Styropor side in patches and strips. A gypsum bedding mortar may be used as the adhesive for normal absorbent and rough surfaces, but a dispersion-type bonding mortar is required for comparatively smooth surfaces, e.g. concrete (Fig. 2).

Fig. 3

The board is then raised into position against the wall with its lower edge resting on wooden wedges. It is trued vertically and horizontally with a levelling rule. Any unevenness in the ground can be largely compensated by a bedding mortar (Figs. 3 and 4).

Fig. 4

The substrate must be firm, dry, and free from dust. Any wallpaper or coats of washable paints must have been removed beforehand. After the composite board has been pressed into position and trued, any excess bedding or bonding mortar that has oozed out at the sides must be removed to avoid thermal bridging (Fig. 5).

Fig. 5

After the bedding or bonding mortar has set, the joints are filled with a sealing compound and reinforced with cloth, glass fibre, or special paper tape (Fig. 6).

Fig. 6

The materials and methods are usually specified by the manufacturers of the composite board. The joints are smoothed after the sealant and reinforcing material have dried (Fig. 7).

Fig. 7

Primer coats on composite board

The surface of composite boards can be made less absorbent and more uniform by applying a primer, e.g. a dispersion. The primer coat also serves a useful purpose in subsequent renovation, in that it facilitates removal of wallpaper.

If the outer wall is comparatively dampproof, e.g. of concrete, a special dispersion-type coating (Diofan® supplied by BASF) should be applied to the surface of the composite board to act as a vapour barrier and thus to prevent damage by condensation.

Fig. 8

Fig. 9

Design of corners

Particular attention must be devoted to the design of corners in order to avoid thermal bridging and the ensuing damage by damp.

A corner inside a room has been taken as an example here to demonstrate how the composite board must be rebated to allow an uninterrupted layer of insulation against the wall. The rebate is cut with a handsaw as shown in the photographs (Figs. 8 and 9).

Projecting corners can be protected by special profiles that are incorporated during application of the mortar.

Laying composite board on ceilings

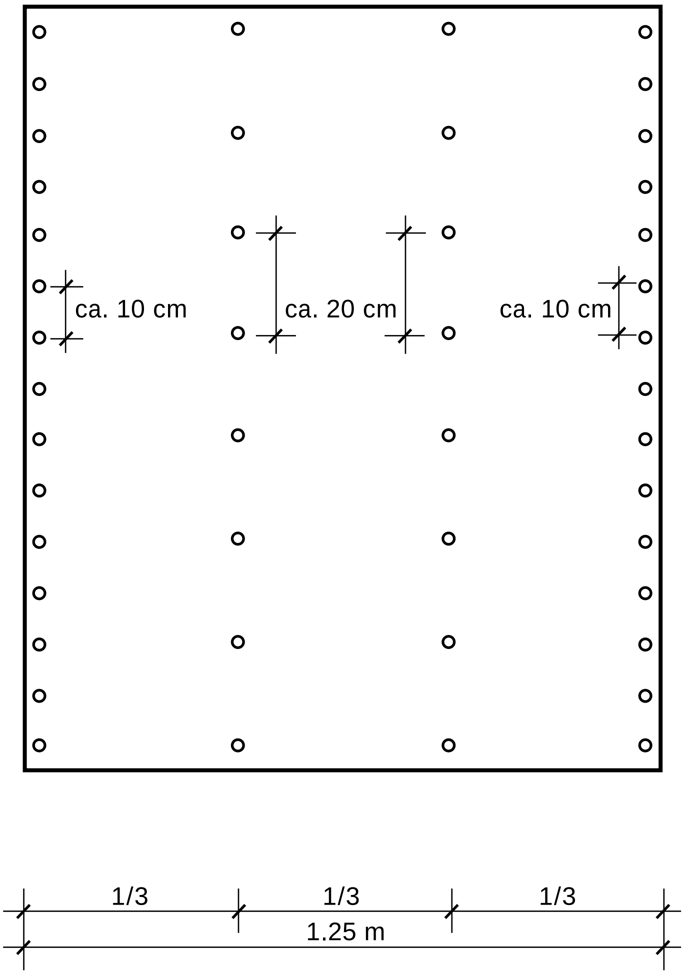
Composite boards are also widely used as panelling in ceilings laid under timber joists. They thus serve the purpose of the final rendering on ceilings and provide the necessary thermal insulation.

The first step is to attach furring to the system or wooden binders and joists. The spacing between the battens in the furring should be one-third of the width of the composite board, i.e. about 42 cm. Special galvanized nails are used to fix the composite board to the furring. The panels must be laid as close together as possible, and the joints should be finished as described for walls (Figs. 10 and 11).

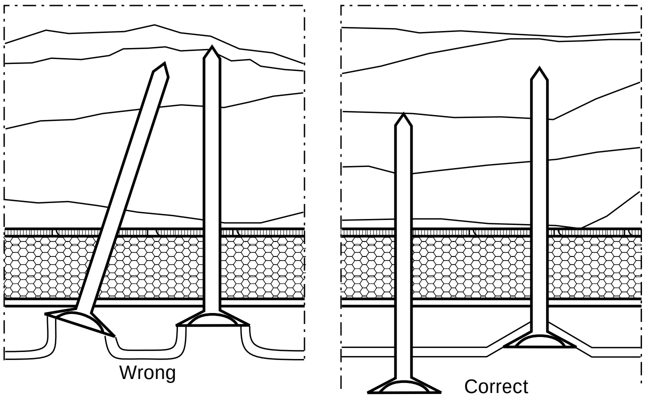
Fig. 10

Fig. 11

Nailing diagram for securing longitudinal strips under ceilings

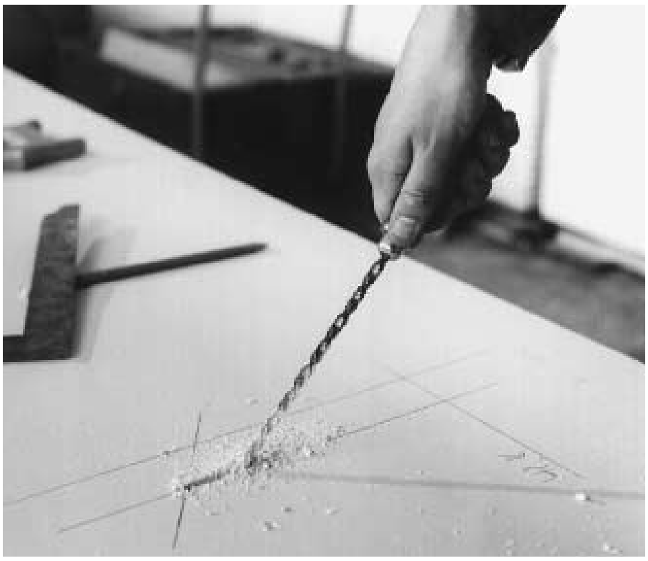


Points to observe in nailing



Tools for working with composite panels.

The panels are cut to size or into lengths with normal handsaws with fine teeth or with a buzz saw.



Recesses and holes or various shapes and sizes are cut out with a toothed lauger.

Circular recesses for electrical and sanitary installations are cut out with a trepanning tool.

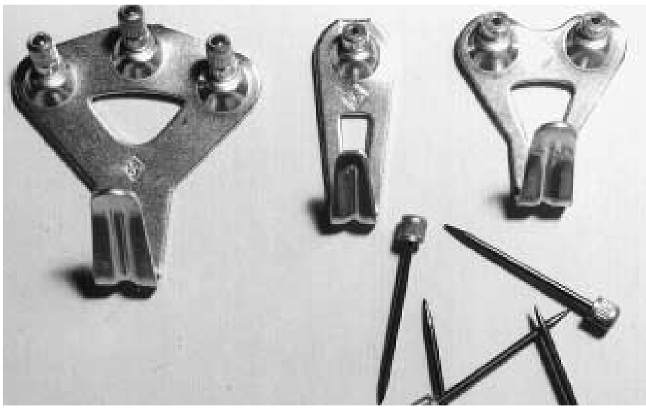
The edges are beveled with a plane.

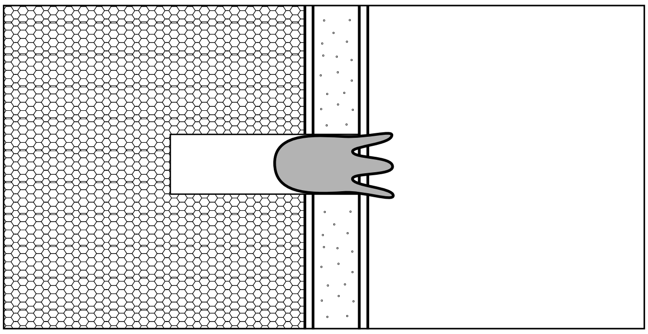
Securing fixtures to composite board

Pictures and other light ornaments can be hung on the wall nails and hooks shown in the photograph on the top right of this page.

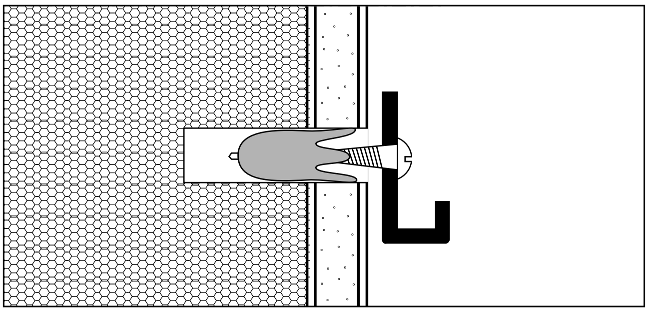
Heavier objects can be secured by special wall plugs, as shown in the right.

The wall plugs for attaching very heavy, projecting fixtures that can exert a bending moment over and above their weight, e. g. a washbasin, must pass through the composite board well into the masonry.

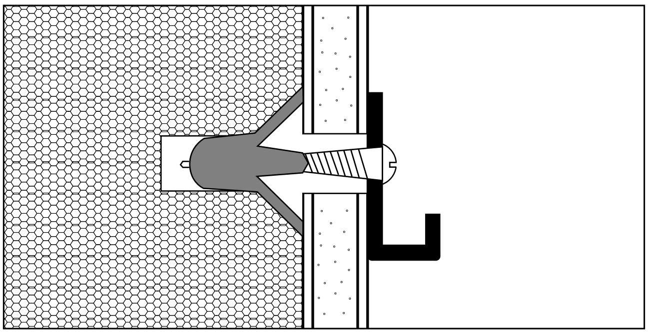




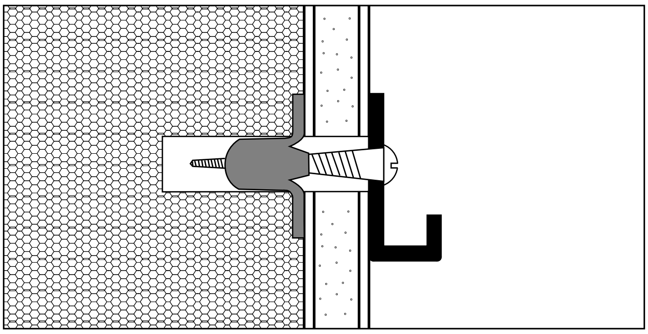
1. Wall plug inserted in drilled hole.



2. The fixture is fastened, and the screw is inserted for a few turns into the plug.



3. The plug is completely splayed by the screw.



4. The screw is tightened.

Electrical installations

Sheathed cables or cables in insulated conduits may be laid in direct contact with expanded Styropor. This does not apply to the types of cable intended only for use in or under plaster.

The installation work is best carried out in two stages. In the first stage, the strands of cable should be laid on the masonry. If the cables have a thicker cross-section than the layer of bonding or bedding mortar, they must be let into a chase. A loop of cable is left at each position where a circuit is required.

Holes to accommodate flush-mounting boxes for sockets, switches or other fixtures must be cut in the composite board before it is fixed to the walls. Afterwards, the empty boxes are secured in position by a dispersion-type adhesive containing cement or by gypsum; and, at the same time, the loop of cable is drawn through them.

It is inadvisable to attach flush-mounting boxes with abundant gypsum to the masonry before the composite panels are laid. This procedure would entail that the insulating material behind the gypsum plasterboard would have to be removed and that thermal bridges would thus be formed.

Note

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47485 July 1991

5 Building

Sandwich structures – light weight interior walls

When it comes to the dry construction of partitions, panels comprised of Styropor foam sandwiched between wallboard (mainly plasterboard) have been proven to be an efficient solution that also offers heat-insulation properties.

The relatively low weight of the panels and their ease of installation make them especially suitable for light, non-load-bearing walls. Considerable advantages are to be gained from this method: clean, dry construction and quick erection produce great savings in time.

The weight of a finished room-high wall is approximately 20 kg/m^2, and can therefore be largely ignored for the purposes of static load calculations. The large size of the panels (1.25 m wide and up to a max. 4.50 m high) means that 3.0 – 5.6 m^2 of wall can be erected at a time.

Once the joints between the panels have been filled, taped and finished, the partition is ready for decorating.

Erection sequence

1. *Styropor strip bonded to ceiling and floor with dispersion-based adhesive (construction adhesive).*
2. *Panel trimmed to 4 cm less than the ceiling height. Normal wood-working tools can be used (see Fig. 1).*
3. *Adhesive applied to the top and side edges of the panel.*
4. *Panel put up edge-on to wall or preceding panel (see Fig. 2).*
5. *Panel made perpendicular and flush by means of metal bars and wooden wedges (see Fig. 3).*
6. *Excess adhesive scraped off and panel cleaned with moist sponge.*
7. *Floor joint filled with dispersion-bound (or gypsum) cement.*
8. *After 48 hrs wedges and bars removed and filling of joints completed.*
9. *Vertical joints filled, taped and finished; wall and ceiling joints finished. After the filler has dried, the wall is ready for decorating.*

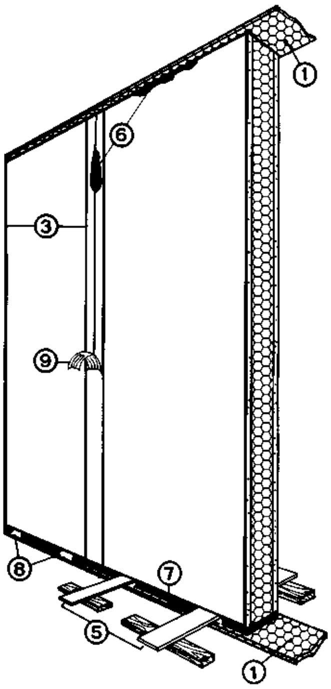
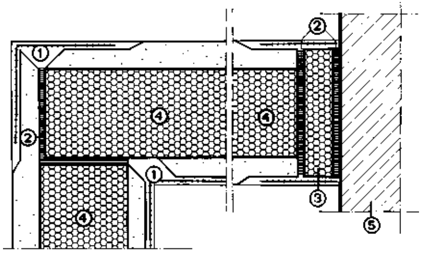


Fig. 1

Fig. 2

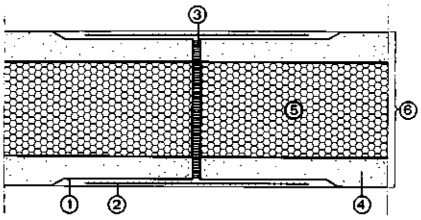
Fig. 3

Treatment of corners and junction with wall



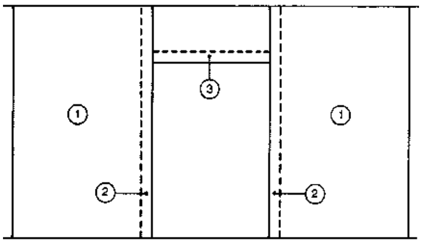
1 Joint filler (the arris may be reinforced with thin aluminium profile)
2 Adhesive
3 Styropor strip
4 Sandwich panel
5 Wall

Butt joint between two panels



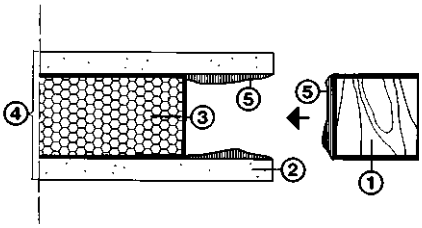
1 Special gypsum joint-filler
2 Reinforcing strip
3 Adhesive
4 Gypsum wallboard
5 Styropor core
6 Sandwich panel

Door frames



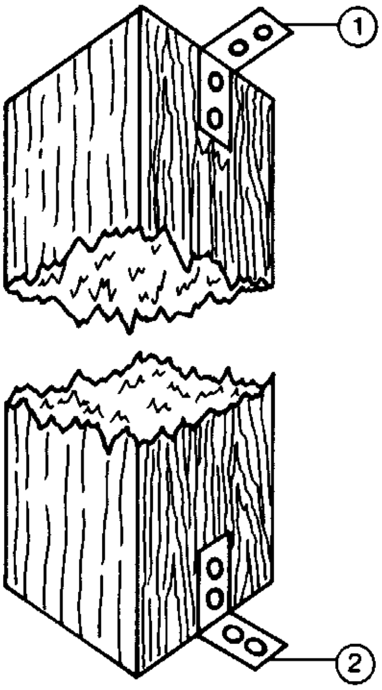
1 Sandwich panels
2 Wooden door-posts
3 Crossbeam

Wooden door-posts reaching from floor to ceiling should be let into two appropriately spaced sandwich panels. The posts are bonded into openings made by removing some of the Styropor core.



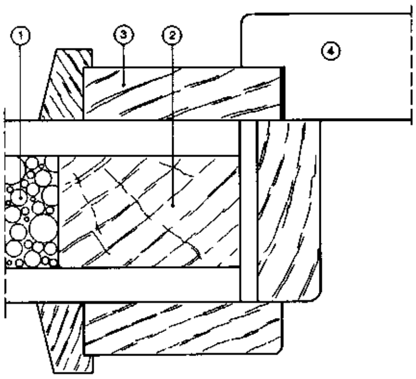
1 Posts for a 60 mm thick sandwich panel (eg, 40 x 40 mm)
2 Gypsum wallboard
3 Styropor core
4 Sandwich panel
5 Adhesive

The posts are secured to the ceiling and floor with angle brackets.



1 Secure post to ceiling with angle bracket
2 Secure post to floor with angle bracket

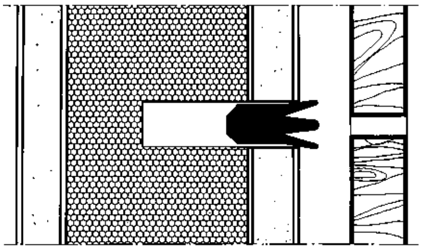
The door lining can then be fixed by screws in the usual way.



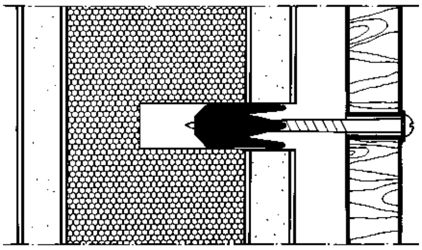
1 Sandwich panel
2 Wooden post
3 Wooden lining
4 Door leaf

Whereas PVC skirting can be glued to the wall as normal, wooden skirting boards and other objects must by secured by other means (eg, toggle anchors). Here the plasterboard is drilled and the fixture then screwed into place.

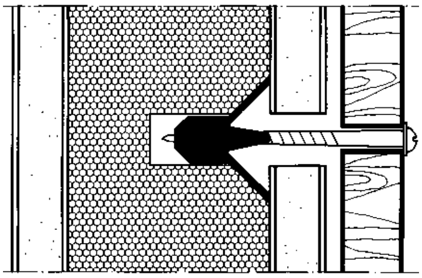
Assembly sequence



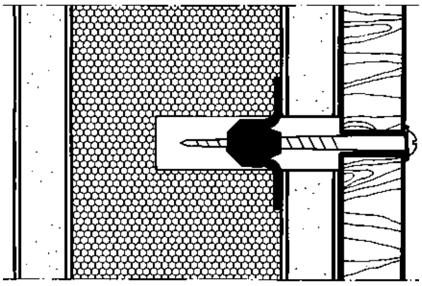
Both plasterboard and fixture are drilled to size. The anchor is inserted into the wall.



The screw is inserted and screwed a few turns into the anchor.



The anchor is pushed into the wall with the help of the screw, so that it engages behind the plasterboard.



The screw is screwed home and the fixture secured. The screw should not be overtightened.

Anchors may be purchased from the relevant outlets.

Anchor type	**Drill bit mm ∅**	**Wood screw mm ∅**
A 4	8	4
A 5	10	5

Pictures, ornaments, etc. can be hung by means of nails and hooks.

Electrical installation

It is possible to let a horizontal or vertical chase into the partition without weakening it very much. The work can be performed with a circular or jig saw, or a high-speed milling machine; this is best carried out before the panel joints are taped and finished, so that the partition can be made good at the same time as the work on the joints is completed.

The chase should be deep enough to take the full diameter of the conduit or sheathed cable, secured in place with a construction adhesive to which cement has been added. Long horizontal chases, particularly those lying halfway up the wall, should be reinforced across the joints.

Conduit boxes or similar boxes to take accessories should be fitted into accurately-cut recesses, made for instance with a hole saw.

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BASF

47294 January 1998

5 Building

Footfall sound insulation under floor tiles

1 General

Ceramic tiles and slabs are highly esteemed for flooring in tropical and subtropical countries. They are hard-wearing, have a high heat capacity, and remain cool. Their one drawback is that they attenuate sound much less than soft floor covering, e. g. carpeting. Thus, although they are comparatively thick, they produce a particularly high level of footfall sound. Hence, especially in the case of tiled floors, the installation of a special insulating layer is needed for the effective insulation impact noise. Some examples are cited in this publication to illustrate points that must be observed in planning and laying tiled floors insulated against impact noise.

The literature in the field of footfall insulation under tiled floors is scanty. As a consequence, the erroneous opinion prevails that tiled floors could not be laid on floating screed surfaces, because the tiles would be unable to withstand inter alia the concentrated loads imposed by the legs of heavy furniture. In actual fact, however, the load is borne solely and exclusively by the underlying concrete screed floor and not by the tiles or the bed of mortar. All that is required is to ensure that the tiles are carefully laid and completely and firmly embedded in the mortar.

The following examples have been selected to demonstrate that tiles can be laid in both living quarters as well as in humid rooms and that thin-bed techniques have recently been extended to embrace tiled floors.

2 Tiled floor in a living room

In this structure, the sub-floor is covered by a layer of flexibilized expanded Styropor panels. Bitumen felt is then laid over the Styropor in order to avoid the acoustic bridges that could be formed if the screed were to flow through the joints between the Styropor panels into the sub-floor. A strip of Styropor board of 1 cm thickness is placed vertically along the periphery and must project slightly above the upper edge of the subsequent floor covering.

Thus the screed layer rests in a trough formed by the layer of insulation covered by bitumen felt, and it does not come into direct contact with any other part of the building. Tiles can then be laid on it by conventional techniques. The total thickness of the screed, the tiles, and the mortar in which the tiles have been laid is about 6 – 7 cm. Once the mortar has set, the projecting Styropor strips at the edges are trimmed to the height of the tiles. The joints at the walls can then be covered by tiled, wooden or plastic skirting.

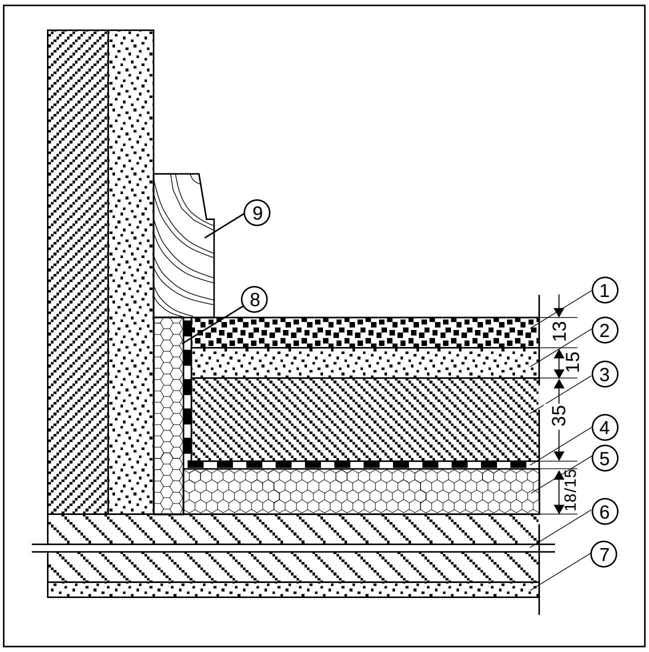

Fig. 1 Tiled floor on floating screed in a living room

1 Floor tiles
2 Bed of mortar
3 Screed
4 Bitumen felt (250 g/m^2 felt)
5 Flexibilized Styropor expanded foam panels as insulating layer
6 Sub-floor
7 Plaster
8 Edge strip of Styropor foam panel
9 Skirting

3 Tiled floor in a humid room with PVC skirting

The main point in this design is that as usual in the tiling sector the walls are tiled before the floor is laid. The stoneware tiled skirting extends almost to the sub-floor, from which it is separated by a joint 1 – 2 cm in width. The advantage of this design is that a plumb and square surface is formed, against which the peripheral strip of Styropor board can be fitted vertically. The tiled floor can then be laid as described in Section 2, and the joint between the wall and the floor can be covered by an extruded PVC profile.

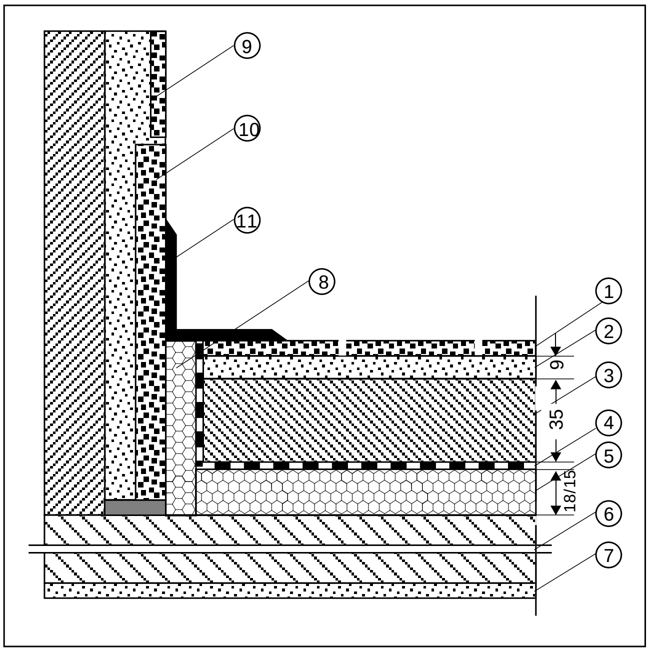

Fig. 2 Tiled floor on floating in a kitchen

1 Floor tiles
2 Bed of mortar
3 Screed
4 Bitumen felt (250 g/m^2 felt)
5 Flexibilized Styropor expanded foam panels as insulating layer
6 Sub-floor
7 Plaster
8 Expanded Styropor edge strips
9 Ceramic tiles
10 Stoneware skirting
11 Plastic angle selection

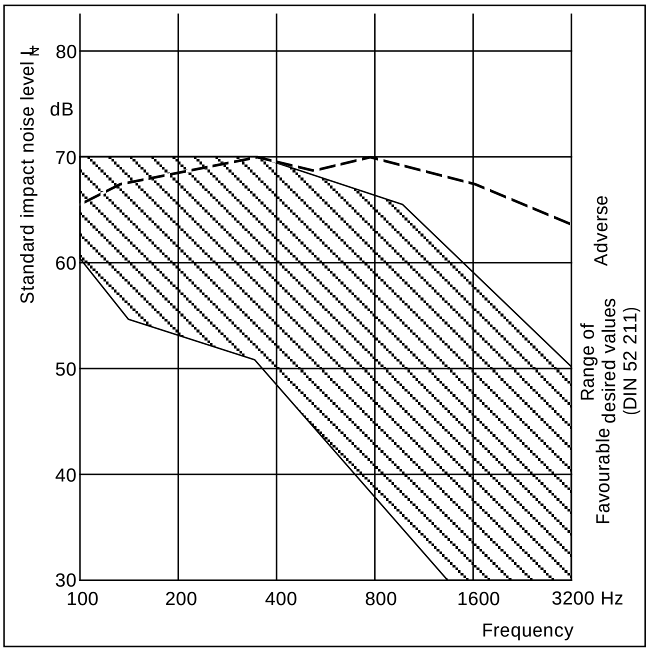

Fig. 3 Footfall sound insulation provided by a floor made up as shown in Fig. 2

4 Tiled floor with straight skirting in a humid room

In the example shown in Fig. 2, the strip of Styropor board at the edges has to be covered by an elastic sealant or by wood or plastic skirting. If it is desired that the joint should not be so visible or that a skirting of a different material should not be used, the method illustrated in Fig. 4 can be adopted. Once the tiles have been laid, the joints filled, and the strip of insulation has been trimmed, a permanently flexible sealant strip 4 mm thick is laid where the skirting has to be positioned. The skirting is then put in place on top of this sealant strip. The reason for inserting a strip 4 mm thick in a joint of only 3 mm height (cf. Fig. 5) is that the strip is compressed somewhat by the weight of the stoneware skirting. In order to eliminate any likelihood that mortar may fall on to the strip of insulation through the space between the sealant strip and the base of the wall, a band of elastic sealant is placed on the sealant strip to form a tight seal against the wall.

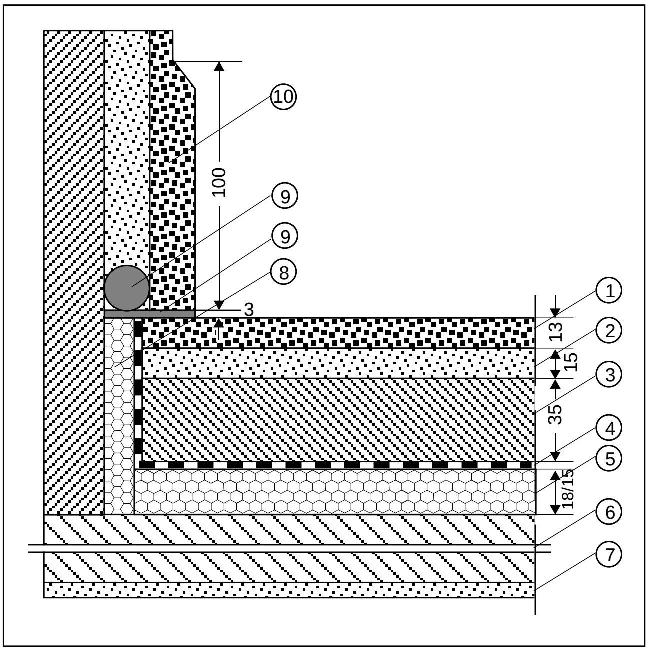

Fig. 4 Tiled floor on floating screed in a kitchen

1 Floor tiles
2 Bed of mortar
3 Screed
4 Bitumen felt (250 g/m^2 felt)
5 Flexibilized expanded Styropor expanded foam panels as insulating layer
6 Sub-floor
7 Plaster
8 Edge strips of Styropor board
9 Permanently flexible sealant
10 Stoneware skirting

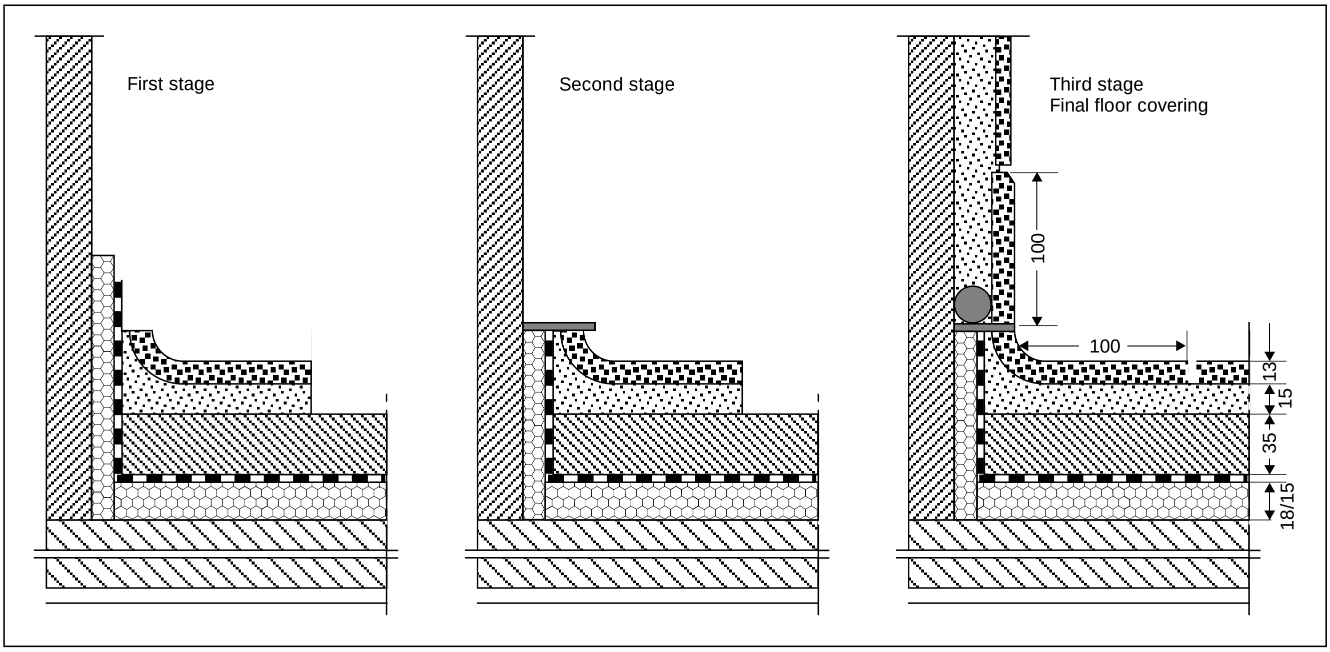

Fig. 5 Tiled floor on floating screed with coved skirting

5 Tiled floor with coved skirting in a humid room

The sharp corners formed by straight skirting are often undesirable, e. g. in bathrooms. They can be easily avoided by using coved skirting.

The procedure is the same as that described in Section 4 and is illustrated in Fig. 5.

6 Thin-bed techniques

The established method of laying tiles in a thick bed of mortar ensures the necessary adhesion and compensates for any unevenness of the surfaces. However, modern glazed or unglazed tiles are very smooth and have great dimensional stability. They can thus be laid using an adhesive layer of reduced thickness on existing screed bases which are insulated against footfall sound. This method of laying has the advantage that work can be done much more economically. For instance, one man can lay about 4 m^2 of tiles in an hour by the thick-bed method; and about 10 m^2 in an hour, by thin-bed techniques.

7 Requirements for applying thin-bed techniques

The surface to be tiled should be perfectly smooth, firm, and not disposed to crumble. Cement screed is the best substrate for durable thin-bed tiling.

8 Thin-bed mortars and adhesives

Depending on the substrate and loading, different adhesive compounds are used for thin-bed techniques:

(a) Mortar mixed from cement and sand with additions of plastic emulsions and polymer dispersions

(b) Structural adhesive mortars, which consist of a dry mixture of sand, cement, and synthetic resins

(c) Synthetic resin adhesives in the form of liquid one-component and two-component adhesives

Thin-bed techniques obviate the need to water the tiles. Adhesion is ensured by a uniform, thin layer of the adhesive, but only slight compensation can be made for areas of unevenness in the substrate.

9 Laying tiles by thin-bed techniques

In standard practice, the walls are tiled before the floor.

The first step in tiling the floor is to smooth out areas of unevenness in the sub-floor with a cement mortar. Afterwards, the edge strips of expanded Styropor foam are glued to the walls with a dispersion-type or contact adhesive (Fig. 6).

Flexibilized 1.0 m x 0.5 m expanded Styropor panels of 18/15 mm thickness are laid edge to edge on the smoothed sub-floor (Fig. 7) and covered with the bitumen felt (Fig. 8) in standard manner. A reinforced cement screed of 35 mm thickness is laid over the insulation (Fig. 9).

The sealant inserted in the gap between the screed and the wall tiles (Fig. 10) must be flexible. This is because the joints must remain watertight, even if the floor moves under load, and a flexible medium prevents impact sound transmission to adjoining or more distant rooms.

The final step is to lay the ceramic tiles. In the example shown here, 5 cm x 5 cm tiles of 4 mm thickness were laid on the cement screed in a mosaic pattern in a 1-mm bed of adhesive mortar composed of sand, cement and a plastic dispersion (Figs. 11–13).

10 Footfall sound insulation of tiled floors on floating screed laid by thin-bed techniques

Evidence of the good acoustic insulation that can be achieved by tiled floors on floating screed laid by thin-bed techniques is given in Fig. 15.

Measurements have revealed that tiled floors laid by thin-bed techni-

Fig. 6 Bare structure with strips of insulation laid against the walls

Fig. 7 Insulating layer consisting of flexibilized expanded Styropor panels laid edge to edge

Fig. 8 The insulating layer partially covered with bitumen felt

Fig. 9 Screed reinforced with structural steel

Fig. 10 Sealing the joints at the edges with an elastic sealant

Fig. 12 Tiled mosaic floor

Fig. 11 Laying the ceramic tiles in a bed of mortar of 1 mm thickness

Fig. 13 Joint between wall and floor tiles filled with elastic sealant

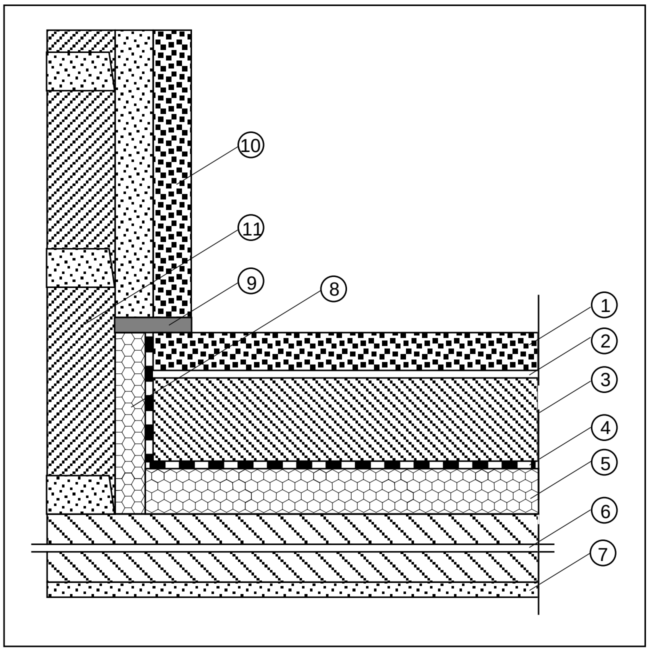

Fig. 14 Cross-section through the completed floor

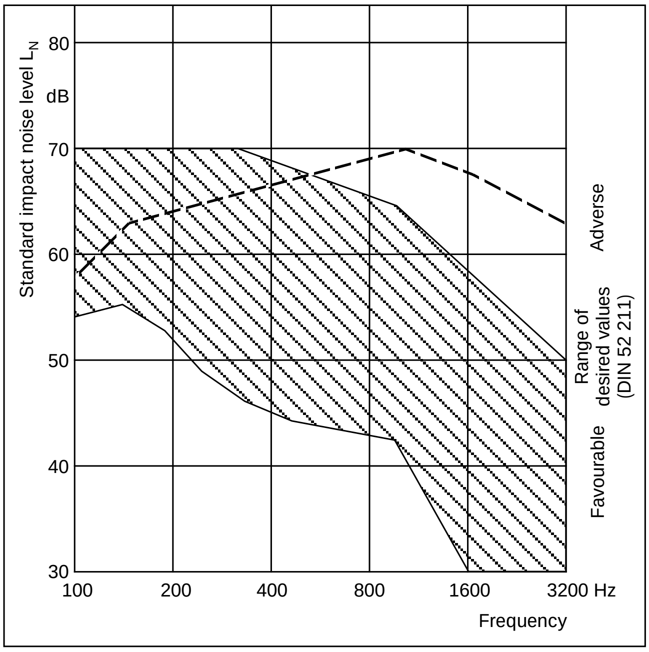

Fig. 15 Footfall sound insulation for floor construction

1 Floor tiles
2 Concrete bonding mortar of 1 mm thickness
3 Screed of 35 mm thickness
4 Bitumen felt (250 g/m^2 felt)
5 18/15 mm insulating layer consisting of flexibilized expanded Styropor panels
6 Sub-floor of 140 mm thickness
7 15-mm layer of plaster
8 Expanded Styropor edge strips
9 Elastic sealant
10 Stoneware skirting
11 Brickwork

ques more than satisfy the proposals for enhanced footfall sound insulation laid down in German standards (DIN 4109, Part 2).

11 Conclusions

Tiles can be economically laid on floating screeds that have been insulated with flexibilized expanded Styropor foam panels. A well-designed structure certainly meets the requirements laid down in the German standard on sound insulation in buildings (DIN 4109). In fact, measurements have revealed that the levels of footfall sound insulation that can thus be obtained are much better than those specified in the standard.

Note

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67056 Ludwigshafen, Germany

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21918 September 1992

5 Building

® = Registered trademark

Ceiling tiles

Expanded Styropor ceiling tiles are of decorative design and may also be coated, but are without cladding.

1. Potential applications

The type and system of ceiling tiles can be selected to accommodate any of the following applications:

(a) Designing the grid, tile profile and color scheme to achieve decorative effects.

(b) Echo control by special sound-absorbent panels or structures.

(c) Reducing the height of rooms by false ceilings, cladding pipes or ceiling joists; renovation of cracked or undulating ceilings.

(d) Additional thermal insulation for ceilings.

Tiles on false ceilings can hardly attenuate footfall sound from the rooms above. In this case, footfall sound insulation above the ceiling is essential.

In the case of open-plan, interior thermal insulation of a ceiling integral with a reinforced concrete roof a check has to be made that this does not give rise to excessive fluctuations in temperature within the ceiling structure which may possibly result in damage to the ceiling or the load-bearing walls. The question of water vapor diffusion must also be taken into consideration. Even when expanded foam panels are employed for decorative reasons or for sound insulation in rooms they should be ventilated at the rear when there is a temperature gradient towards the outside. An example is a false ceiling. If the outer roof side of a solid slab ceiling is sufficiently well insulated, physical problems hardly ever occur.

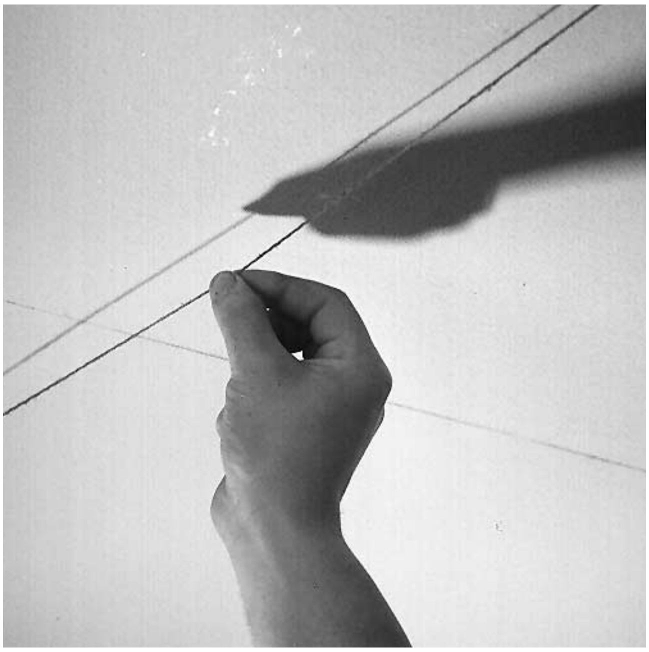
2. Forms supplied

Styropor ceiling tiles are either cut from blockware or molded. Their thickness is 10, 15 or 20 mm. The edges are mostly chamfered or formed to allow tongue-and-groove joints. Square tiles are supplied in sizes of about 30 x 30 cm to 62.5 x 62.5 cm. Their surfaces may be smooth or textured, white or colored, slashed (with longitudinal, criss-cross or annular slashes), semiperforated, or needled (for improving sound absorption).

3. Conformance with building regulations

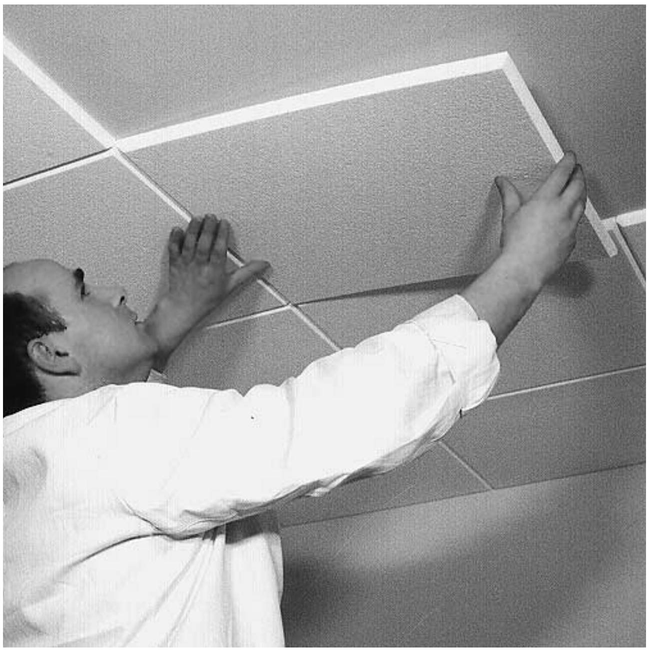
In Germany, ceiling tiles in general must satisfy the requirements laid down in DIN 4102 for normally flammable Class B 2 building materials. Styropor F ceiling tiles conform to the requirements laid down in DIN 4102 for flame-resistant Class B 1 building materials.

In Germany, Class B 1 materials may be used in building construction only if the manufacturer is entitled to identify his product by the corresponding proofmark (PA-III-No.). This also applies to ceiling tiles attached by means of flame-resistant (low flame spread) adhesives. In this case, the tiles are regarded as “non-burning” (forming drops). They thus constitute a much smaller fire hazard than conventional wood panelling, which is usually classified as a normally flammable Class B 2 building material according to DIN 4102. Details on the conformance of Styropor ceiling tiles with German building regulations are given in our Technical Information leaflet TI 433.



Fixing the centre of a room by means of a chalk line

Pressing a tile into the bed of adhesive with a lambskin roller



Placing a tile in the bed of adhesive

Example for laying tiles under a lathwork grid

4. Laying ceiling tiles

Ceiling tiles may be secured directly to the unplastered or plastered ceiling by means of adhesives or secured to a lathwork lattice.

1. Attachment to the ceiling by means of adhesives

The shuttering ridges on the underside of new, in-situ cast concrete ceilings must be removed before ceiling tiles are laid. If there are distinct irregularities in the surface of the ceiling, the depressions must be leveled off with filler. Paints that can be washed off or are liable to peel as well as wallpaper must be removed. Damaged plaster must be repaired, and crumbling plaster must be strengthened or knocked off.

The most suitable adhesives for securing ceiling tiles are dispersion types (cf. TI 620 and 621).

The adhesive manufacturer's instructions must be observed in preparing the substrate and in fixing the tiles.

The tiles should be laid outwards from the centre of the ceiling in order to ensure a symmetrical pattern. The centre of the ceiling can be marked by snapping a taut chalked string. The tiles can be pressed into the bed of adhesive with a lambskin roller or a sander with the disk covered by expanded foam. Any excess adhesive on the surface of the tiles must be immediately washed off.

2. Laying under a lathwork lattice

The laths may be secured direct to the ceiling or suspended at a distance from it. Well-seasoned wood should be used for the lathwork, and the width of the laths should be about 6 – 8 cm. The only wood preservatives that may be used for impregnating the laths are aqueous salt solutions.

Light-metal systems are normally used for suspending false ceilings from lightweight roofs (industrial roofs) or in open-plan rooms.

3. Ceilings that extend to the outside of a building or over rooms that are not permanently heated, e.g. hobby rooms, must meet the more demanding requirements for structural thermal insulation. In such

cases, it is advisable to combine the tiles with an equally thick insulating layer of Styropor foam.

5. Surface treatment

In the course of renovation Styropor ceiling tiles can be coated with conventional emulsion paints, which are best applied by means of a long-hair lambskin roller.

Note

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5 Building

Single-shell flat roof

Single-shell, unventilated roof: Expanded Styropor foams as flat-roof insulation

Roofs must allow rainfall to drain off reliably. As a rule, even flat roofs should also be constructed with a slope, especially since roof structures having a gradient of less than 2 % require special measures to reduce risks associated with catchment water.

Common substructures include ceilings made from concrete cast in situ or from prefabricated concrete slabs or other massive slabs, from contoured sheet metal as well as from wooden beams.

Apart from natural, chemical, biological and physical stresses, **flat roofs** are **exposed** to a special degree to **thermal stresses** and to the **strains** resulting from them. Changing levels of heating on the surfaces of roofs and temperature differences between the inside and outside take their toll on the sealing material and building structure. **Temperature-dependent changes in linear dimensions can result in harmful deformations of building materials and structural components.**

Correctly installed Styropor insulation protects the structure and the materials against these unwanted effects. Furthermore, an insulation system made from Styropor designed to take account of energy considerations makes a valuable contribution to environmental conservation through energy savings by heat conservation in summer as well as in winter.

Uses of flat-roof structures

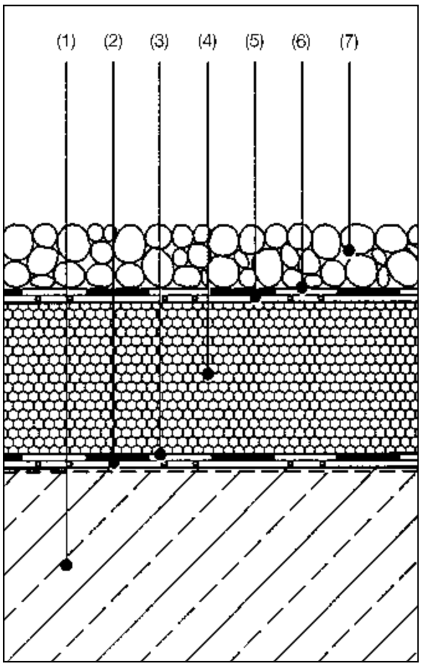
Uses are distinguished as follows:

- **unused areas,** accessed only for purposes of servicing and maintenance;
- **used areas,** that is to say **can be walked on,** i. e. suitable for temporary occupation by humans (e. g. terraces);
- **suitable for vehicles,** i. e. can be driven over by passenger vehicles or trucks (parking decks, fire department access driveways …);
- **garden layouts in the form of extensive plantings** of undemanding, low-level and low-maintenance plants, and **intensively cultivated garden layouts** for vegetation and plants requiring a lot of attention.

Fire precautions for flat roofs

In accordance with various **legal** stipulations, **roofs** in general must fulfill the **requirements:**

- that in the installed state the **building materials** used are at least **normally flammable,** i. e. **readily flammable building materials** must not be installed;
- that their **covering is resistant** to **airborne burning material** and **radiant heat.** What is known as a hard roof covering is required.



Note
On account of its single-shell construction and the clear definition of the individual functional layers the transmission of heat, diffusion of water vapor or condensation of moisture through or in the unventilated flat roof can be calculated exactly, making it safely predictable in physical terms.

The following, which **do not require any special certification,** are regarded as **hard roof coverings:**

- any **flat roof superstructures** completely **covered by a bed of gravel** of diameter 16/32 mm and thickness ≥ 5 cm;
- **flat roof superstructures** having at least a **double-layered sealing membrane made from bitumen roofing sheets** applied directly on a **closed, supporting underlying layer,** corresponding at least to the **normally flammable class of building materials,** or on an **additional thermal insulation layer** corresponding at least to the **normally flammable class of building materials.**

Styropor F from BASF is a **rigid polystyrene foam with a flame-proof finish** belonging to the **flame-resistant class of building materials.**

Thus Styropor F fulfills all of these important requirements **and even exceeds them.** Furthermore, according to a test report, thermal insulation materials made from **Styropor F** are classed as **non-burning and do not form falling burning particles or droplets.**

Further information on the fire-resistant properties of **Styropor** may be obtained from **“Technical Information 130”.**

Functions and principle of the layered structure of flat roofs

1. **Substructure or support layer**
   In the form of a heavy, rigid structure composed of steel-reinforced concrete for limited spans or in the form of a lightweight, flexible ribbed structure made of wood, steel or reinforced concrete with a support layer on the upper side made of wood or sheet metal with trapezoidal corrugations for larger spans.
2. **Separating and leveling layer**
   For covering over small shrinkage and stress cracks as well as to provide protection against rough areas and possible chemical effects of the support layer.
3. **Vapor barrier layer**
   Having the purpose of preventing excessive diffusion of moisture from the underlying rooms, i. e. excessive accumulation of condensed water under the sealing layer. At normal room conditions, i.e. inside at 20 °C and 50 % relative humidity, a Styropor insulating layer designed in accordance with DIN 4108 is protected without further need of certification when the barrier value, S_d* >100. Loosely laid or spot-bonded or strip-bonded vapor barriers can simultaneously assume the function of a separating and leveling layer.
4. **The thermal insulation layer serves**
   - to produce **comfortable room conditions** all year round;
   - **to save energy** in the heating and, if necessary, cooling of the rooms under the shelter of the roof;
   - in association with the vapor barrier, to protect the flat roof structure against excessive accumulation of condensed moisture;
   - **to avoid or reduce** temperature-induced **strains and deformations** in the support layer (thermally induced changes in linear dimensions).

The thickness of the thermal insulation layer is determined by the requirements of the heat conservation or energy saving regulations.

5. **Vapor-pressure equalizing and separating layer for**
   - forming a continuous layer of air between the thermal insulation and sealing layers in order to relieve and distribute local build-up of vapor pressure which can arise from trapped or diffusing moisture;
   - ensuring the intrinsic mobility of the sealing layer and preventing the transmission of stresses and movements when there are external temperature differences;
   - preventing detrimental chemical interactions between the thermal insulation and sealing layers;
   - acting as a protective layer in the case of plastic sealing membranes without rugged surface protection. Protection of the flat roof structure against airborne burning material and radiant heat.
6. **Sealing layer for**
   - sealing the flat roof structure and the building as a whole against all forms of precipitation and against accumulation of water. Bitumen-based sealing membranes are normally constructed in two layers. The layers are bonded to one another over their entire area in order to prevent occlusions of air and moisture. Sealing membranes based on plastic are composed of one layer, laid loosely, weighed down with an overburden and/or mechanically fixed. A protective layer, e. g. a fibrous plastic web, has to be laid under plastic sealing membranes when the underlying layer requires this and the sheeting used is not laminated on the underside to a non-woven plastic mat. A separating layer, made e. g. from coarse fiberglass matting weighing 300 g/m^2, is necessary if the roof sealing membrane is not compatible with other layers, e. g. when PVC-P/NB is laid on polystyrene or when wooden shuttering is impregnated with oil.
7. **The surface protection layer has the effect of**
   - protecting the sealing membrane against mechanical damage and against airborne burning material and radiant heat;
   - attenuating external temperature differences and providing protection against direct solar radiation (especially UV radiation).

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* *Equivalent diffusion layer of air*

A distinction is made between

- **light surface protection,** used only for bitumen-based sealing membranes; in this case the upper layer is slate chippings usually coated on to bitumen sheet at the factory; this coating can also assume the function of a separating layer with respect to heavy surface protection or with respect to utility layers;
- and **heavy surface protection,** e. g. covering with gravel, coverings passable on foot or by vehicles, extensive garden layouts and intensively cultivated garden layouts.

Rigid Styropor foam in flat roof construction

The most important criteria for the use of **thermal insulation material in flat roof construction** are:

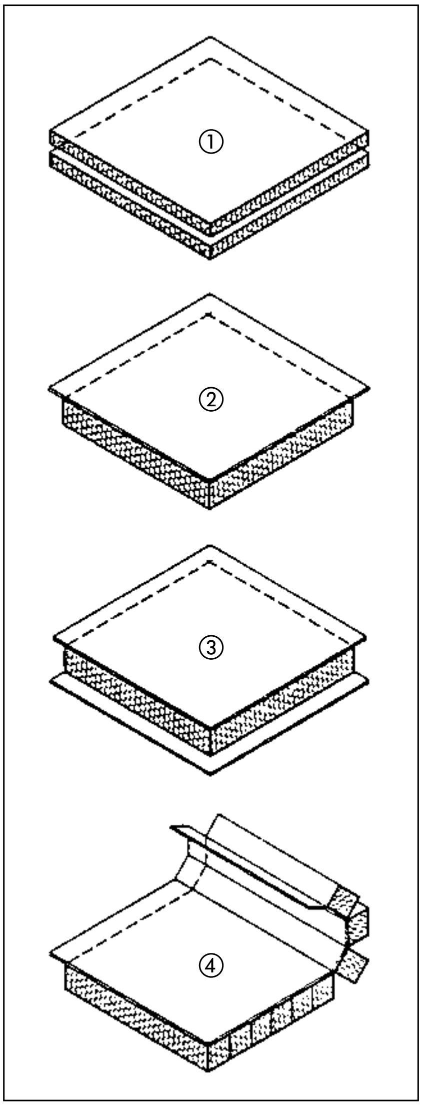
- **thermal conductivity;**
- **water absorption;**
- **compressive stress,** i. e. the long-term compressive load at < 2 % compressive strain;
- **flexural and tensile strength** (in the case of flexible support layers and moving connections);
- **dimensional stability,** ability to retain volume and shape;
- short-term and long-term **thermostability** (during heat sealing/ in long-term use);
- **resistance** to rotting and aging;
- **fracture and abrasion resistance,**
- **machinability.**

The overall behavior of thermal insulation materials made from rigid Styropor foam in relation to these in part highly heterogeneous criteria can be described as optimal.

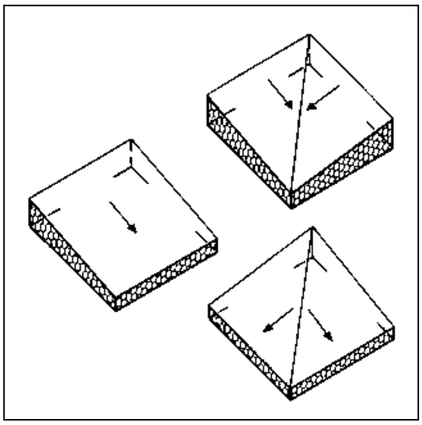
The grades of rigid Styropor foam panels to be used in various flat roof structures and the corresponding minimum bulk densities are laid down in Germany in DIN 18 164, Part 1.

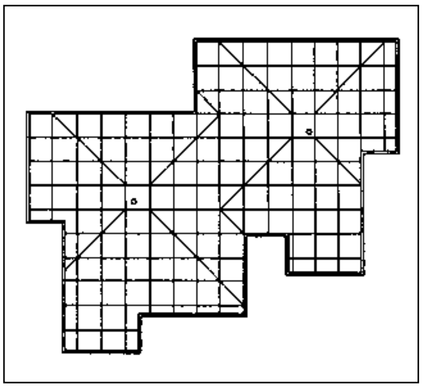
According to this

- application grade **W** should be employed for **double-shell, ventilated flat roofs;**
- application grade **WD** should be employed for **single-shell, unventilated flat roofs** which are unused;
- application grade **WS** should be employed for **single-shell, unventilated roofs** which are **walked on, driven over or laid out as a garden** (designated as “WS+WD” in the terms of the Gütegemeinschaft Hartschaum e.V. [German rigid foam quality association]).



① *Panels without lamination*
② *Roof elements laminated on the upper side, level or in sloping roof system*
③ *Roof elements laminated on both sides, level or in sloping roof system*
④ *Rolled-up or hinged webs.*

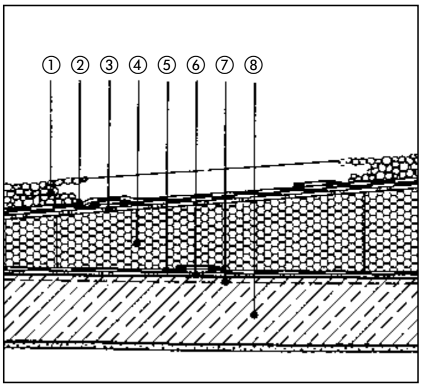




Thermal insulation materials made from rigid Styropor foam are supplied in various forms for single-shell flat roof structures.

As a rule **roofing elements for the insulation of slopes** are cut from rigid Styropor foam in accordance with computer-controlled cutting lists using automatic program control to form panels measuring 100 x 100 cm having the planned gradient including associated groove and spine panels. In this case the grooves and spines should as far as possible run at angles of less than 45°. This requires precise planning of the entire sloping insulation system and the position of the roof downpipes.

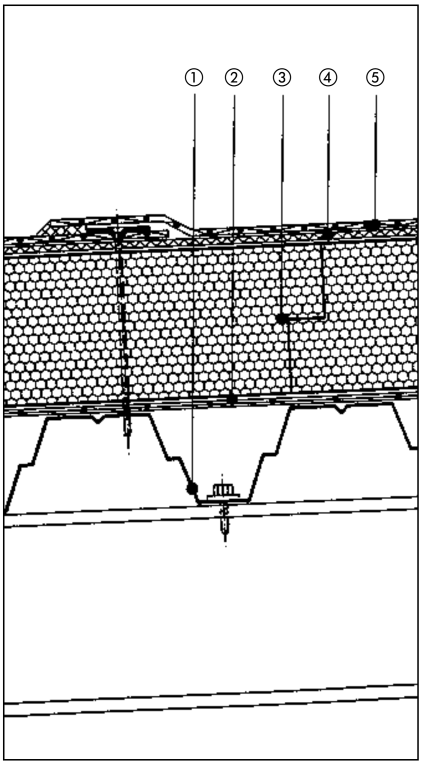
Properties	**Requirements** **PS 15 SE**	**PS 20 SE**	**PS 30 SE**
Applicability	Thermal insulant e. g. walls, ventilated flat roofs, sloping roofs	Thermal insulant under compressive loads e. g. unventilated flat roofs	Thermal insulant for special applications under compressive loads e. g. parking decks
Application grade	W	WD	WS + WD
Bulk density	15 [kg/m^3]	20 [kg/m^3]	30 [kg/m^3]
Fire properties	German building material class B1: flame-resistant		



① *Surface protection layer and overburden*
② *Roof sealing membrane*
③ *Vapor pressure equalizing layer*
④ *Styropor sloping roof element*
⑤ *Vapor barrier layer*
⑥ *Leveling layer*
⑦ *Primer*
⑧ *Substructure*

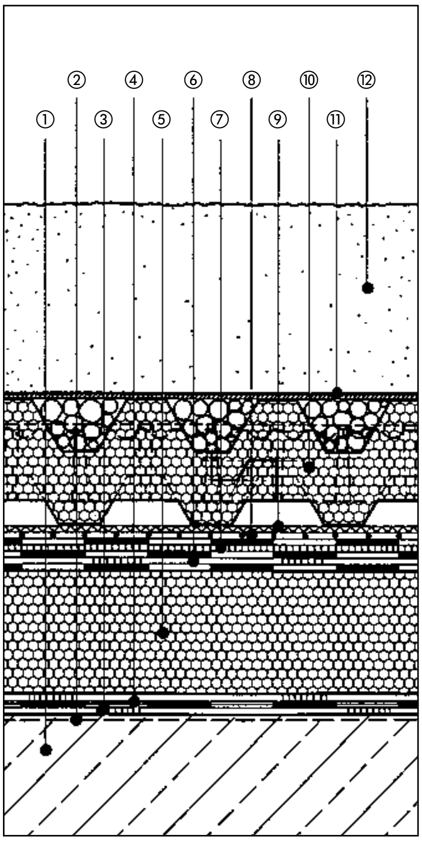
Flat roof construction with sloping insulating layer

If laminated or unlaminated Styropor is laid loosely in an unventilated roof, overburdens for securing it against lifting forces due to wind are necessary. In practice gravel beds, which also serve as surface protection*, composed of 16/32 gravel have proved to be an effective covering.



① *Support layer, galvanized trapezoidal steel sheets*
② *Vapor barrier layer*
③ *Styropor insulating element*
④ *Vapor pressure equalizing or separating layer*
⑤ *Sealing layer*
⑥ *Surface protection layer, sealing layer coated with slate chippings*
⑦ *Square-cap screw for fastening to the steel sheets*

Mechanical means of fastening are preferably used when laying insulating panels on steel sheeting with trapezoidal corrugations. As a rule the other layers of the roof structure are also fastened at the same time along with the Styropor roofing elements.



① *Support layer*
② *Primer*
③ *Separating and leveling layer*
④ *Vapor barrier layer*
⑤ *Styropor insulating element*
⑥ *Vapor pressure equalizing or separating layer*
⑦ *Sealing layer*
⑧ *Layer to prevent penetration of roots*
⑨ *Layer providing protection against mechanical damage*
⑩ *Drainage layer composed of Styropor moldings*
⑪ *Filter fabric*
⑫ *Vegetation layer*

Further alternatives for securing by means of overburdens include deposits of soil, e. g. for roof garden layouts, or coverings enabling utilization of the flat roof.

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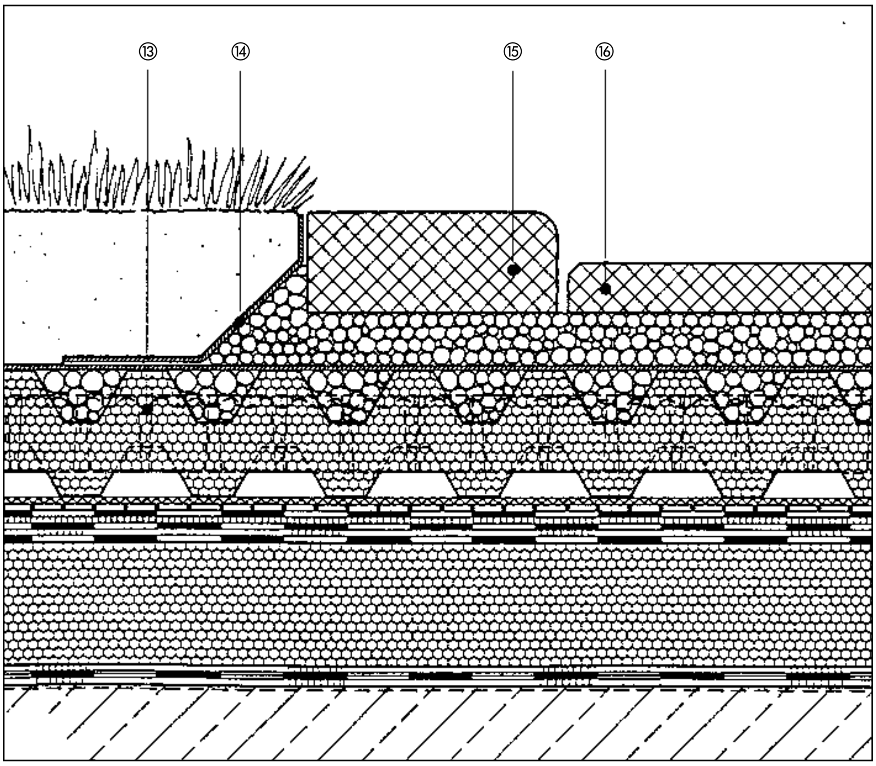
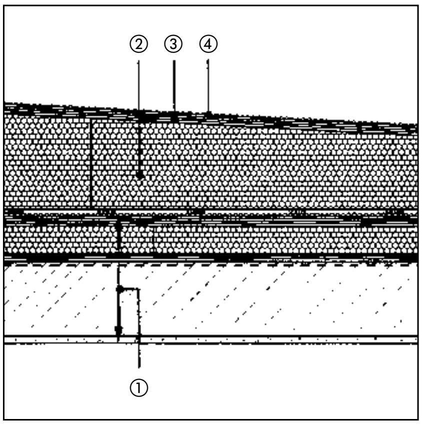
* *See Functions and principle of the layered structure of flat roofs, Item 7.*



Linkage of an intensively cultivated area with a trapped-water irrigation system to a terrace covering with open joints.

⑬ *Water level of the trapped-water irrigation system*
⑭ *Filter fabric laid against the edge of the concrete curbstones*
⑮ *80/20 mm concrete curbstones laid flat to act as the boundary to the garden area*
⑯ *Covering composed of concrete slabs as a walkway*



① *Old roof (without gradient)*
② *Sloping Styropor roofing elements bonded in strips*
③ *First layer of roof cladding: spot-bonded bitumen sheet*
④ *Second layer of roof cladding: Sealed bitumen sheet, coated with slate chippings and bonded over its entire area*

Abb. 1 Dachelemente für Gefälledämmung.

Renovation of flat roof sealing systems

The problem of waste material is assuming ever greater importance in the renovation of flat roofs. The first consideration must, therefore, be whether it is possible to leave the existing insulating layers, even those saturated with moisture, on the roof together with the old roofing sheets. This is a practicable, environmentally friendly and economical solution in many cases.

Any undulations, bubbles or folds present in the now unserviceable roof sealing membrane have to be slit open and pasted over. In such renovations an additional Styropor insulating layer should always be installed under the new sealing membrane. Particularly, since an additional Styropor insulating layer can usually be laid without problem in the thicknesses required by energy considerations on the old roofing sheet after it has been cleaned up*. Just as in a new building, a vapor pressure equalizing layer, a roof sealing layer and surface protection layer have to be fitted on top of this. Securing the roof against lift arising from wind forces is also necessary. In the case of flat roofs having a gradient of less than 2 % it is recommended that the additional thermal insulation be constructed as a sloping insulating layer composed of sloping Styropor elements to produce controlled run-off of water.

* *A separating layer, composed e. g. of coarse fiberglass, is needed if the old roof sealing membrane is not compatible with Styropor.*

Abb. 2
Die Rollbahn, bzw. Rollbahnen verklebt mit Kaltkleber.

References

- Industrieverband Hartschaum e.V. [German industrial association for rigid foam]: “Styropor insulating panels” [in German]
- Zentralverband des Deutschen Dachdeckerhandwerks [Central association of German roofers]: “Code of practice for heat conservation in roofs” [in German]

Note

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Technical Information

Styropor® 620

BASF Plastics

44414 January 1998

® = Registered trademark

5 Building

Bonding expanded Styropor foam – General

Introduction

One of the most important methods of fixing Styropor foam is to bond it with an adhesive. Best results are achieved by selecting the right adhesive for a particular job. This entails knowledge of the processes involved in the structural design and of the correct mode of operation. In the text that follows, therefore, we will explain the basic considerations and terms which are of importance in connection with this.

What is bonding?

Bonding is the joining of materials with the aid of an adhesive. DIN 19 921 defines an adhesive as a non-metallic substance which is capable of holding together (or bonding) materials by the processes of superficial sticking (adhesion) and attractive forces between the molecules of the adhesive (cohesion*) without fundamentally altering the structure of the materials.

At the boundary surfaces of two solid materials forces are in operation which cause mutual attraction; these are adhesive forces. At less than 1/1000 mm, the range of these forces is small. In exceptional circumstances they may actually bond materials together. For example, two pieces of metal, whose surfaces have been ground extremely flat and thoroughly cleaned, will adhere strongly to one another when pressed together. Normally however, the surfaces can never be obtained so flat as to enable the intermolecular forces to bridge the gap without the help of an adhesive compound.

The adhesive compound’s job is to form a “bridge” between the surfaces to be bonded. This means that it must develop adhesive forces at the surface of both materials so that in combination with the internal strength (cohesion) of the film of adhesive itself the two surfaces are held together.

The only possibility for the molecules of an adhesive to come sufficiently into contact with a rough surface is when the adhesive is in a fluid state. Without an intermediate fluid (or plastic) phase, no bonding can take place.

The form that this phase takes – whether the adhesive is present as a solution or coated on to the material in the molten state – is of little importance in principle.

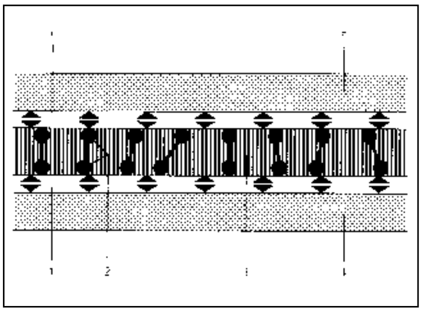

Fig. 1 Schematic section of an adhesive joint

1 = adhesion
2 = cohesion
3 = adhesive film
4 = material 1
5 = material 2

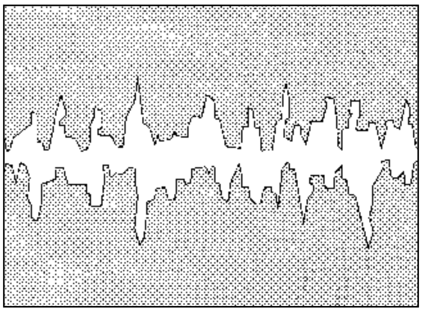

Fig. 2 Magnified cross-section through two materials to be bonded

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* *These and other terms are explained in the short glossary at the back of this bulletin.*

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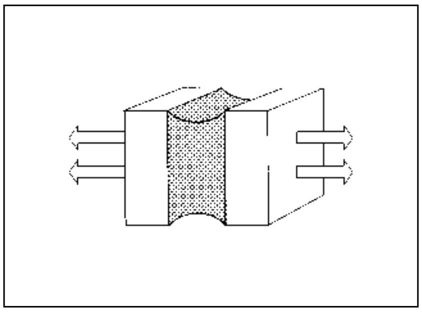

Fig. 3 3 Joint subjected to tensile stress

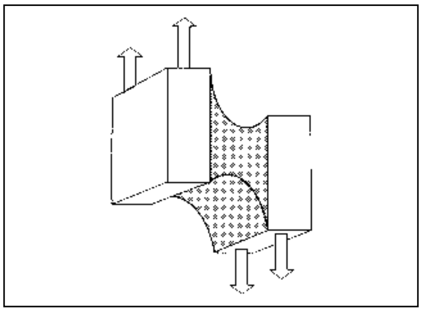

Fig. 4 Joint subjected to shear stress

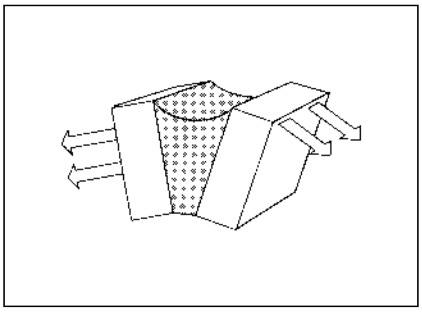

Fig. 5 Joint subjected to cleavage stress

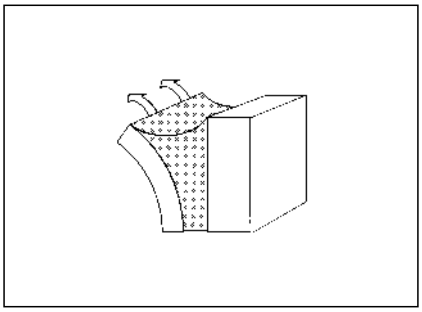

Fig. 6 Joint subjected to peeling stress

Design features of bonding

When workpieces are bonded the following stresses can occur:

a) **Tensile stress**
The forces act perpendicularly to the adhesive layer. This results in an even load over the whole bonded surface (Fig. 3).

b) **Shear stress**
The forces act in the same plane as the adhesive layer, that is to say parallel to it (Fig. 4). This again results in an even load over the whole bonded surface. Tensile shear strength means the shear strength (of the bonded joint) measured by the application of a tensile load. Its value depends on the rate of tear.

c) **Cleavage stresses**
The forces act in such a way that one part of the joint is heavily loaded while the other remains unloaded (Fig. 5). This results in uneven stresses over the whole bonded surface.

d) **Peeling stresses**
The forces act along a thin line at the end of the joint (Fig. 6). Only a fraction of the surface area of the joint is involved. Again, this results in uneven stresses over the surface of the joint.

When designing for adhesives the following points should be noted:

a) **The surfaces of the joint should be made as large as possible to guarantee the reliable transmission of forces.**
Although it is also possible to achieve a strong joint with a high-grade adhesive applied in spots, nevertheless an adhesive joint is principally a surface joint. The forces that act are transmitted through the adhesive film. The adhesive film produces a solid, closed joint that distributes stress evenly over its whole width.

b) **Applied forces should act on the maximum possible surface area of the adhesive layer.**
This means that the joint must be loaded in a way that is favorable to adhesives, i.e. the design should be such that only shear and tensile stresses occur. This way the forces are distributed over the entire surface of the adhesive surface. Stress peaks should be reduced if possible. If the applied forces tend to cleave or peel the adhesive layer the circumstances are already considerably less favorable. The lowest strength values occur when a peeling load is applied, because, here, the edge of the adhesive is used to carry forces and so force distribution only takes place along a line. When bonding different materials, it is necessary to take into account any differences in elasticity or hardness as well as coefficient of expansion of these materials. Two bonded materials with different coefficients of expansion put greater demands on the adhesive. When applying general formulae to calculate the strengths of joints, it is always necessary to consider any special properties of the adhesive.

c) **If peeling forces cannot be avoided in the design, they must be absorbed by appropriate securing members.**
One of the main advantages of bonding is that considerable variations in the gap width can be allowed for by using a suitable adhesive. If the gap is fairly large the joint can often be reinforced by incorporating glass fiber fabric. The fabric must be well impregated by the adhesive and must not contain any air occlusions.

Points to note in the choice and use of an adhesive

So what is the most suitable adhesive for a particular Styropor foam joint? To answer this question, a distinction must first of all be made between the following:

a) Operating conditions that play a role while the adhesive is being handled (mainly producing the adhesive layer, joining and drying the surfaces of the bonded parts).

b) Conditions which prevail continuously in usage, e.g. long-term loading, etc.

c) Economic factors.

a: Operating conditions

1. To what type of substrate are the Styropor panels to be glued? (Is the material absorbent or not?)
2. What is the condition of the substrate on both sides of the joint? (Is it rough or smooth, moist or dry, dusting or non-dusting? Is there a surface layer which must be removed before gluing, e.g. old wallpaper?)
3. Can adhesives containing solvents (flammable or potentially explosive) be used at all? (e.g. buildings which are already glazed and have a central recirculatory air system.)
4. Is mechanical treatment of the substrate necessary? (e.g. removing old paint from an outside wall by sandblasting.)
5. How should the adhesive be applied? The processing time is not only influenced by the type of glue but also by how it is applied, e.g. with a brush or trowel, or by pouring, spraying, rolling or dipping.
6. Under what conditions is drying carried out? The curing time essentially depends on the outside temperature. At elevated temperatures, the curing times are shorter; however there is an upper temperature limit depending on the type of material and

adhesive. In the case of Styropor foam this limit is 85 °C.

The method of drying depends on the nature of the adhesive used. The solvents in contact adhesives and the liquid phase in dispersion adhesives serve merely to produce the required viscosity during application. Afterwards the solvent is quite superfluous. It must be allowed to evaporate, with the liquid phase changing to the solid phase before the adhesive can achieve its proper function, i. e. to bond.

7. In the case of **wet assembly** the parts to be joined must be held together with pressure until the adhesive has set. Here, the use of dispersion adhesives is only possible if at least one of the substrates is porous so that the water can evaporate. With two-component adhesives this is unnecessary.

8. In the case of **contact adhesion,** the solvent is allowed to evaporate from both substrate surfaces to which the adhesive has been applied. Bonding is achieved by pressing both surfaces together within the open assembly time of the adhesive. The correct moment to join the surfaces together is determined by a touch test.

b: Usage conditions

1. To what stresses will the joint produced with the aid of an adhesive be exposed? The stresses can arise from external forces, exposure to water and water vapor, and high or low temperatures. Such conditions may be encountered constantly, occasionally or cyclically. Deformations to the structural components will take place under the influence of external forces. Frequently, these forces must be taken up by the adhesive layer. The effects of cold and heat may cause internal stresses as a result of differential thermal expansion of the joined parts and the adhesive, thus placing great demands on the adhesive's elasticity (expansion coefficient). With many adhesives, there is the danger that embrittlement will occur at low temperatures.

2. What fire-safety requirements must the bond meet? In the case of building applications which require flame retardant properties in the insulating layer, only those adhesives may be used which are guaranteed by proofmark not to impair the flame resistance of the insulating layer. Application of unsuitable adhesives to flammable as well as non-flammable surfaces can change the fire behavior of rigid foam made from Styropor F in such a way that the foam/substrate bond no longer meets the level of fire resistance as set out in the building regulations. In the case of Styropor F foam bonded to solid mineral substrates, officially confirmed tests have demonstrated its flame resistance for a series of different types of joints.

C: Economy

The prices of adhesives are highly variable. However, the adhesive should not be judged solely according to the price per kilogram but rather the cost per square meter of bonded surface should be taken into consideration. Sometimes an expensive adhesive is so simple to use that it is more economical than a less expensive one.

Important points in avoiding defective adhesive joints

For trouble-free gluing, the following points should be observed.

Prerequisites for working with adhesives

a) Adhesives should always be **stored** according to the manufacturers instructions.

b) The **storage stability** (the period of time between manufacture and usage of the adhesive) varies between a few months and several years. Therefore it is important to use up older stocks first. Manufacturers instructions must always be followed.

c) **Clean tools and surfaces** are the fundamental prerequisites for achieving good results. Tools must be cleaned after use.

d) **Do not use too much adhesive.** This is not only wasteful but also slows drying and can even have a detrimental effect on the strength of the bond.

e) **Be careful with adhesives which contain solvents.** There is always the danger of fire. The workplace must be well ventilated.

f) Pay attention to the **manufacturer's recommended pot life** for the adhesive – otherwise, especially in the case of two-component adhesives, there may be some unpleasant surprises.

The main causes of poor bonds are:

a) too little adhesive applied.

b) dry joint; in this case bonding has not been carried out within the prescribed drying time after application of the adhesive. An indication of this is when the surfaces are parted and the films on both surfaces appear undamaged and adhere well to the coated surfaces.

c) absorbent substrate; the adhesive soaks into the substrate so that no more remains on the surface.

d) Shrinkage of the adhesive film leads to reduced elasticity.

Technical Information leaflet 621 deals with adhesives that are used for bonding Styropor foam and their application.

Glossary of terms relating to adhesives

Adhesion: The sum of the forces which enable a substance (adhesive) to stick to the surface of a material. In the case of smooth, impermeable surfaces what is known as the “specific adhesion” is the sole cause of sticking. In the case of porous materials, located between the layer of adhesive and the material there is a region impregnated by the adhesive which results in mechanical anchoring also known as “mechanical adhesion” In most adhesive joints specific and mechanical adhesion operate in combination.

Adhesive: A substance capable of holding materials together by adhesion to the materials and through its own cohesive forces. Animal glue, gum mucilage, and starch paste are all adhesives; cements are also adhesives, but are generally understood to contain fillers that allow the adhesive to be applied thickly.

Aging: Change (usually deterioration) in bonding strength with time under defined conditions.

Cohesion: The process by which a substance is held together by intermolecular forces of attraction; these forces account for the strength of a layer of adhesive.

Consistency: The combination of properties that confers resistance to deformation and flow.

Contact adhesive (Instant adhesive): An adhesive that is applied to both the materials to be joined and adheres to itself on contact after most of the solvent has evaporated. The higher the contact pressure the better the two films of adhesive flow into one another. Adhesion occurs immediately and correction is no longer possible. Used especially in veneer work and the application of laminar coverings to curved surfaces.

Coverage: The area in full-surface application over which a defined quantity of adhesive can be spread and still achieve adhesion. Usually specified in m^2/kg. Strongly dependent on the coarseness and wettability of the surfaces to be bonded.

Curing: The process of changing the properties of an adhesive film by physical, chemical, or physical and chemical means.

Dispersion: Generic term for emulsion and suspension. Dispersal of a finely divided solid, e. g. leather or wood fibers, in a liquid, e. g. water, is called a suspension. Dispersal of a liquid, e. g. oil, in another liquid is called an emulsion.

Dispersion adhesive: An adhesive based on a dispersion.

Drying time: The time that must elapse between the application of a solvent-based adhesive and assembly of the joint.

Elasticity: 1. The property of recovering original size and shape after removal of deforming forces.
2. Loosely, the property of being readily deformed and almost recovering original size and shape after removal of deforming forces.

Emulsion: (see also Dispersion) A system in which fine particles of a liquid are suspended in another liquid without dissolving in the latter. An example is milk in which milk fat is suspended in water.

Filler: A non-adhesive organic or inorganic additive that improves the workability, permanence, strength, etc., or reduces shrinkage stresses of an adhesive.

Flame resistance: Ability of a dried film of adhesive to ignite and burn.

Flammability: Ignitability and combustibility of a dried film of adhesive.

Flash point: The lowest temperature at which a liquid gives off sufficient vapor (under defined conditions) to produce a flash when exposed to a flame. Determination by various methods e. g. Abel-Pensky.

Hardener: A substance or mixture of substances that promotes the setting or curing of an adhesive by chemical means.

Heat resistance: The ability of an adhesive joint to withstand defined stresses at elevated temperatures (highly dependent on test method).

Hot-melt adhesive: An adhesive that is applied in the molten state and sets on cooling.

Hot setting: Setting an adhesive at temperatures of 100 °C or more. The term warm setting is used when the required temperature is below 100 °C but above 30 °C.

Instant adhesive: Synonym for contact adhesive.

Intrinsic adhesion (Specific adhesion): The state in which two materials are bonded by intermolecular forces. Often accompanied by mechanical adhesion.

Joint area: The area of the location at which two materials are held together by an adhesive.

Joint gap: The space between the faces of two materials that are to be held together by an adhesive.

MAC: Abbreviation for maximum allowable concentration; formerly listed for airborne contaminants in places of work by the American Conference of Governmental Industrial Hygienists. The Conference has replaced MACs by threshold limit values (TLV).

MAK: Abbreviation for maximale Arbeitsplatzkonzentration in Germany. Corresponds to the former American MAC (q. v.) or the present American ceiling value, but the MAKs listed by the German Bundesinstitut für Arbeitsschutz are usually (but not always) the same as the American TLVs (see MAC).

Mechanical adhesion: The state in which two materials are bonded mechanically, e. g. by penetration of the surface of a porous material by another material. Usually accompanied by intrinsic adhesion.

Open assembly time: The time between applying adhesive to one or both materials to be joined and assembly of the joint.

Permanence: The ability of an adhesive film to withstand given service conditions.

Pot life (Working life): The time during which a two-component adhesive remains workable (under given conditions) after the components have been mixed together. Information on pot life always relates to temperatures of about 20 °C. At higher temperatures the pot life can be considerably shorter.

Pressure-sensitive adhesive: An adhesive that will adhere to a surface after brief pressure at room temperature, but has permanently low cohesion, which allows the joint to be broken cleanly at any time (e. g. sticking plasters, self-adhesive tape, sticker labels, etc.).

Primer: A usually low-viscosity coating applied in advance to a material to improve its adhesion to an adhesive.

Setting: The process of hardening of an adhesive film by physical, chemical, or physical and chemical means.

Setting time: The time required for an adhesive to set under defined conditions.

Solids content: The mass fraction of non-volatile substances in an adhesive.

Specific adhesion: Synonym for intrinsic adhesion.

Spread: The mass of adhesive applied to unit area of joint; usually specified in kg/m^2.

Suspension: System in which fine particles of a solid are suspended in a liquid without dissolving in it.

Tack: Expression for stickiness.

Thermoplastic: A plastic that softens on heating and sets again on cooling.

Thermoset: A plastic that is essentially infusible and insoluble after curing by heat or chemical means.

Thinner: A mixture of solvents added to an adhesive to change its viscosity.

TLV: Abbreviation for threshold limit value, now applied to airborne contaminants in places of work by the American Conference of Governmental Industrial Hygienists. TLVs are time-weighted averages over a 7-h or 8-h working day, or exceptionally over a 40-h working week. Generally there is an associated maximum allowable concentration (MAC) for short time exposure, such that

$$(MAC) = k\ (TLV),$$

where k, the excursion factor, is greater than 1. However, for certain fast-acting toxic substances the TLV is also a ceiling value (or maximum allowable concentration), i. e.

$$(MAC) = (TLV)$$
$$\text{or } k = 1.$$

TLVs for gases or vapors are expressed as volume fractions (ppm) or as mass concentrations (mg/m^3); TLVs for solid or liquids are expressed as mass concentrations, or as particles per unit volume (for mineral dusts).

Touch test: An assessment of the tack of partly dried films of contact adhesives by light pressure of the finger or finger and thumb. The film should feel slightly sticky but no longer be transferred to the finger as a result of filament formation.

Two-component adhesive: An adhesive that sets or cures by the chemical reaction (cross-linking) of two components (bonding agent and curing agent) that are mixed before use or at the time of forming the joint.

Viscosity: Ability of an adhesive to flow. Non-flowing, pasty products are better described as being of firm consistency.

Warm setting: Setting an adhesive at temperatures above 30 °C and below 100 °C. The term hot setting is used when the required temperature is 100 °C or more.

Wet assembly: The application of adhesive to the least absorbent material and assembly of the joint while the adhesive is still fluid enough to wet and adhere to the second material. Pressure must usually be applied for a certain time until the adhesive has set.

Working life: Synonym for pot life.

Note

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5 Building

Bonding expanded Styropor foam; Adhesives

Introduction

As is well known expanded foams made from Styropor are manufactured from polystyrene containing a blowing agent. Polystyrene is a thermoplastic that is dissolved, or at least softened, by most common solvents. Hence any adhesives applied to expanded Styropor must be solvent-free or contain only those solvents that do not attack polystyrene. To be on the safe side, only those adhesives that are labelled as suitable for EPS (expanded polystyrene) should be used. If there is any doubt about the suitability of a given adhesive, a thin layer must be applied to a small piece of expanded Styropor. The adhesive is then covered with a sheet of glass. In this way it can be seen whether the rigid foam is attacked.

In Germany adhesives manufacturers label their products in accordance with DIN 16920 “Adhesives: Guidelines for classification”. They are first of all identified according to structure, for example as dispersion adhesives, hot-melts, etc. They additionally provide information with regard to adhesive composition, spreading rate, bond strength, suitability for given substrates, whether a primer is required, whether the adhesive is to be applied on one or both sides, drying time, assembly pressure, setting time, etc. All the manufacturer’s instructions must be strictly observed, as otherwise the bonds will be of poor strength.

The product ranges of the manufacturers cover different types of adhesives each of which may be suitable for special applications. Adhesives supplied by different manufacturers may differ widely in their properties, even though they are produced from the same raw materials. Hence, some discernment is required in selecting an adhesive for a given purpose, and the manufacturer should always be consulted in cases of doubt.

With regard to issues of safety in an application the adhesive manufacturer’s instructions should be followed.

Classification of adhesives

It is difficult to classify adhesives in a precise, generally applicable manner. It may be done according to their intended use, composition, or method of processing. The following list is based on differences in intended use and chemical composition.

A Two-component adhesives

1. Adhesives based on epoxy resins.
2. Adhesives based on polyurethane two-component resins.

B Dispersion adhesives

3. Adhesives based on polymer dispersions and natural and synthetic rubber latices.
4. Adhesives based on bitumen emulsions.
5. Mixed adhesives (structural adhesives) in paste form.
6. Mixed adhesives (structural adhesives) in powder form.

C Contact adhesives

7. Adhesives based on solutions of polymers, natural rubber or resins, or synthetic rubber.

D Bitumen adhesives

8. Cold-setting adhesives based on plastic-modified bitumen solutions.

E Hot-melt adhesives

9. Bitumen adhesives: Standard bitumen (B 25 or B 45), blown bitumen (e.g. 85/25), and special adhesive bitumen cements.

F Pressure-sensitive adhesives

10. Pressure-sensitive adhesives made from dispersions.
11. Pressure-sensitive adhesive solutions.
12. Adhesive tapes and films.

Characteristics of individual types

A Two-component adhesives

1. Adhesives based on epoxy resins.
2. Adhesives based on polyurethane two-component resins.

Handling

The individual adhesive components are supplied separately. No more mixture should be prepared than can be used up within the pot life. Setting ensues without solvent by reaction of the adhesive components. The adhesive is applied on one side.

Substrate

The substrate must be dry, even, clean, and degreased.

Applications

Mainly for strong bonds on non-absorbent materials, such as metals or glass; can be used also for other materials.

B Dispersion adhesives

3. Adhesives based on polymer dispersions and natural and synthetic rubber latices.
4. Adhesives based on bitumen emulsions.

Handling

The adhesives are supplied ready for use, and can be applied by spray gun, brush, serrated trowel, or roller. These adhesives set by evaporation of water, and the parts are assembled while the adhesive on both faces is still wet. A bond is achieved after drying, i.e. removal of water.

Substrate

The substrate must be smooth and absorbent; if it is very absorbent it should be primed with adhesive diluted with 5 –10 times its own volume of water. Gypsum plasters or slightly dusting but still load-bearing surfaces are best treated with an impregnating primer.

Applications

Can be used only on concrete, masonry, plaster, or wood-based materials, which allow absorption of water.

5. Mixed adhesives (structural adhesives) in paste form (mixtures of polymer dispersions, fillers and cement).
6. Mixed adhesives (structural adhesives) in powder form (mixtures of hydraulic binders, fillers and redispersible powder).

Handling

Structural adhesives in the form of pastes are mixed with cement and those in the form of powders are mixed with water. They are applied wet on one side. Bonding is based on drying of the adhesive and the hydraulic binding of the water.

Substrate

The substrate must be absorbent, but can be either rough or smooth; unevenness of up to 10 mm can be taken up. Very absorbent substrates, gypsum plasters, and slightly dusting but still load-bearing surfaces should be primed with adhesive diluted with 5 –10 times its own volume of water.

Applications

Primarily used for absorbent substrates such as concrete, masonry, plaster and wood-based materials; can also be used for filling rough surfaces. An immediate bond is formed, which strengthens when the hydraulic binder hardens.

C Contact adhesives

7. Adhesives based on solutions of natural rubber and resins, or synthetic rubber or polymers.

Handling

The adhesives are supplied ready for use. They are applied by a finely serrated trowel, a brush, or spray gun to both parts to be joined. About 10 min to 30 min after the adhesive has been applied (depending on temperature and humidity) the parts can be assembled, pressed together, and lightly tapped. The adhesive is flammable. Thinners should not be used except in accordance with the manufacturer’s instructions.

Substrate

The substrate must be smooth, dry, and degreased; it can be absorbent or non-absorbent, but very absorbent substrates should be pretreated with dilute adhesive.

Applications

Used for bonding EPS to a wide variety of substrates, but subsequent failure of the bond is common, owing to frequent neglect of the manufacturer’s instructions relating to the open assembly time. Useful for temporary bonding of Styropor foam panels under unventilated claddings.

D Bitumen cold-setting adhesives

8. Cold-setting adhesives based on plastic-modified bitumen solutions.

Handling

The adhesives are supplied ready for use and are spread in strips by an applicator. The pasty adhesive is made to form a bed, and the rigid Styropor panels are laid in it. The time allowed for final, fine positioning of the panels is five minutes.

Substrate

The cold-setting adhesives can be applied on all substrates that permit bonding with bitumen, e.g. solid reinforced concrete ceilings, prefabricated pumice concrete parts, sheet steel sections, bitumen roofing rolls, etc. It may be necessary to apply a coat of bitumen beforehand.

Applications

The technique preferred in practice for unventilated roofs is to lay the rigid Styropor panels in strips and bond them to the substrate with the cold-setting bitumen adhesive. The number of adhesive coats is laid down in DIN 1055 “Design Loads for Buildings”.

E Hot-melt adhesives

9. Bitumen hot-melt adhesives: Standard bitumen B 25 and B 45, blown bitumen, e.g. 85/25, and special adhesive bitumen cements (bitumen with additives, adherent from 50 °C).

Handling

Standard or blown bitumen is applied plentifully to the substrate while special adhesive bitumen cements can be spread directly on to the Styropor panel. The expanded Styropor is pressed into position almost immediately, but the temperature of the adhesive should then be not more than about 100 °C. The adhesive sets rapidly by cooling. Application of adhesive on one side.

Substrate

The substrate should be dry. It may be smooth or roughened, and absorbent or non-absorbent.

Applications

Bitumen hot-melt adhesives are used mainly for roofing, industrial insulation, and cold store construction.

Field of application

	Types of adhesive	Brickwork	Concrete	Plaster & rendering	Gypsum plasterboard	Wood	Fiberboard & chipboard	Woodwool slab	Asbestos-cement sheet	Ceramics	Roofing felt	Light metals	Steel, iron, sheet metal	Glass, glass-reinforced plastics	Expanded Styropor foam	Textiles	Decorative plastic laminates	Paperboard	PVC sheet	Polyethylene film
		Suitable for bonding expanded Styropor foam to:																		
A	1. Epoxy resins	○	◒	◒	◒	◒	◒	○	●	●	○	●	●	●	◒	◒	●	◒	◒	○
	2. Polyurethanes	○	◒	◒	◒	◒	◒	○	●	●	○	●	●	●	◒	◒	●	◒	◒	○
B	3. Polymer dispersions	●	●	●	●	●	●	●	◒	◒	○	○	○	○	◒	●	◒	●	○	○
	4. Bitumen emulsions	●	●	●	●	●	●	●	◒	◒	○	○	○	○	◒	●	◒	●	○	○
	5. Structural adhesives (paste form)	●	●	●	●	●	●	●	◒	◒	○	○	○	○	◒	●	◒	●	○	○
	6. Structural adhesives (powder form)	●	●	●	●	●	●	●	◒	◒	○	○	○	○	◒	●	◒	●	○	○
C	7. Contact adhesives	◒	●	●	●	●	●	◒	◒	◒	○	●	●	●	●	●	●	●	◒	○
D	8. Bitumen cold setting adhesives	●	●	●	◒	○	◒	◒	◒	○	●	◒	●	○	●	○	○	○	◒	○
E	9. Bitumen hot-melt adhesives	●	●	◒	◒	●	●	●	●	●	●	●	●	◒	●	◒	◒	◒	○	○
F	10. Pressure-sensitive adhesives (dispersions)	○	◒	◒	◒	◒	◒	○	◒	◒	○	◒	◒	◒	◒	◒	◒	●	○	○
	11. Pressure-sensitive adhesives (solutions)	○	◒	◒	◒	◒	◒	○	◒	◒	○	◒	◒	◒	◒	◒	◒	●	◒	○
	12. Self-adhesive tapes & films	○	◒	◒	◒	◒	◒	○	◒	◒	○	◒	◒	◒	◒	◒	◒	●	◒	●

● = Commonly used
◒ = Not commonly used; but possible
○ = Not possible

F Pressure-sensitive adhesives

10. Pressure-sensitive adhesives made from dispersions.
11. Pressure-sensitive adhesive solutions.
12. Adhesive tapes and films.

Handling

One-sided application of the adhesive or attachment of the adhesive tape. The joint can be assembled any time after the solvent or aqueous phase has evaporated; an immediate bond of limited strength is formed with slight pressure.

Substrate

The substrate must be smooth, dry, and degreased; it can be absorbent or non-absorbent.

Applications

This type of adhesive is usually only used when a strong, permanent bond is unnecessary or impossible to achieve; a common use is for bonding thin films to expanded Styropor foam.

Note: The information in this bulletin is intended as a brief review; it cannot replace the adhesive manufacturer's detailed advice and instructions, which should always be followed.

Note

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5 Building

Shuttering for ceilings, cavity work

1 General

An important costs factor in placing concrete is the formwork. The costs involved depend on the geometry and finish of the concrete parts. The numerous recesses that have to be formed for services in concrete structures necessitate high costs in labour and materials.

The traditional method of nailing wooden boards together to form a recess is time-consuming and expensive. Styropor box-outs can be easily and rapidly cut out from blockware by conventional tools. It is precisely in cases where the box-outs are of complicated geometry that the very ease with which they can be produced and removed is a great advantage.

2 Production of box-outs

Box-outs for recesses and slots in all shapes and sizes can be easily obtained from expanded Styropor by unskilled labour (Fig. 1).

Standard box-outs in various sizes can be supplied. The density is usually 13 – 15 kg/m^3. They can be fashioned on the building site by conventional tools, e.g. handsaws or circular saws (Fig. 2). If large numbers have to be produced, e.g. in builders' yards and precast-concrete works, an advantage may be gained by hot-wire cutters (Fig. 3).

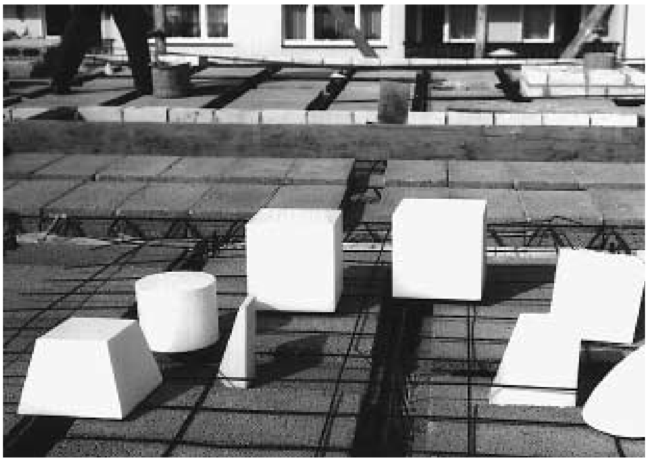

Fig. 1 Various expanded Styropor box-outs.

3 Securing the box-outs

Owing to their low weight (density of 13 kg/m^3 or more), Styropor box-outs must be firmly secured before the concrete is placed, as otherwise they may float or be pushed out of position. No difficulty is involved in nailing them to wooden forms. They can be attached by nails, wire, staples, or adhesives. If they are to be attached to masonry, concrete or metals, adhesives are suitable (Figs. 4 and 5).

The adhesives must not contain any solvents that attack the expanded plastic and must be expressly labelled as “adhesives for expanded Styropor”.

Dispersion-type adhesives are suitable for bonding expanded Styropor to wood, concrete, plaster, or masonry. Preference should be given to hot-melt, e.g. bitumen, or contact adhesives for fixing to metal surfaces. In any event, it is always advisable to clean the surfaces before they are bonded. Normally, the adhesive need be applied only on the one side.

Many of the oils used as formwork release agents attack expanded Styropor. This is a fact that has to be taken into consideration for fair-face concrete but not for recesses. As a rule, wax release agents do not attack expanded Styropor.

4 Removing the box-outs

Expanded plastic box-outs can be rapidly removed by simple tools from slots and recesses in cured concrete. If the form passes through a structure, it can be easily pushed out.

If difficulties are encountered in removing them mechanically, the box-outs can be burnt away, e.g. with a blowlamp or a welding torch. However, this method must not be resorted to in an enclosed space owing to the large volumes of soot that are given off. It is also unsuitable for fair-face concrete. Care must be taken to ensure that there are no other combustible materials in the vicinity.

Another means of removing expanded plastics from slots and recesses is to melt them, e.g. by electrically heated wire loops or blowers that discharge air at a temperature of 200 °C. However, cutting out or melting in this manner is unsuitable for fair-face concrete, because the melted polystyrene adheres to it.

Fig. 2 Cutting the box-out with a saw.

Fig. 3 Cutting box-outs with a hot wire.

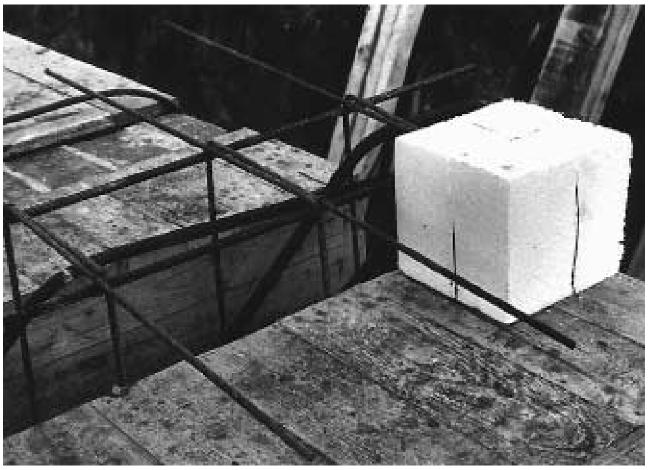

Fig. 4 Box-out.

Styropor box-outs can be readily removed from fair-face concrete by sandblasting.

A large number of recesses of the same size often have to be formed in concrete structures. In this case, it is advisable to wrap the box-outs in polyethylene film secured by nails. After the concrete has cured, the film is slit open, and the expanded Styropor blocks, which are slightly conical, can be easily removed and rewrapped in film for reuse.

5 Economics

Depending on the complexity and size of the slots and recesses, Styropor box-outs allow savings in material and labour of between 20% and 70 %. In countries with a high wage level, labour-intensive wooden box-outs can no longer be economically justified.

6 Conclusion

Expanded Styropor, which is a very versatile building material, is also an indispensable aid in forming slots and recesses. In this case, too, the decisive advantages in its favour are its economics and the ease with which it can be handled and worked.

Note

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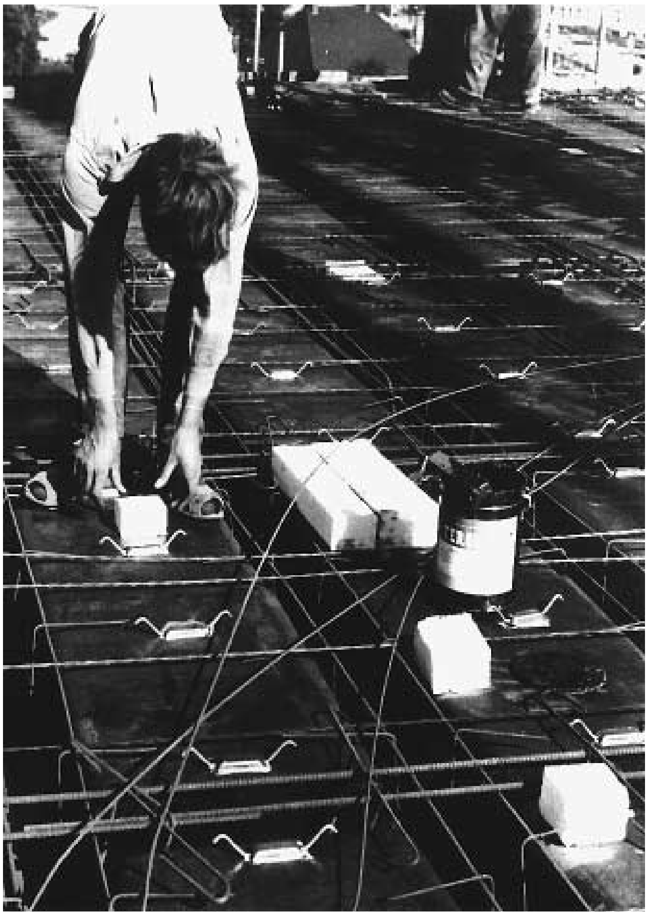

Fig. 5 Fixing box-outs with an adhesive.

Flg. 6 Box-outs for a concrete floor slab in a multi-storey building.

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5 Building

Shuttering for ceilings; ribbed ceilings and floor; reusable formwork

1 Seeger lightweight forms for reinforced concrete ribbed, waffle, and beam-and-slab floors

In the Seeger system for constructing ribbed, waffle, and beam-and-slab floors, expanded Styropor blocks are used as forms that can be frequently reused. The forms are not intended for a given grid plan or modular system, but are made to order in the required dimensions and are supplied ready for installation on the building site.

A flat air cushion specially intended for this application and of the requisite size is placed on top of each block (Fig. 1). A connection on the air cushion leads downwards through a hole in the centre of the form.

The form and the air cushion are wrapped in Lupolen® film, the ends of which are simply stapled to the form. The film acts as a release agent.

The forms thus prepared are placed on a flat open formwork and held in place by boards. The steel reinforcement is then set out, and the concrete is placed (Fig. 2).

After the concrete has cured and the lower formwork has been removed, the film on the underside of the forms is cut open from corner to corner (Fig. 3).

The air cushion is inflated by means of a small portable compressor, e. g. of the type used for spraying paints, or a compressed-air cylinder (Fig. 4).

As the air cushion expands, it forces the form from the concrete and the film. The slight conicity of the forms facilitates removal.

The remainder of the film hanging from the recess can be easily pulled out by hand (Fig. 6). The forms recovered are rewrapped in film and can thus be reused. The same applies to the air cushions (Fig. 7).

Fig. 1
Expanded Styropor form with air cushion


Fig. 2 Setting out the forms on open formwork


Fig. 3 Undersight of floor after removal of the forms


Fig. 4 Inflating the cushions with compressed air


Fig. 5 The air cushions force the forms from the floor

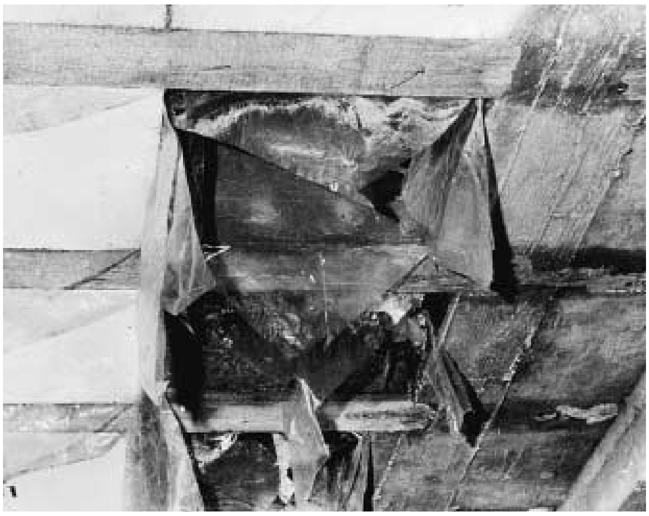
Fig. 6 Recess in floor after removal of form


Fig. 7 Wrapping the form in polyethylene film for reuse

These forms are economical if they can be frequently reused in ribbed and waffle floors. This case arises in multi-storey buildings and in floors that have to be laid in several sections.

The following times were determined on a building site for setting and recovering the forms in a floor span of 16 x 24 m = 384 m^2.

1. Setting out lightweight forms on prepared falsework	21 hours
2. Recovering the forms and air cushions and removing the remaining film	11 hours
3. Rewrapping the forms and air cushions in film for reuse	32 hours
Total	64 hours

Thus the time required for assembling, striking and remaking the forms is 64 : 384 = 0.166 hours (= 10 minutes per square metre of floor).

Since conditions vary from the one building site to another, the above figures cannot be considered as a general rule, but must be regarded merely as a guide.

Fig. 8 *Oversize form with air cushion wrapped in polyethylene film*

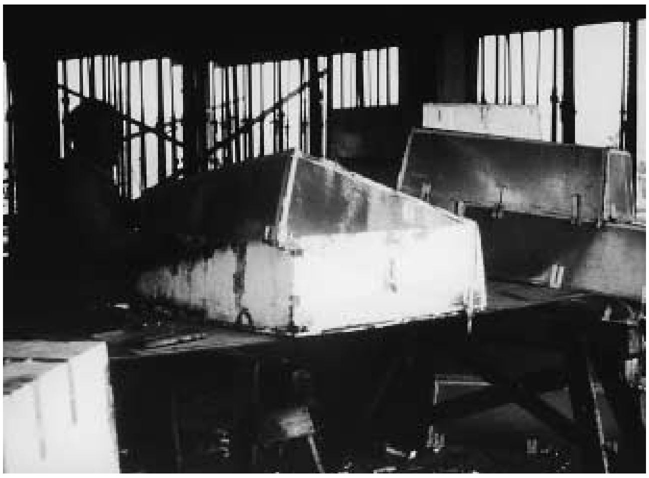

Abb. 9 *Oversize form with polyester hood*

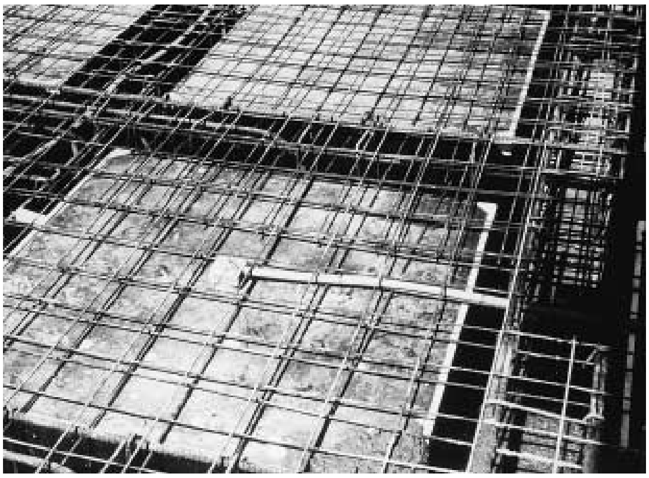

Fig. 10 *Oversize form with plywood hood*

Fig. 11 *Removing oversize form from recess*

Experience has shown that the losses in trimming and fitting are of the order of 1 – 2 % for each time the forms are used. The number of times that they can be reused depends on how they are handled and on the specifications for the finished concrete. If they are carefully handled, they can be reused 20 – 25 times. Forms that can no longer be reused can be retained as a source of material for blockouts.

By virtue of their extremely light weight, expanded Styropor forms are easy to handle in making up and striking the formwork and easy to transport. They also reduce the risk of accidents. Together with the air cushion and the Lupolen wrapping, a form of 1.00 m x 0.50 m x 0.40 m weighs only 4.0 – 5.0 kg.

The lightweight forms can be walked on and need no special protection while they or the reinforcement are being set out. Provided that planks are laid over them, they will also support loaded wheelbarrows.

Seeger lightweight forms produced from expanded Styropor can be used in all buildings with ribbed or waffle floors.

2 Large recesses

Reinforced concrete ribbed, waffle, and beam-and-slab floors that extend over wide spans and have to support heavy loads can be economically produced with particularly deep and wide coffers (Fig. 8).

These oversize waffle forms can be produced in one piece in sizes up to 1.25 m x 1.25 m x 1.00 m. Larger forms are produced by bonding a number of parts together by means of adhesives.

The remarks in Section 1 on air cushions, wrapping in film, and removal from the formwork also apply in this case.

The large expanded Styropor waffle forms are provided with protective covers for the construction of smaller fair-faced concrete coffered and waffle floors. The covers may be produced from flat, glass reinforced polyester panels (Fig. 9) or from 4-mm plywood panels coated with a plastic (Fig. 10). In this case, there is no need to wrap the forms in film. After the expanded plastic block has been ejected (Fig. 11), the covers can be withdrawn from the floor without difficulty, because they have very little rigidity. They can also be frequently reused.

Fig. 12 Form for fair-faced concrete waffle floor

Fig. 13 Forms in place with steel reinforcement

3 Fair-faced concrete floors

Integral thermoformed plastics hoods, stiffened with expanded Styropor blocks, are used in the construction of fair-faced waffle floors. Since they are completely braced by the expanded Styropor, they may be quite thin and thus inexpensive (Fig. 12).

All the edges on the plastics hoods are slightly rounded off. The projecting rims on the periphery of the plastic mouldings serve as spacers when the forms are set out on close sheeting and also provide the forms for the lower soffit faces. These very smooth plastics hoods guarantee a fair-face finish of the highest quality.

Again, the forms are removed from the floor by means of the air cushion, which lies between the expanded Styropor block and the plastics hood. The hood itself remains in the floor, but can be removed by hand owing to its great flexibility.

Note

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5 Building

Special shuttering; basement windows

The small casement windows often provided in basements and cellars can be disproportionately expensive when the walls are of reinforced concrete. Special box-outs must be made for the openings, and the installation of the windows themselves requires a great deal of work.

Most of the additional work and expense can however be saved by using special Styropor mouldings that replace box-outs and hold the metal window frames in the required position. The complete unit consists of the window itself – with painted, galvanized, or plastic-coated metal frames – encased in moulded Styropor, which in turn is wrapped in polyethylene film to keep it clean. The unit weighs scarcely more than the complete window, and can be handled without difficulty.

The way the unit is mounted in the wall form is shown in Fig. 1. A wooden batten is nailed to the inside of the outer sheeting (Fig. 1a & 2), and the unit is pushed onto it (Fig. 1b & 3). A second batten is placed in the slot provided, and the inner sheeting is placed in position (Fig. 1c). The second batten is nailed through the inner sheeting, and the concrete is placed and vibrated on either side of the unit (Fig. 1d). The necessary battens and nails are supplied with the units.

After the wall form has been struck the Styropor form can be left in position until the building is complete. It is then opened and removed, leaving the window properly embedded and the opening cleanly finished (Fig. 4).

Units are supplied for wall thicknesses of 25 cm, 30 cm, or 35 cm.

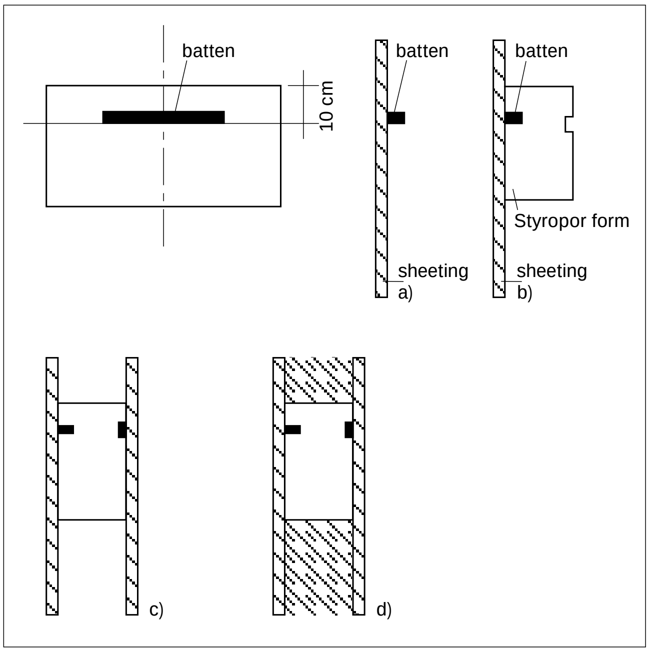

Fig. 1
Mounting unit in wall form

Fig. 2 Nailing the first batten to the sheeting

Fig. 3 Forcing the unit onto the first batten

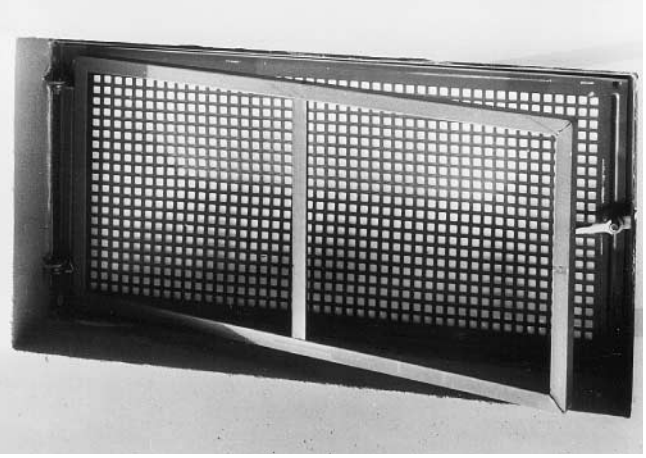

Fig. 4 Completed window
(Schöck Betonelemente GmbH, 76534 Steinbach)

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors from the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Technical Information

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Styropor®

Forschungsgesellschaft für Straßen- und Verkehrswesen
Arbeitsgruppe Erd- und Grundbau

Code of Practice Using Expanded Polystyrene for the Construction of Road Embankments

Edition 1995

English translation of the German „Merkblatt für die Verwendung von EPS-Hartschaumstoffen beim Bau von Straßendämmen“

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Introductory note

The present Code of Practice was drawn up by the Lightweight Materials task group of the working committee on roadbuilding on soils of low bearing capacity.

It is intended to give advice on the use of expanded polystyrene in earthworks in the light of practice, particularly experience gained in Scandinavia, Japan, and the Netherlands.

Contents

1 Introduction

To reduce settlement of earthworks constructed on soils of low bearing capacity, various techniques, including soil replacement, surcharging, and vertical drainage, have been developed in the past. Expanded polystyrene (EPS) block has been used successfully for this purpose, which has led to consideration of how this material can be used in Germany too.

In Germany, extensive experience of the use of EPS block in road construction is confined to applications involving geothermal insulation[1], but the *Bundesanstalt für Straßenwesen* has conducted several large-scale trials in which the fill was partly replaced by EPS blocks[2]. In drawing up the present Code of Practice, which indicates a number of ways of using EPS block in road construction, the Lightweight Materials task group of the Society's working committee on roadbuilding on soils of low bearing capacity has taken account of the results of those trials.

It must be emphasized that advice given here is not an alternative to a site investigation by a competent consulting engineer.

According to special investigations, the economics of using EPS block in roadbuilding compares not unfavourably with those of alternative ways of tackling the problem.

2 Special terms

Expanded polystyrene, EPS

Cellular polystyrene, commonly made from expandable polystyrene bead, which is available commercially under a variety of tradenames, e.g. Styropor®. EPS is a rigid closed-cell cellular plastic (ISO 472–1979). The commercial material has extremely low density but it is strong enough for inclusion in earthworks[3].

EPS block

Blocks of cellular polystyrene, generally made from expandable polystyrene bead[3, 4].

Surcharging

Temporarily depositing loose material above formation to increase the rate of consolidation; used in the construction of embankments on soils of low bearing capacity to anticipate inherent settlement[5].

3 Applications

3.0 Overview

There are many kinds of EPS, supplied in many forms, but the material found useful in road construction has a density of at least 20 kg/m^{-3} and comes in rectangular prisms 1.0 m x 0.5 m in section and 4 m long. EPS block of lower density may be used for the cores of noise barriers.

As detailed in § 6, the EPS block is used in embankments to replace part of the mineral fill. In this way, the value of the gross loading intensity at the base of the embankment can be reduced to less than that of the bearing capacity of the ground below. The technique exploits the low density and advantageous physical properties of EPS (cf. § 4).

EPS has been used by the construction industry for years without harm to health or the environment. Scrap EPS can be reused or recycled[6].

The uses of EPS block in earthworks include
- construction of new embankments,
- widening existing embankments,
- repair of damage due to settlement or subsidence,
- construction of noise barriers, backfill adjacent to construction works.

3.1 Construction of embankments

Replacing some or most of the fill in embankments in accordance with the principles described in § 6 (and illustrated by Fig. 1 – 3) can solve many problems. For instance:
- Loads can be adapted to the bearing capacities of soils.
- Interference settlement of neighbouring structures can be avoided.
- Roads may not need to be diverted to avoid difficult ground (e.g. extremely soft soils, ground close to rivers and lakes, old refuse tips).
- Less or no soil may need to be replaced.
- Less material need be transported.
- Construction work can be completed sooner.

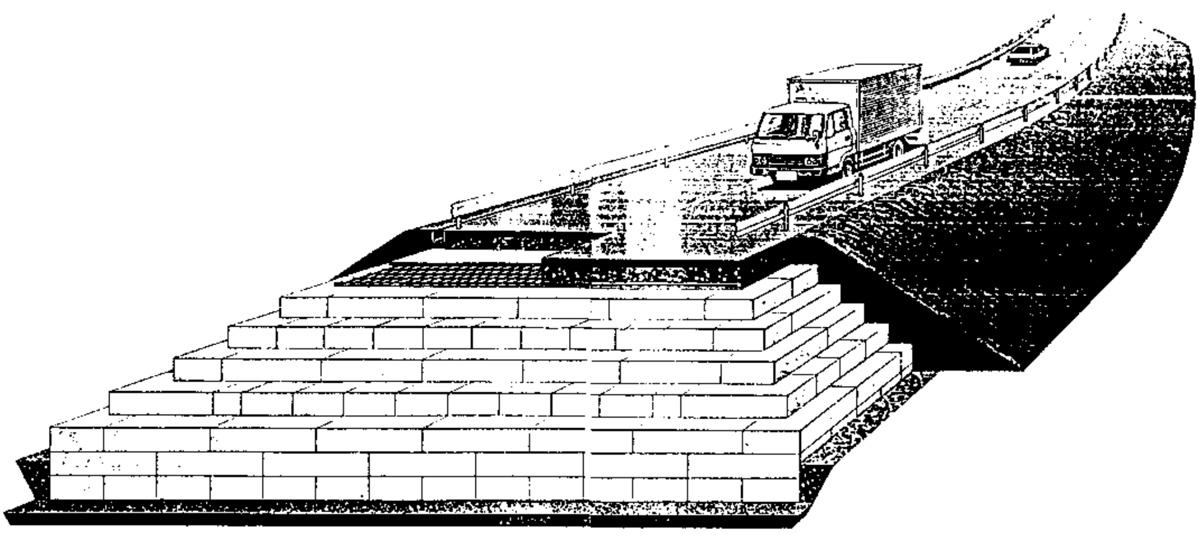

Fig. 1 Principle of building road embankments on cores built from EPS block

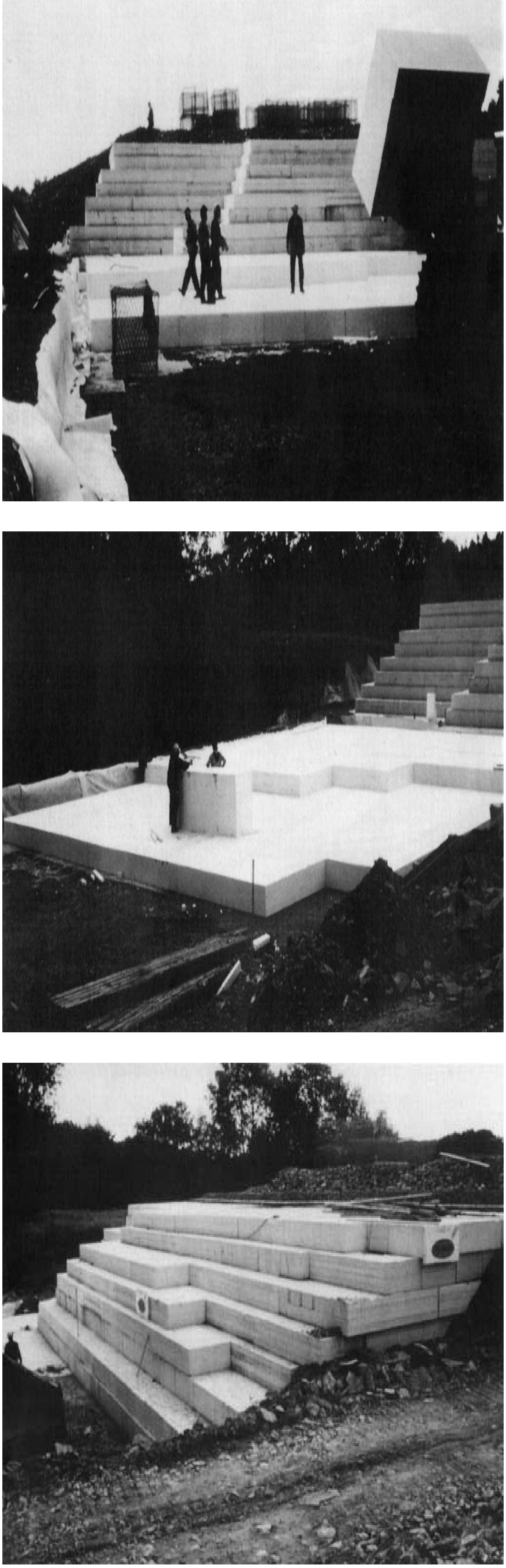

Fig. 2 Construction of EPS-cored embankment for a section of the Göteborg-Uddevalle motorway (E 6), Sweden

Fig. 3 Construction of EPS-cored embankment for a section of the new Hardinxveld-Giessendam access road, Netherlands

Table 1a Physical properties of EPS block

Quantity/unit	Numerical value			Method
Density	15	20	30	DIN 53420
Stress/kPa				
instant strain 10%	60–110	110–160	200–250	DIN 53421
final strain 1.5–2.0%	25–30	40–50	70–90	
Flexural strength/kPa	60–300	150–390	330–570	DIN 53423
Shear strength/kPa	80–130	120–170	210–260	DIN 53427
Elasticity modulus/MPa in compression	1.6–5.2	3.4–7.0	7.7–11.3	DIN 53457
Volume fraction of water 50-mm cube immersed 7 d	≤ 7%	≤ 7%	≤ 7%	DIN 53433

3.2 Construction of bridge ramps

Because of the heights that have to be reached, foundations of ramps leading to bridges may present difficult technical problems. Concerning the gradients of such ramps there is no freedom of choice, and surcharging is not usually an option, since material would have to be piled too high. Consequently, the answer when the bearing capacity is otherwise too low is soil replacement more often than not. In this way, differential settlement of bridge and ramp can be avoided.

It has been found however, particularly in Sweden, that the settlements of ramps can be reduced to those of the bridges they serve by incorporation of EPS block (cf. Fig. 4).

3.3 Widening embankments

Differential settlement is a common problem when existing embankments have been widened. Consolidation due to the weight of the new fill may lead to considerable deformation, possibly causing changes in crossfall or longitudinal cracking, or both.

If the additional fill is made up partly of EPS block, subsequent defects can be minimized or avoided altogether. The advantage of using this extremely light material is especially obvious when the site offers little space, since the novel method of construction lends itself well to the use of gabions (see Fig. 5). In extreme cases, embankment slopes not far removed from the vertical are possible.

3.4 Repairing defects caused by settlement

Localized settlement or subsidence, whose possible causes are many, is a frequent source of damage to roads. Quite often, a limited area of soil with reduced resistance to consolidation is causing the trouble, and restoring the road formation with additional mineral fill simply adds to the load and the likelihood of renewed settlement. If however much of the mineral fill is replaced by EPS block (as shown in Fig. 6 & 7 for settlement adjacent to a bridge or culvert), the loading intensity is reduced considerably, so that no further settlement takes place.

3.5 Miscellaneous applications

Other applications involving the use of EPS block in place of mineral fill that have been tried successfully outside Germany include
- repair of damage due to slip,
- raising the height of an existing embankment,
- construction of subgrade for extensive pavement (e.g. for motorway service areas) on soils of low bearing capacity,
- construction of noise barriers on ground prone to excessive settlement,
- bridging culverts, conduits, etc.,
- backfill adjacent to construction works,
- construction of embankments near structures that would be adversely affected by interference settlement.

4 Technical data on EPS block

4.0 General

EPS block is made up of rigid closed-cell cellular thermoplastic whose mechanical properties are largely functions of its density. Values of the physical quantities relevant to the use of EPS block in earthworks, taken from Ref. 3, are given in Table 1a.

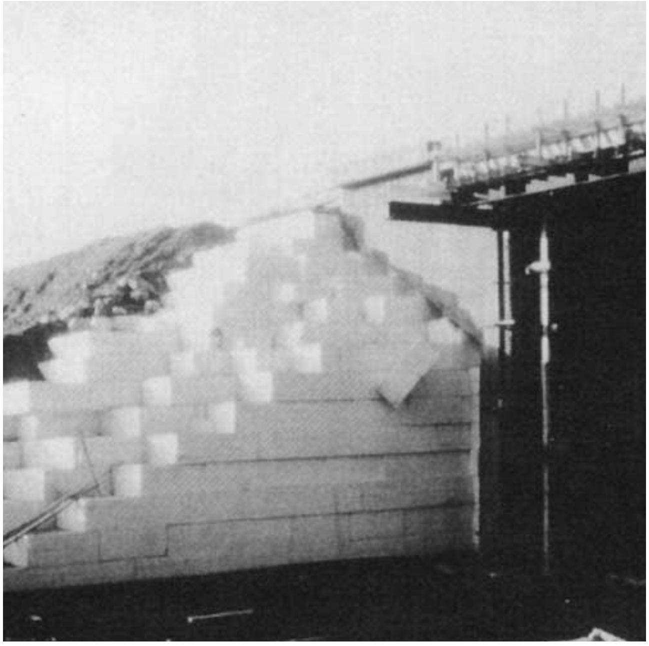

Fig. 4 Construction of EPS-cored ramp for a bridge over a section of the Göteborg-Uddevalle motorway (E 6), Sweden

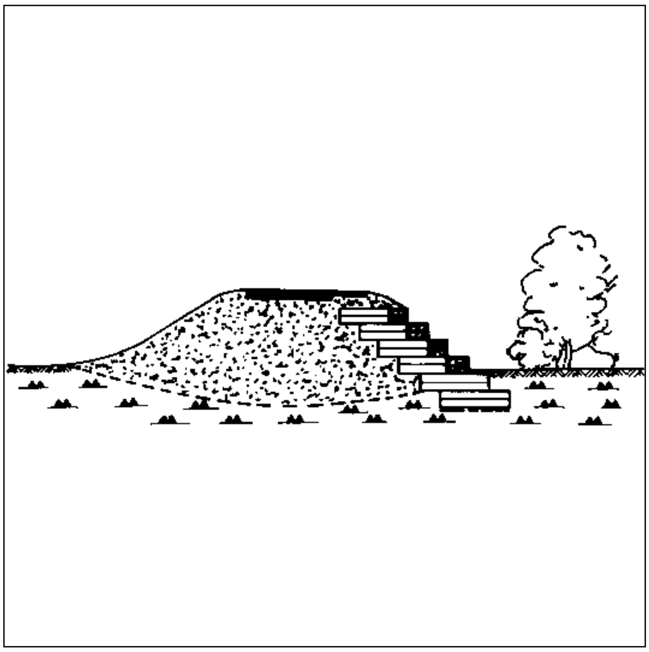

Fig. 5 Widening a steep-sided embankment with EPS block

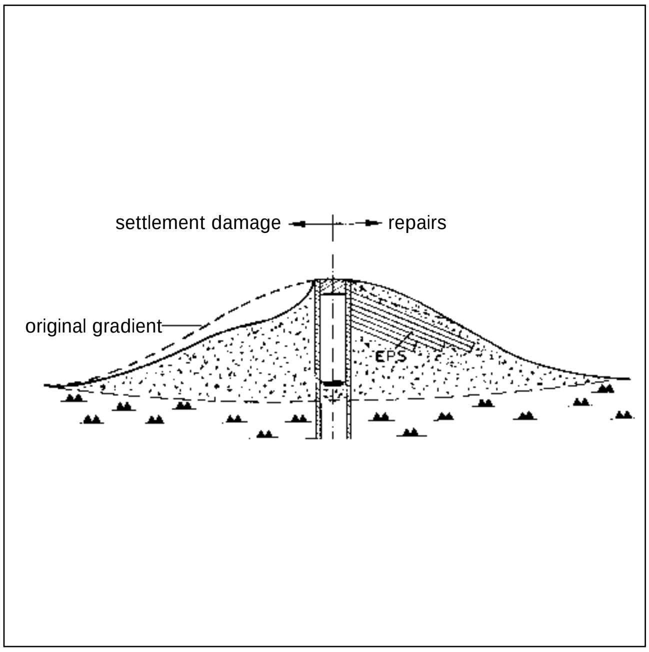

Fig. 6 Reducing weight with EPS block before repairing damage to a ramp (lengthwise section – horizontal scale greatly foreshortened).

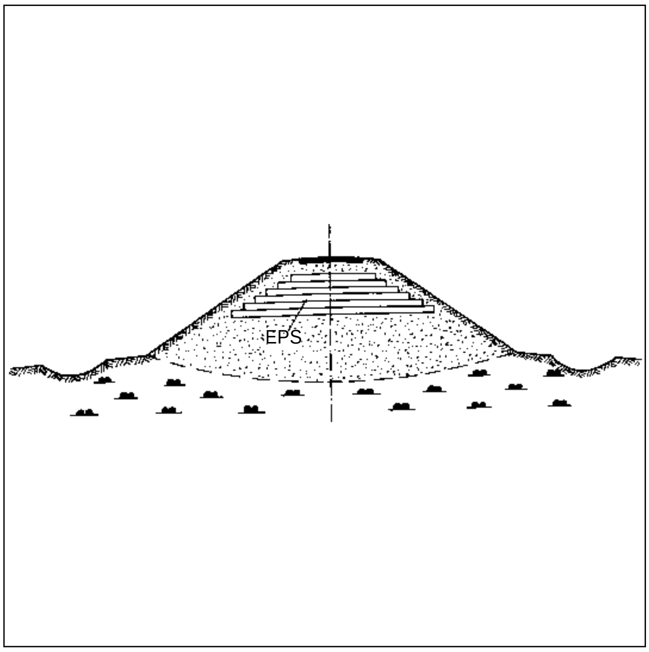

Fig. 7 Cross-section corresponding to Fig. 6

4.1 Resistance to compression

Like other mechanical properties of EPS block, resistance to compression is a function of the density of the dry material (cf. Table 1). Experience gained over many years has shown that although the volume fraction of water in EPS that is constantly exposed to water tends to a steady value of about 10 %, this has no effect on the mechanical properties of the material.

When EPS is compressed in laboratory tests in accordance with DIN 53421, stress-strain curves characteristic of viscoelastic behaviour are obtained (cf. Fig. 8). Brittle failure does not occur, so it is usual, for quality control purposes, to quote the stress corresponding to strain of 10 %. Strain of this magnitude is however of no practical significance, since it is no longer reversible. When EPS is subjected to small stresses, there is little plastic deformation, as tests by the *Bundesanstalt für Straßenwesen* have shown, and what there is does not increase after repeated loading and unloading[2].

As far as prolonged compression is concerned, only initial strains up to about 1.5 % are of interest. Over this range, from zero to 1.5 % or so, the stress is strictly proportional to the initial strain, the slope increasing with density, as shown in Fig. 9. If the stress is maintained, the strain increases, but very slowly. Fig. 10 shows isochronous stress-strain curves corresponding to Fig. 9 but for compressions continued over a period of 50 a. For any given stress, the creep strain is the difference between the initial and final strains.

When the EPS fill (density ≥ 20 kg·m^{-3}) is covered with road construction materials of more than 0,6 m thickness, plastic deformation resulting from dynamic traffic loads is negligibly small.

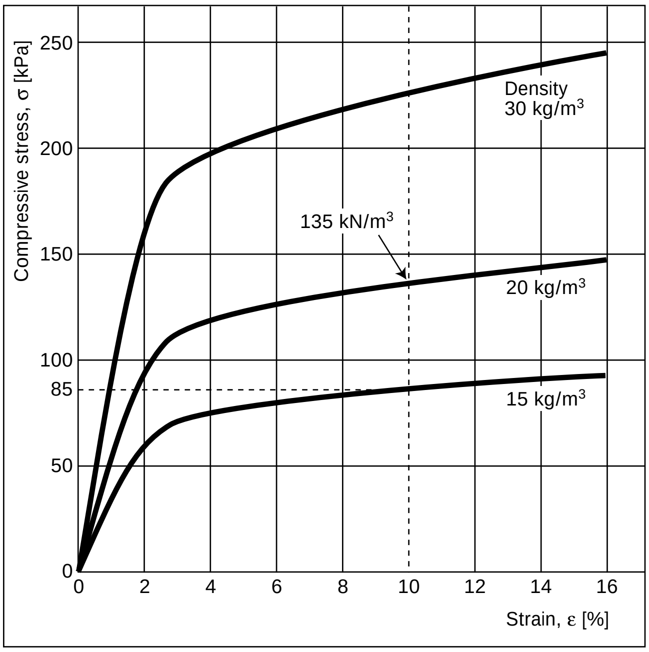

Fig. 8 Compressive stress, σ, vs strain, ϵ, for EPS of various apparent densities, ρ, measured in accordance with DIN 53421. The value of σ are averages.

4.2 Chemical behaviour

EPS block is resistant to soaps and to inorganic substances such as dilute acids and alkalis and salt solutions. It is attacked by organic solvents, including hydrocarbon fuels and lubricants. Further details are given in Table 1b.

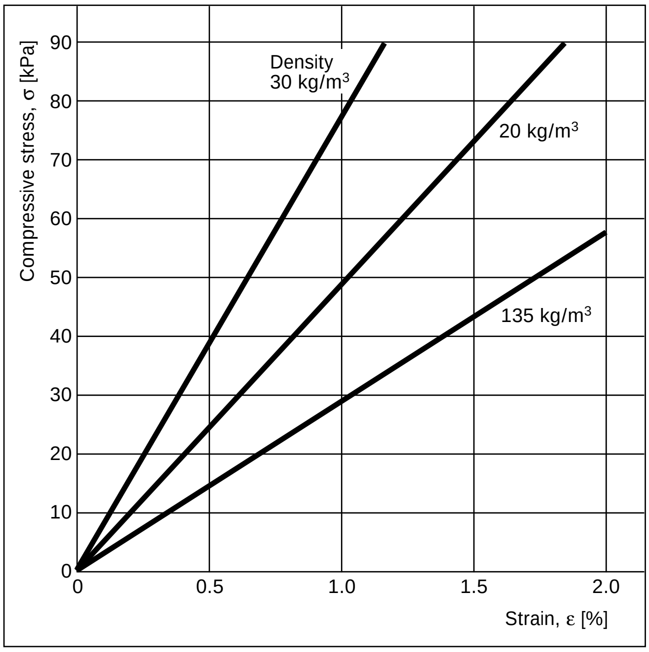

Fig. 9 Compressive stress, σ, vs strain, ϵ, for EPS of various apparent densities, ρ, measured in accordance with DIN 53421. Linear portions of curves in Fig. 8

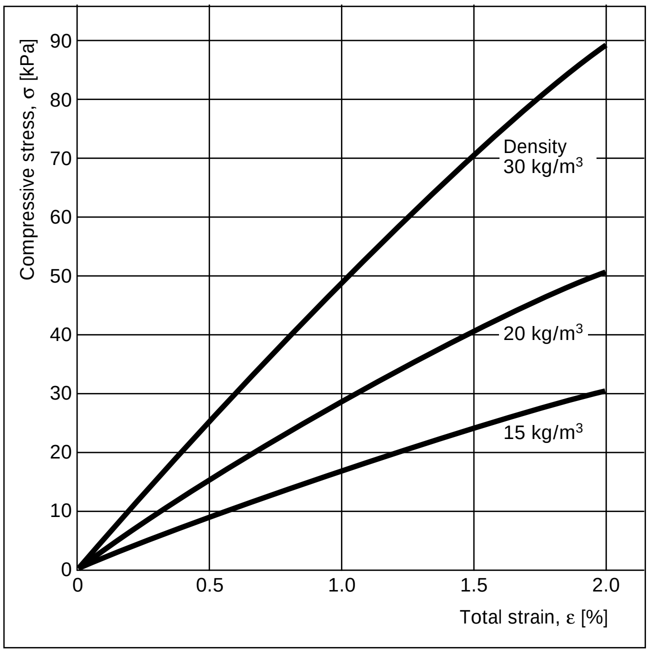

Fig. 10 Compressive stress, σ, vs total strain (instantaneous strain, ϵ, and creep, ϵ_c) for EPS of various apparent densities, ρ, after 50 a.

EPS block in road embankments can be protected from any of the aggressive substances mentioned by a suitable impermeable covering, as described in § 6.4.

4.3 Biological properties

EPS is no threat to surface water or groundwater and has no other harmful effect on the environment. It does not break down chemically, neither is it broken down or attacked by any form of microorganism, for which it provides no nourishment, or any plant or creature. Experience of its use in roadbuilding has shown that it suffers no damage from rodents or plant roots that is likely to affect stability in any way.

4.4 Burning behaviour

All EPS is combustible, but a distinction must be made between EPS containing no flame retardant and that containing an appropriate proportion of an effective flame retardant. EPS with no flame retardant is classed as an easily flammable building material in Germany (Class B 3 according to DIN 4102), while flame-retardant types of EPS are classed as difficultly flammable (Class B 1)[7].

5 Design notes

5.0 General

Building EPS into earthworks on soils of low bearing capacity reduces settlement and the risk of failure of either the earthworks or the structures they support.

5.1 Improving stability of embankments

Embankments with EPS cores have self weights considerably less than they would be otherwise, and on soils of low bearing capacity their stability is much enhanced.

5.2 Reduction of settlement

To reduce settlement after completion of the embankment, consolidation may be accelerated by a large surcharge, which should not removed until just before the EPS block is introduced. The same end-reduction in net loading intensity – can however be attained by prior excavation and replacement of soil by EPS block (cf. Fig. 11).

In either case, the weight of the material taken away (i.e. the weight of the surcharge or of the excavated soil) should be greater than the gross loading intensity, which the sum of the traffic loads, the weight of the EPS block, and the materials covering it.

In estimating settlement, swelling of the soil due to stress relief and secondary consolidation should be taken into consideration.

The height of the lowest layer of EPS block must be such that the EPS cannot be lifted by flotation in areas subject to flooding. This requires knowledge of the maximum HWM.

Table 1b Chemical resistance of EPS

Contacting substance	Effect	Contacting substance	Effect
Saline solutions, seawater	○	organic solvents, e.g. acetone, ethyl acetate, toluene, xylene, trichloroethylene, thinners	●
Soap, detergent solutions	○	Saturated hydrocarbons, e.g. white spirit, solvent, petroleum	●
Bleaching solutions, e.g. hypochlorite, chlorine water, hydrogen peroxide	○	Petroleum jelly, white oil	◊
Dilute acids	○	Diesel fuel	●
35% Hydrochloric acid, 50% nitric acid	○	Gasoline (all grades)	●
Fuming sulfuric acid, glacial acetic acid, 100% formic acid	●	Alcohols, e.g. Methanol, ethanol	◊
Caustic soda or potash solution, strong ammonia	○	Silicone oils	○

Key:
○ *No effect, even after prolonged contact*
● *Surface attack or shrinking after prolonged contact*
◊ *More or less shrinking or dissolution*

5.3 Choice of embankment construction

Except when the EPS block is used to replace excavated soil (cf. § 5.2), it may be positioned near the base, middle, or top of embankments.

The choice depends on
- the highway type,
- the nature of the underlying soils,
- the likelihood of flooding,
- the nature and magnitude of previous loads on the underlying soil,
- site conditions, including local building, the presence of pipelines, etc.

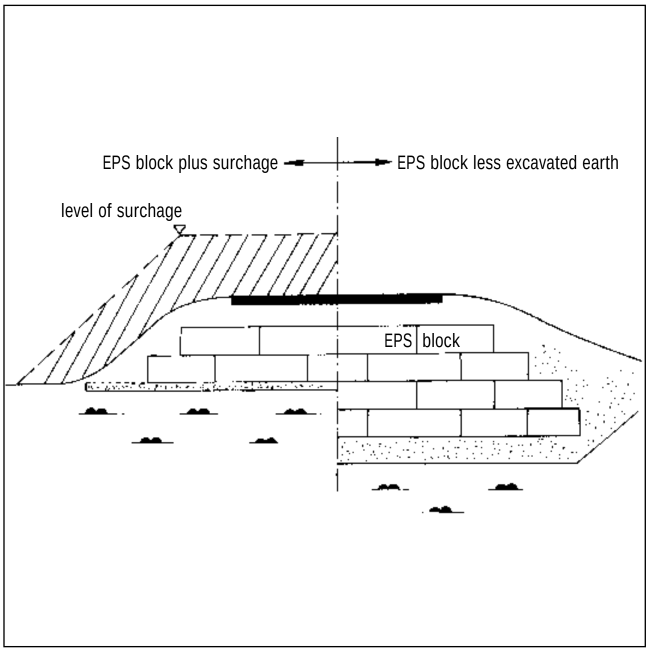

Fig. 11 Two ways of making the net loading intensity lower after construction before it: surcharging (left) and replacing excavated earth by EPS block (right).

Construction A (EPS near the base) should be chosen if conditions – particularly gradients – allow, since this gives minimum net loading and is suitable for every type of highway, because of the depth of cover over the EPS block. Construction C (EPS near the top) requires greater attention to the nature and thickness of the overlying layers, which distribute the expected loads.

Construction A: EPS near the base (Fig. 12)

An adequate depth of material covering the EPS block must be deposited ahead of loaders etc. To facilitate this, initial protection may be given by a concrete slab, at least 12 cm thick and reinforced centrally, placed over the EPS block.

If the depth of material over the EPS block is 1.50 m or more, no special arrangements need be made for fixing protective barriers, signposts, and so on.

Construction B: EPS near the middle (Fig. 13)

An adequate depth of material covering the EPS block must be deposited ahead of loaders etc. Both to facilitate this and to ensure that the value of the deformation modulus, E_{v2}, is at least 0.045 MPa at formation level,* protection should be given by concrete slab placed over the EPS block. The slab, of B 25-concrete, should be at least 12 cm thick and reinforced centrally with Q 131 steel-fabric reinforcement to limit cracking.

Construction C: EPS near the top (Fig. 14)

The sub-base must be deposited ahead of loaders etc. and compacted with light non-dynamic machines. Over the EPS block is B 25-concrete slab, at least 12 cm thick and reinforced centrally with Q 131 steel-fabric reinforcement to limit cracking. If the sub-base lies on the EPS block direct, provision must be made for fixing protective barriers, signposts, etc. (cf. § 6.6).

5.4 Stability

Using the appropriate methods of calculation (cf. DIN 1054, DIN 4017, and DIN 4084), the designer must confirm that the system – including earthworks and the supported structures – is stable with respect to shear due to differential settlement, slip, and flotation. He must assume the most unfavourable conditions, and conditions while the system is under construction must also be taken into account.

For buoyancy calculations, the density of the EPS may be put at no more than 20 $kg \cdot m^{-3}$, but for load calculations the density of the water-saturated material must be assumed; this value should be taken as 100 $kg \cdot m^{-3}$ (erring on the side of caution).

The values of the friction factors for both EPS – EPS and EPS-ground may be put at approximately 0.5.

** Required by German roadbuilding regulations (TStO).*

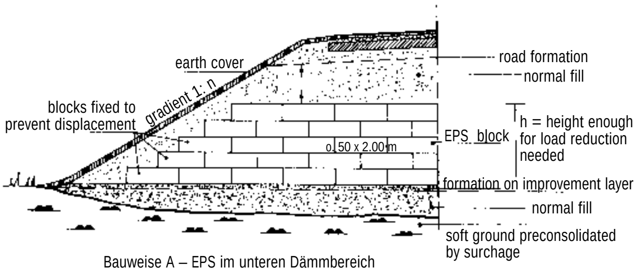

Fig 12 Construction A

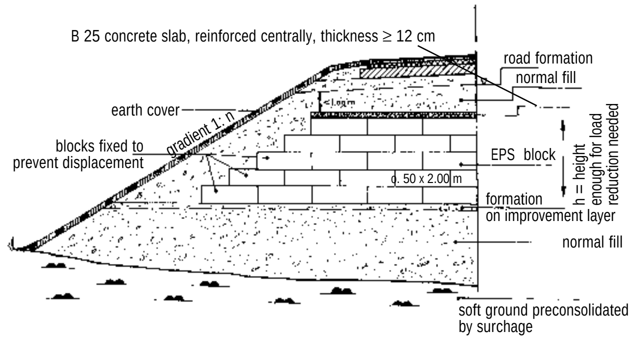

Fig 13 Construction B

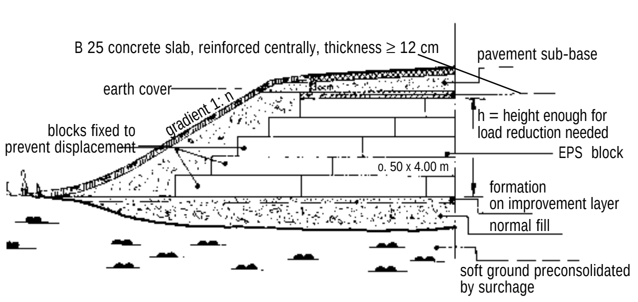

Fig 14 Construction C

6 Constructional principles

6.0 General

The bottom of the core of EPS block should be above the mean height of the water table. If there is any possibility of flooding, buoyancy effects must be considered.

Suitable drainage measures must be taken; on sloping sites this is particularly important.

6.1 Supporting layers

The bottom layer of EPS block has to be supported over its entire lower face, so a plane surface, inclined as appropriate, must be prepared. Departures from planarity may not exceed (±1 cm in 400 cm). The material used is generally sand; its thickness depends on the ground and the machines to be employed.

6.2 Construction of EPS cores

The EPS block must be laid flat, with staggered joints; no voids or open joints may be left. The joints must be offset by at least 50 cm. There must be at least two layers of EPS block, and only entire blocks may be used on either side of each layer. Any blocks cut to fit – this must be done on site – are to be within the layers. To prevent displacement of blocks during construction, they should be fixed together at intervals with polyurethan-based adhesive or mechanical fasteners (e.g. barbed dowels, dia. 117 mm, at distances of 1–2 m).

Any water at or near the ground surface must be pumped off until the EPS block is covered by material whose weight is sufficient to prevent flotation.

Since individual EPS blocks are light enough to be easily lifted by wind while they are being transported or installed, appropriate precautions must be taken. Once EPS blocks are in place, they should be covered as soon as possible.

EPS offcuts should not be left on site or burnt: they should be collected for recycling[6].

Until the EPS block has been completely covered by noncombustible material, smoking and the use of naked flames should be forbidden.

6.3 Construction above the EPS block

As a rule, the subgrade of the road distributes the load on and protects the EPS block, while its surface constitutes the road formation. During construction, loads imposed by traffic may not exceed limits set according to the thickness of material over the EPS block.

Loads are spread particularly well by reinforced concrete slab, 12–15 cm thick, formed in situ, but strengthened layers of other materials may be used instead. In the case of EPS block positioned near the bottom of the embankment (i.e. Construction A), the thickness of the covering makes load distribution by a strengthened layer unnecessary. But in any case, traffic in direct contact with the EPS block is not permissible.

The construction of the pavement above road formation accords with usual practices and rules,* but the thickness of material in contact with the upper surface of the EPS block or of the concrete slab over it should not be less than 30 cm, to allow adequate compaction.

** In Germany, the relevant legislation ist the RStO.*

6.4 Protection of EPS block

The EPS block must be adequately protected by the materials over it. Protection against substances that dissolve EPS or cause its breakdown (cf. § 4.2) may, if required, be provided by an impermeable sheet under the earth covering.

6.5 Embankment slopes

The stepped sides of the core of EPS block must be bounded by planes whose slopes are consistent with stability, the required profile, the covering material, and the kinds of vegetation intended.

The depth of soil covering the sides may not be less than 25 cm, measured normally to the planes bounding the core of EPS block. If slopes greater than 1:1.5 are proposed, and soil-mechanical considerations allow them, the soil should be secured against slip by appropriate measures, such as reinforcement with geotextiles or gabions.

Where the sides of the embankment are to be greened by other than shallow-rooted plants, the soil covering over the EPS block must be deep enough to allow the roots to provide adequate anchorage.

6.6 Subsidiary highway components

If the depth of material covering the top of the EPS core is 1.50 m or more, no special arrangements need be made for anchoring subsidiary components such as safety fences, direction signs, etc. Depths of less than 1.50 m necessitate provision of concrete anchor blocks, which can be factory-made components resting on the load-spreading course or cast in situ in EPS forms (cf. Fig. 15).

Cables can be laid within the EPS if necessary, provided the ducts or channels required are bridged in such a way that the loadbearing capacity of the whole system is not adversely affected. Note that without special precautions, work involving welding or soldering will not then be permissible.

7 Requirements

EPS block that is to withstand traffic loads must satisfy all the requirements given below.

7.1 Structure

Any section through EPS block must be uniform in appearance and display beads well fused together throughout.

7.2 Block geometry

EPS block is made in a number of sizes, but a common size nowadays is 1.00 m x 0.50 m x 4.00 m.

7.2.1 Squareness

The distance between any edge and the true perpendicular through the common apex may not exceed 3 mm at a point 500 mm from the apex, the measurements being made normal to and along the true perpendicular (cf. Fig. 16).

7.2.2 Dimensional accuracy

Measured from apex to apex, the length, width, and height of a block may be neither less than or greater than the nominal value by more than 0.5 %.

When a block has been installed, with its largest faces horizontal, neither of the shorter edges may project upwards by more than 7 mm at any point (assuming it is perpendicular to a 4-m edge) and neither of the longer edges may project upwards by more than 4 mm at any point (assuming it is perpendicular to a 1-m edge). If necessary, blocks must be trimmed to ensure that these requirements are met.

7.3 Density

The mean density of a dry EPS block may not be less than the nominal density. The density of no single specimen may be less than 90 % of the nominal density.

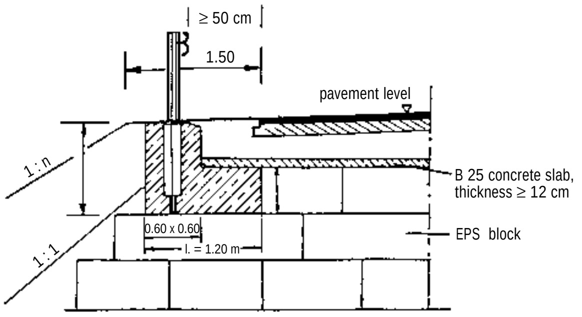

Fig. 15 Uprights of safety fence anchored in concrete (factory made or formed in situ) resting on EPS block

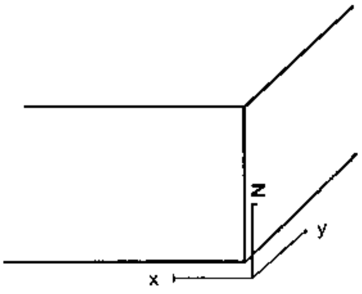

Fig. 16 Testing for squareness

7.4 Resistance to compression

The mean value of the compressive stress required for immediate strain of 10 % may not be less than the lowest declared value for the nominal density concerned (given in Table 1a). The value for no single specimen may be less than 90 % of the mean.

7.5 Flexural strength

For EPS block of nominal density 20 kg · m^{-3} or greater, the mean value of its flexural strength must be at least 220 kPa. The value for no single specimen may be less than 90 % of the mean.

7.6 Water absorption

The volume fraction of water found in specimens after immersion for 7 d may not exceed 7 %.

8 Testing

8.1 Extent and nature of tests

For the purposes of quality assurance, tests should be carried out to establish suitability of the material, in the course of manufacturing quality control, and as spot checks. The tests to be carried out in each category are given in Table 2.

Table 2 Contractual tests for supply of EPS block

Property	**Method**	**Purpose** apt-ness	QC	check
Squareness	§ 8.3.1	–	●	●
Dimensional accuracy	§ 8.3.1	–	●	●
Density	§ 8.3.2 DIN 53420	●	●	●
Compression resistance	§ 8.3.4 DIN 53421	●	●	–
Flexural strength	§ 8.3.4 DIN 53423	●	●	–
Water absorption	§ 8.3.5 DIN 53433	●	–	–

8.2 Sampling; test specimens

When the samples are cut from blocks, they should be generously sized, so that the dimensions of the sawn test specimens to be prepared from them can correspond accurately with those laid down.

Samples are to be taken at the numbered positions shown in Fig. 17. The “height” of the block, *h*, corresponds to the height when the block is lying on one of its largest faces. All four samples must have the height *h*, and the other dimensions must be at least as follows:

50 mm x 50 mm	Samples 1, 2, and 3
150 mm x 200 mm	Sample 4

Cubic specimens (one from the middle and one from near the top or bottom; cf. Fig. 17) for density and compression measurements are cut from each of Samples 1 – 3. Sample 4 is used solely to provide specimens for fexural strength tests, which are taken from the middle.

8.3 Test procedures

8.3.1 Block geometry

Squareness and dimensional accuracy are measured in accordance with §§ 7.2.1 and 7.2.1.

8.3.2 Density

The density of the dry material is measured in accordance with ISO 845 (BS 4370 Part 1, DIN 53420, etc.). The cubic specimens with 50-mm edges are sawn from the middle and the top or bottom of each of Samples 1 – 3.

8.3.3 Resistance to compression

The specimens used for density measurements are also used to obtain stress-strain curves in compression in accordance with ISO 844 (DIN 53421). The quantity measured is the stress corresponding to 10 % strain.

8.3.4 Flexural strength

The value of the flexural (cross-breaking) strength of EPS, determined in accordance with ISO 1209 (DIN 53423), is an indication of the degree of fusion of the individual expandable polystyrene beads. The test is carried out on each of five specimens, 120 mm long and of section 25 mm x 20 mm, all of which are sawn from the middle of Sample 4.

8.3.5 Water absorption

The uptake of water by immersed specimens is measured in accordance with DIN 53433.

8.4 Frequency of testing

The minimum number of blocks to be tested in the course of manufacturing quality control is related to the volume of EPS to be supplied under the terms of the contract:

total volume ≤ 500 m^3	at least 2 blocks
total volume ≤ 1000 m^3	at least 4 blocks
total volume ≤ 1000 m^3	at least 4 blocks from first 1000 m^3, 1 block from each 1000 m^3 after

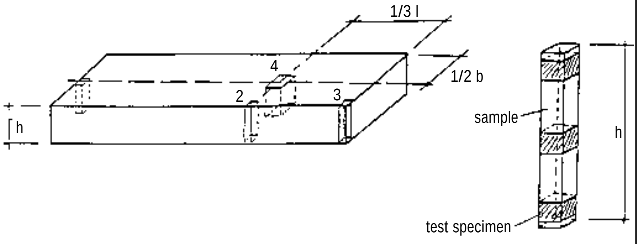

Fig. 17 Position to cut out samples

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Technical Information

Styropor® **800**

BASF Plastics

24558 January 1998

6 Highway construction/ Ground insulation

® = Registered trademark

Rigid Styropor foam as a lightweight construction BASF material for highway foundations: GEOFOAM®

1 General

The main consideration when constructing roads on poor load-bearing subsoil is that every load deforms the soft soil layers; and the greater the load, the greater the deformation. This deformation process continues over years, depending on the thickness of the soil layers. The low shear resistance of poor load-bearing subsoils means that concentrated loads should be avoided as far as possible, otherwise these layers will give at the sides. Compensating for this form of subsidence by laying new material (e. g. in structures at highway intersections) leads to further settlement due to the additional burden.

The conventional techniques of subsoil improvement by complete or partial replacement of the soil are often time consuming and therefore costly. By employing lightweight materials, the weight of the road embankment – and with it the load on the subsoil – is reduced considerably.

A largely subsidence-free method of construction is thus obtained in poor subsoil conditions when practically no additional loads are brought to bear – i.e. by using extremely lightweight materials in the embank-

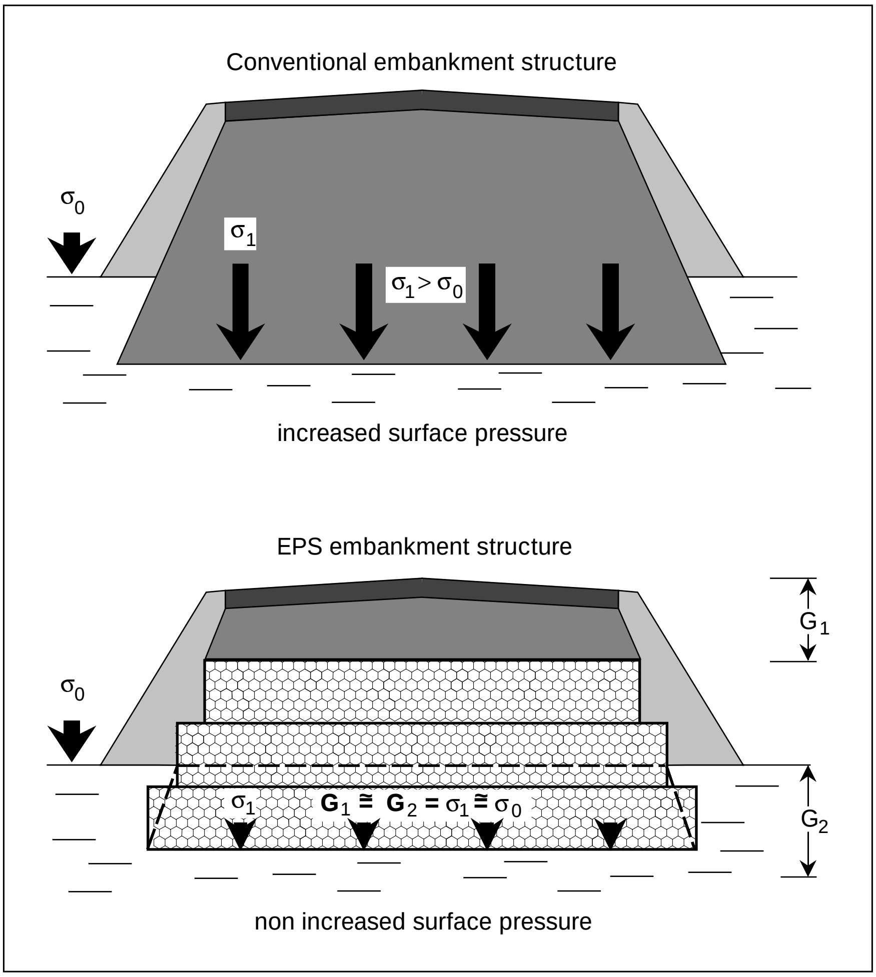


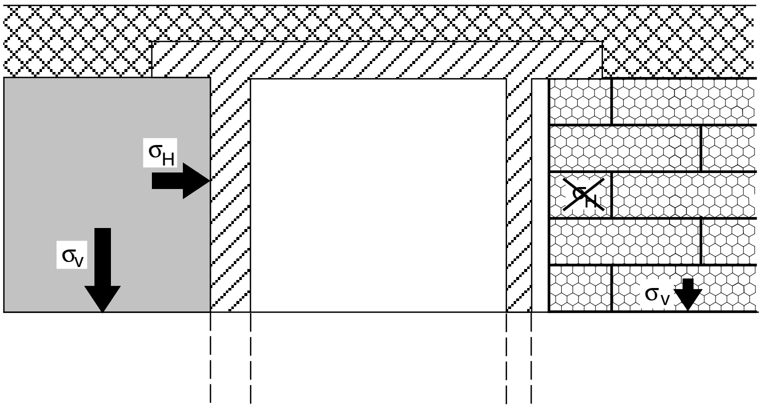
Fig. 1 Comparison of conventional and EPS embankment structures.

ment such as blocks of Styropor foam (see Figs. 1 and 2).

Among specialists in the trade this type of construction is also known as the GEOFOAM method.

2 Experience to date

Experience with Styropor (EPS) foam panels used as frost protection for highways and railroads formed the basis for the development of this construction technique. This method of construction has been applied since the middle of the 1960s, mainly in countries with severe winters (e.g. alpine regions, Canada and the Scandinavian countries) where the deeply penetrating ground frosts make it necessary to provide correspondingly costly frost-proof sub-bases for highways and railroads (see Figs. 3 and 4). With the appearance in 1984 of the code of practice “Stabilization of roadways with thermal insulation layers made from rigid foam plastics” by the German Institute for Road and Transport Research (Soil Mechanics Working Party), “antifrost construction methods” can now be ranked alongside other standard construction techniques.



With the EPS method no horizontal forces act on the bridge abutment and supporting walls (lighter design)

Fig. 2

The use of rigid EPS foam, not only for protective antifrost layers in the form of insulating panels, but as a load-transmitting substructure for highways and bridge approach ramps in the form of large blocks, is based on this practical experience and on the fact that lightweight (-approx. 20 kg/m^3) Styropor foam possesses high bending and shear strength for distributing both dead weight and live loads over poor load-bearing subsoils. It therefore offers higher efficiency than conventional building materials (Fig. 5).

In Germany, the Lightweight Building Materials Study Group of the Working Committee for Highway Construction on Poor Load-bearing Subsoils in the aforementioned Soil Mechanics Working Party produced a **“Code of practice for the use of rigid EPS foams in the construction of highway embankments”** which was published in 1995 [6].

2.1 Economic efficiency

The price of rigid EPS is much lower than that of other foam materials, but in comparison with conventional materials used in road substructures, it is considerably more expensive. However, a simple cost comparison is not enough – the alternative construction methods must be also considered. When this is done

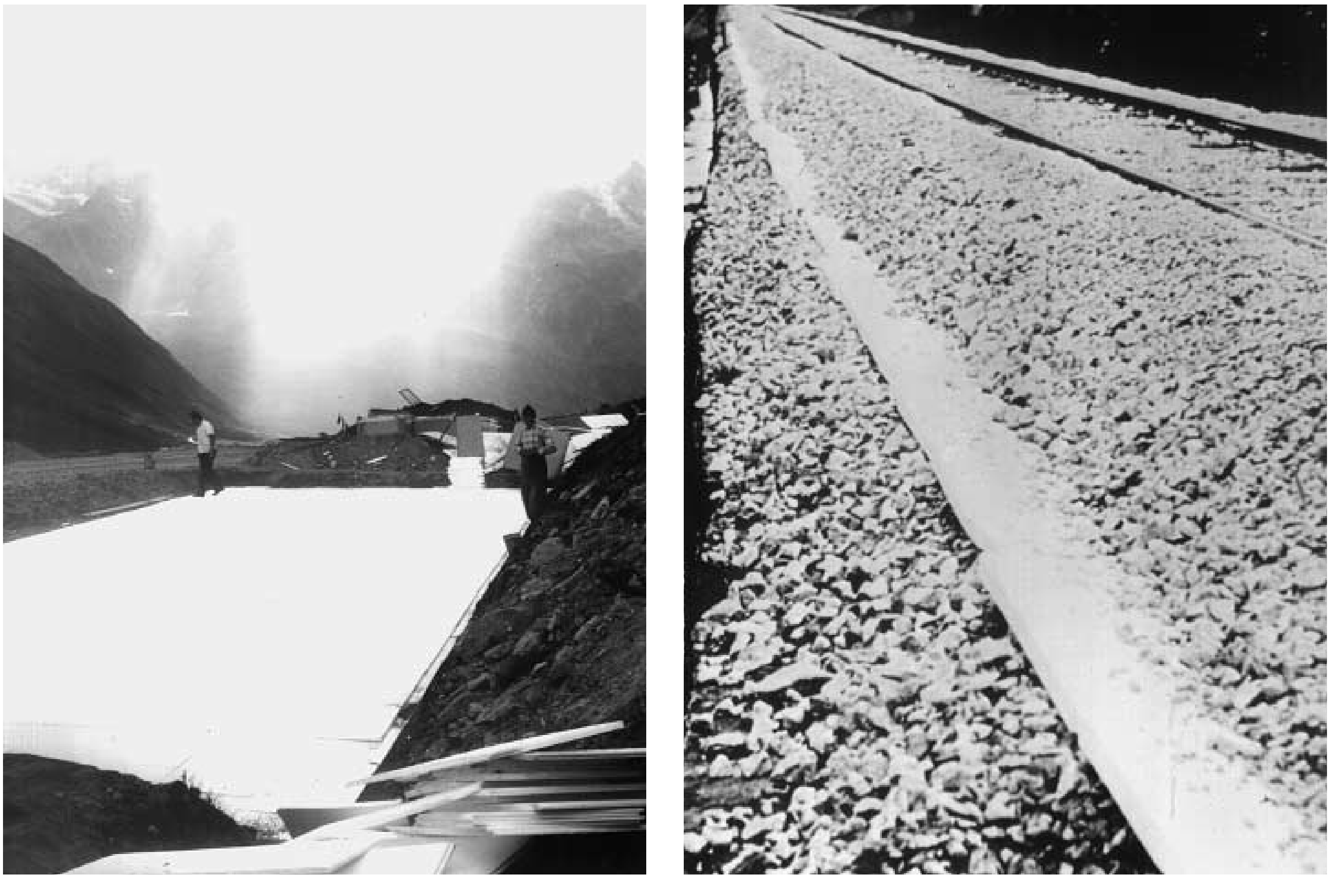


Fig. 3 and 4   Frost protection in highway and railroad construction using EPS rigid foam panels.

Fig. 5 Embankment construction using EPS (Hardinxveld-Giessendam, NL).

it turns out that, depending on local conditions, the Geofoam method certainly affords a technically and economically interesting solution. This is particularly the case for engineering structures (e. g. bridges, supporting walls, pipelines, etc.) where subsidence is to be avoided. Experience from abroad has shown that in certain cases it was possible to achieve a cost reduction of 50 % by comparison with conventional building techniques. There are also obvious advantages when the filler material has to be transported to the construction site over long distances or special conditions have to be met on environmental grounds.

3 Rigid foam made from Styropor

EPS is the standard abbreviation for **E**xpanded **P**oly**s**tyrene. The German standard used for rigid EPS foam as an insulating material in the building and construction industry is DIN 18 164, Part 1. Expanded foams made from Styropor have been produced worldwide since 1950 and they have mainly been used in the construction and packaging industries.

Starting with the beads of Styropor granulate, which contains a blowing agent, the manufacture of EPS foams takes place in three stages: **preexpansion, intermediate aging and molding** (Fig. 6). During the first stage, the granulate is heated and made to expand – rather like pop-corn when it is made (Fig. 7). The blowing agent contained in the raw Styropor is pentane, a naturally occurring hydrocarbon. The pentane expands the Styropor granules into individual closed-cell foam particles about fifty times their original volume. Next, the preexpanded material is stored to allow air to diffuse into it and the blowing agent partly to diffuse out. Finally, the preexpanded particles are placed in a mold and further expanded so that the foam particles fuse together. The result is a compacted foam material whose volume consists mostly of air trapped in many microscopically sized cells.

The special manufacturing process makes it possible to vary the bulk density of the Styropor foam over a wide range. Because the properties of the material largely depend on its density, foams can be made with a range of application-specific properties: from insulating panels to lightweight construction material.

Styropor FH is a grade for making foams with enhanced resistance to aromatic-free hydrocarbons by comparison with foams made from other Styropor grades. The suitability of this product for a specific application must be tested in each case.

3.1 Physical properties

The most important properties of rigid Styropor foam are described in Tables 1 and 2.

The following properties are of most significance in road construction:

- closed cell structure, which means very low water absorption
- frost resistant and rotproof
- no breeding ground for pests, mold or putrefactive bacteria
- biologically safe (no danger to ground water, no ozone-damaging blowing agent)
- good performance under sustained static and dynamic loading.

3.1.1 Mechanical performance

EPS foam is a thermoplastic which unusually for elastic materials exhibits viscoelastic behavior when under load. This is why the compressive stress at 10 % compressive strain is quoted (DIN 53 421/EN 826) instead of the compression strength. This value, however, already lies in the range of irreversible compressive strain and is therefore only of infor-

Fig. 6 The processing stages in the production of EPS foam: raw granulate (left), pre-expanded particles, molded foam.

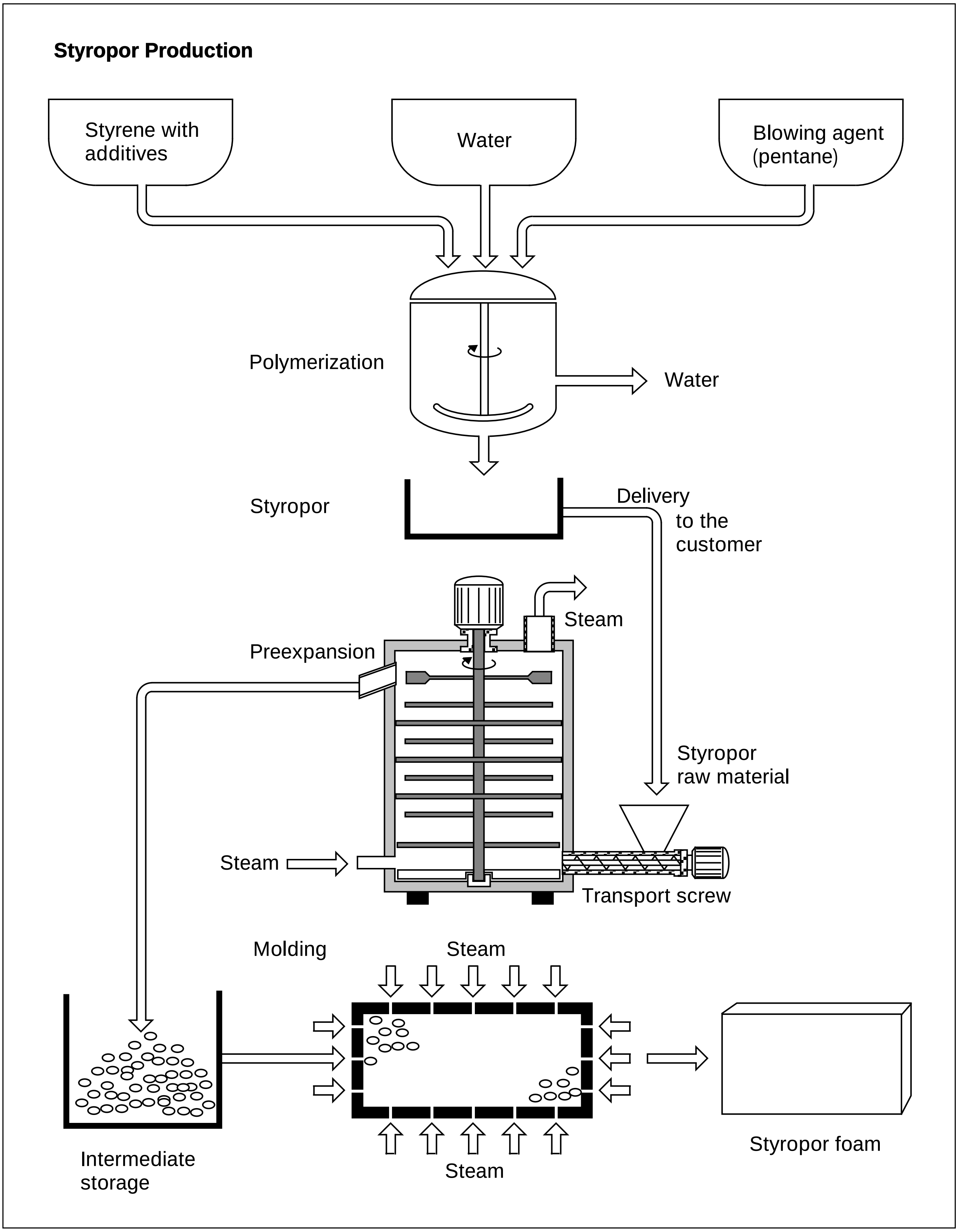


Fig. 7

mation value for quality control. The compressive stress/compressive strain curves in Fig. 8 show that compressive stress increases linearly until the limit of elasticity is reached at a compressive strain of 1.5 to 2 %, depending on the bulk density of the material. As permanent deformation of the cells begins, the compressive strain climbs much more rapidly; however no sudden fracture occurs.

When designing for permanent loads, values must therefore be chosen which lie in the linear range of the compressive stress/compressive strain curve. Sustained loading trials show that below the compressive strain limit of 2 % no appreciable creep deformation occurs even over years (see TI 140 Resistance to aging and long-term performance).

To illustrate the deformation behavior, Fig. 9 a shows the load-dependent initial compressive strains as a function of the bulk density of the rigid foam and Fig. 9 b shows the associated total compressive strains after a loading duration of 50 years.

Table 1 Properties of expanded foams made from Styropor for building applications

Properties1)	**Test standard**	**Unit**	**Test results**		
Quality grades	Quality terms		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18 164, Part 1		W	WD	WS+WD
Minimum bulk density	EN ISO 845	kg/m^3	15	20	30
Building material class (product type Styropor F)	DIN 4102		B1, flameproof	B1, flameproof	B1, flameproof
Thermal conductivity Measured value at +10 °C	DIN 52 612	mW/(m · K)	36 – 38	33 – 35	31 – 34
Calculated value	DIN 4108	mW/(m · K)	40	40	35
Compressive stress at 10% compressive strain	EN 826	kPa	65-100	110-14-	200-250
Sustained compressive load-bearing capacity at 1.5 – 2% compressive strain after 50 years	ISO 785 2)	kPa	20 – 30	35 – 50	70 – 90
Flexural strength (without foam skin)	EN 12 089	kPa	150 – 230	250 – 310	430 – 490
Shear strength	DIN 53 427	kPa	80 – 130	120 – 170	210 – 260
Tensile strength	DIN 53 430	kPa	160 – 260	230 – 330	380 – 480
Modulus of elasticity (compressive tests)	EN 826	MPa	1.0 – 4.0	3.5 – 6.5	7.5 – 11.0
Heat deflection temperature, short-term	DIN 53 424 2)	°C	100	100	100
Heat deflection temperature, long-term at 20 kPa		°C	75	80	80
Coefficient of linear thermal expansion		1/K	5-7 · 10-5	5-7 · 10-5	5-7 · 10-5
Specific heat	DIN 53 765	J/(kg · K)	1,210	1,210	1,210
Water absorption when kept under water, after 7 days	DIN 53 434	vol.%	0.5 – 1.5	0.5 – 1.5	0.5-1.5
Water absorption when kept under water, after 28 days		vol.%	1.0 – 3.0	1.0 – 3.0	1.0 – 3.0
Water vapor diffusion resistance coefficient					
Calculated value by DIN 4108, Part 4 (most favorable and least favorable value)	DIN 52615	1	20/50	30/70	40/100

1) *Values are laid down in DIN 55 471, Part 2*
2) *Depending on test standard*
** 1 N/mm^2 = 1,000 kPa*

Table 2 Resistance of Styropor foam to chemical agents

Chemical agent	**Styropor P + F**
Salt solution (sea water)	+
Soap and wetting agent solutions	+
Bleaching agents, such as hypochlorite, chlorine water, hydrogen peroxide solutions	+
Dilute acids	+
36% hydrochloric acid, nitric acid up to 50%	+
Anhydrous acids (eg, fuming sulfuric acid, 100% formic acid)	–
Sodium hydroxide, potassium hydroxide and ammonia solutions	+
Organic solvents such as acetone, acetate esters, benzene, xylene, paint thinner, trichloroethylene	–
Saturated aliphatic hydrocarbons, surgical spirit, white spirit	–
Paraffin oil, Vaseline	+ –
Diesel oil	–
Gasoline (regular and premium grades)	–
Alcohols (e. g., methanol, ethanol)	+ –
Silicone oil	+

+	*Resistant: the foam remains unaffected even after long exposure.*
+ –	*Limited resistance: the foam may shrink or suffer surface damage on prolonged exposure.*
–	*Not resistant: the foam shrinks or is dissolved.*

The amount of creep (%) occurring during this sustained loading is given by the difference between the initial and the total compressive strains. On grounds of safety the bulk density of the rigid Styropor foam blocks is to be chosen such that the planned loads bring about a total compressive strain of at most 1.5 %.

This is illustrated by way of example in Fig. 9 c. For a compressive load of 35 kN/m^2 a rigid Styropor foam having a bulk density of 20 kg/m^3 is chosen. Its total compressive strain over a period of 50 years is 1.3 % (≤ 1.5 %). The initial compressive strain on application of load is 0.7 %. The difference of 0.6 % between the initial compressive strain (after completion of construction) and the total compressive strain yields the level of creep deformation of the rigid foam during the 50 years of operation of a highway structure.

In studies by the German Federal Institute for Highways [5] traffic loads were simulated by means of an impulse generator which are equivalent to a million wheel loads with a weight on the axle of 10 metric tons. In all variants the overburden height of the rigid Styropor foam blocks (of bulk density 20 kg/m^3) amounted to 56 cm. The results showed that no permanent deformations of the rigid foam surface occurred as a result of the (simulated) live loads, i.e. formation of depressions could not be found. This has now been confirmed by experience in practice which has since been documented.

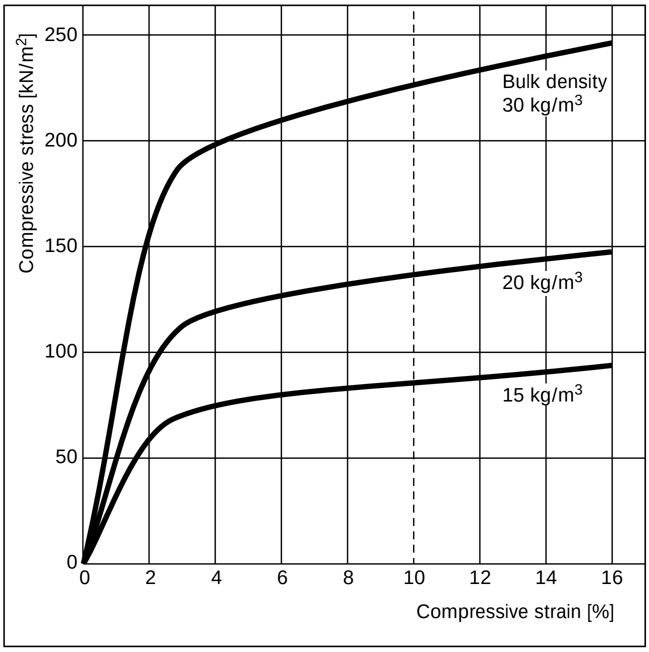


Fig. 8 Compressive stress/compressive strain curves for rigid Styropor foams of different bulk densities.

3.1.2 Behavior towards chemicals

Expanded foams made from Styropor are resistant to alkalis, soaps, dilute acids and salts (see Table 2). Organic solvents attack the foam to a greater or lesser extent. In the longer-term the action of the solvents contained in gasoline or diesel oil causes the foam to shrink or to start dissolving.

Practical trials have shown that the protection afforded by the upper layers of material usual in highway construction is enough to prevent damage to the EPS substructure from small amounts of escaped fuel. When larger amounts of fuel are involved (e. g. in a tank truck accident), the foam can be replaced at the same time as the contaminated earth is removed; this work would have to take place in any case – on environmental grounds.

Covering the expanded foam substructure with PE sheeting gives it additional protection; however, this is not normally necessary.

3.1.3 Biological properties

Rigid EPS foams made from Styropor offer no breeding ground for microorganisms. It does not decay, rot or turn moldy. Bacteria in the soil do not attack the foam. Animals can damage it by gnawing or burrowing, but many years of road building experience have shown that they do not prefer it to other conventional insulating materials. EPS foams have no environmentally

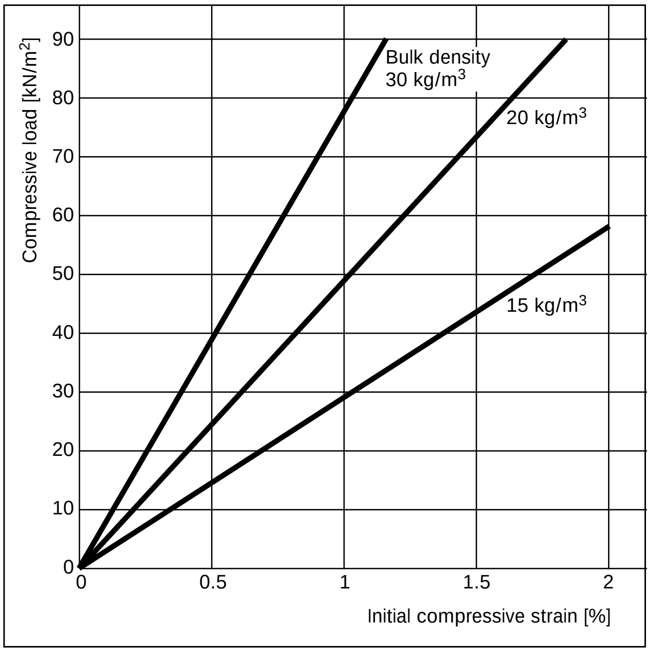


Fig. 9 a Compressive load versus initial compressive strain on application of load for rigid Styropor foams.

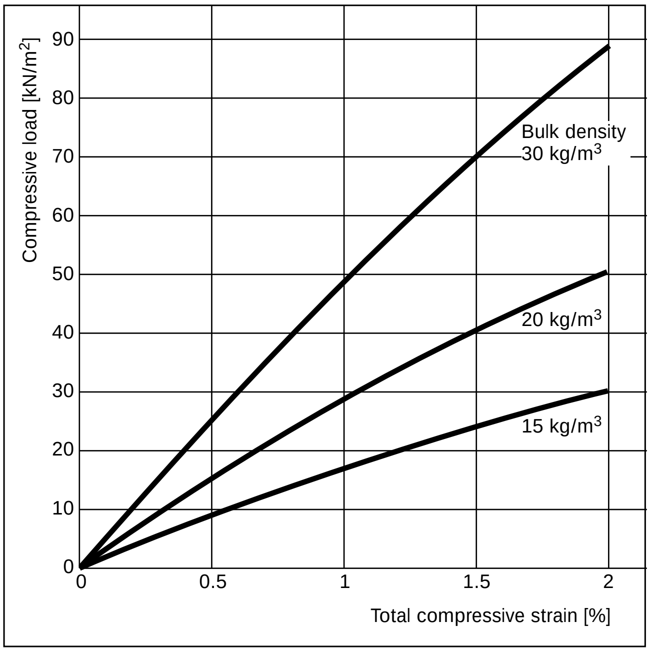


Fig. 9 b Compressive load versus total compressive strain for rigid Styropor foams; duration of loading: 50 years damaging effects and do not endanger water (crushed EPS waste is used in agriculture to break up and drain the soil).

4 Experience in other countries

The first large stretch of road to use rigid EPS foam blocks as a substructure was built in Norway in 1972 (Fig. 10). This development was initiated by the Norwegian Road Research Laboratory in Oslo which, for many years, has gathered and evaluated experience gained in practice of the use of rigid EPS foam panels as an antifrost layer in highway and railroad construction (see "Frost J. Jord" series of publications from NRCC). Although positive results about this method of embankment construction were published, interest was initially confined to Scandinavia. It was only in 1985, when at an international road building conference in Oslo a report was given on the practical experience then extending over a decade, that this construction method first caught the attention of experts from countries in which difficult soil conditions are common (e.g. in the polder areas of Holland, in southern France, USA, Canada and in Japan). Here the Geofoam technique affords an economic alternative to conventional building methods.

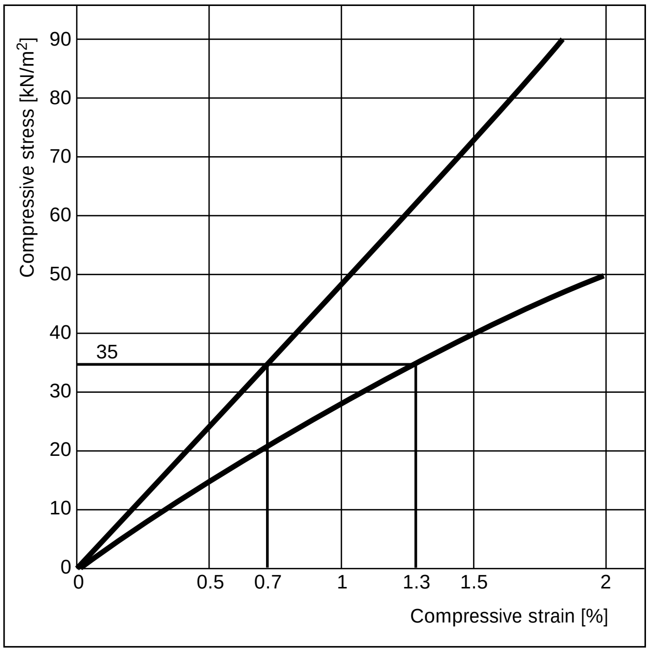


Fig. 9 c Total and initial compressive strain for rigid Styropor foam having a bulk density of 20 kg/m^3 as a function compressive load.

Fig. 10 GEOFOAM construction method using rigid foam blocks made from Styropor in the extension of the Emden western bypass close to a bridge structure on the A 31 Autobahn.

In the meantime, numerous studies have become available from research institutes in different countries on the theory and practical use of the Geofoam method.

4.1 Areas of application

It is mainly used in the following areas of highway construction:

Substructure directly on top of poor load-bearing subsoils

Reduced loads on subsoil. The most common application so far.

Backfill at bridge abutments

To reduce the earth pressure (-caused by horizontal forces) and differential settlement at bridge abutments.

Valleyside roads

For rebuilding slide areas on valleyside roads with vertical construction on the valley side.

In order to reach the correct decision as to the appropriate construction method the following aspects have to be taken into consideration:

- the volume of traffic using the highway
- the subsoil conditions
- the prevailing water conditions
- the nature and extent of prestresses on the subsoil, and
- the local conditions, such as e.g. position of pipes and peripheral development.

In Germany the code of practice issued by the Institute for Road & Transport Research [6] should be followed when using the EPS construction method. This provides guidance inter alia on sizing and structural principles (see Fig. 11).

If the subsoil conditions and gradients permit it, method "A" with EPS in the lower part of the embankment is recommended. In this case without any restrictions on traffic loading it is possible not only to achieve maximum reduction in weight of the embankment but also no special measures are necessary for the foundations of road signs, barrier devices, etc. Where there are high traffic loads method "C" can only be implemented when there are adequately sized, load-distributing layers above the EPS and is probably only rarely employed in such cases.

4.2 EPS quality assurance

The following are tested:

- Dimensional accuracy of the expanded foam blocks
- Bulk density ($\geq$ 20 kg/m^3)
- Compressive stress ($\geq$ 0.11 N/mm^2 at 10 % compressive strain) according to DIN 53 421. For sustained loading, values which are 20 – 25 % of this measured value can be expected.
- Bending strength ($\geq$ 0.22 N/mm^2) according to DIN 53 423).

The above tests are carried out on a representative sample of foam specimens according to the volume to be installed.

The absorption of water (e. g. when in contact with ground water) is simply used to calculate the dead weight and has no effect on the mechanical properties of the foam.

Many years of experience in Norway has shown that even under unfavorable conditions the volume of water absorbed does not rise above 10 %. (For determining settlement, a weight of 1.0 kN/m^3 is used).

As long as the EPS blocks are made from Styropor F their fire behavior complies with building material class B 1 according to DIN 4102, Part 1 (flame-resistant). The foam blocks must be stored for at least two weeks between manufacture and use.

4.3 Method of construction work

The following information on construction work is based on practical experience in the use of EPS lightweight construction techniques in different European countries.

The first layer of foam blocks is placed on a compacted leveling course. The amount of unevenness in the leveling course must not be more than 10 mm in 4 m; this guarantees a flat enough surface for laying the foam. All the layers of foam are positioned with their joints offset with respect to one another.

The coefficient of friction between the foam blocks is approximately 0.5. To avoid slippage when several layers are built, the blocks are bound to each other using either two spike grids or two spots of PUR adhesive per block (see Fig. 12). So far heights of up to 8 m have been achieved. It is important to determine the height of the water table. Any lifting forces which occur as a result of the water level reaching the foam blocks must be compensated for.

Structures bordering the pavement (e. g. guard rails) may be anchored into the 10 cm-thick concrete layer that is usually placed above the EPS course to distribute compressive forces. If such a layer of concrete is not used, an anchorage can be achieved by casting concrete transverse beams between the Styropor blocks at set intervals, the blocks themselves acting as formwork.

Steep-sided embankments (see Fig. 13) can be drained of water by creating openings in the EPS substructure. Water channels can be cut into the foam blocks at the building site with a chain saw. Small holes and gaps between the blocks do not damage the substructure.

The sub-base course on top of the EPS substructure is deposited ahead of the advancing machinery. Compacting the loose sub-base course can be achieved with the usual construction site equipment. Because of the vibrational damping behavior of the EPS substructure, the sub-base course is, as a rule, compacted by static means in several relatively thin layers.

4.4 Design

When designing the highway, the EPS substructure is viewed as a stratum with an elastic modulus of 5 N/mm^2. In Holland, dimensioning calculations have been carried out on this basis using the “linear elastic” multi-layer model with the aid of a computer program called CIRCLY; these have proved to be reliable in practice.

In Norway, because of the many years of practical experience that has been gained there, dimensioning is carried out on a “semi-empirical” basis. Here the thickness of the material above the EPS substructure lies between 35 cm and 60 cm depending on the projected volume of traffic that will use the road (see Section 3.1.1).

As observations so far have shown, there is no risk of early frost formation on the road surface if the layer above the EPS is thicker than 35 cm.

5 Prospects

In Norway, around 50,000 m^3 of EPS foam block are used annually for highway construction (see Fig. 14).

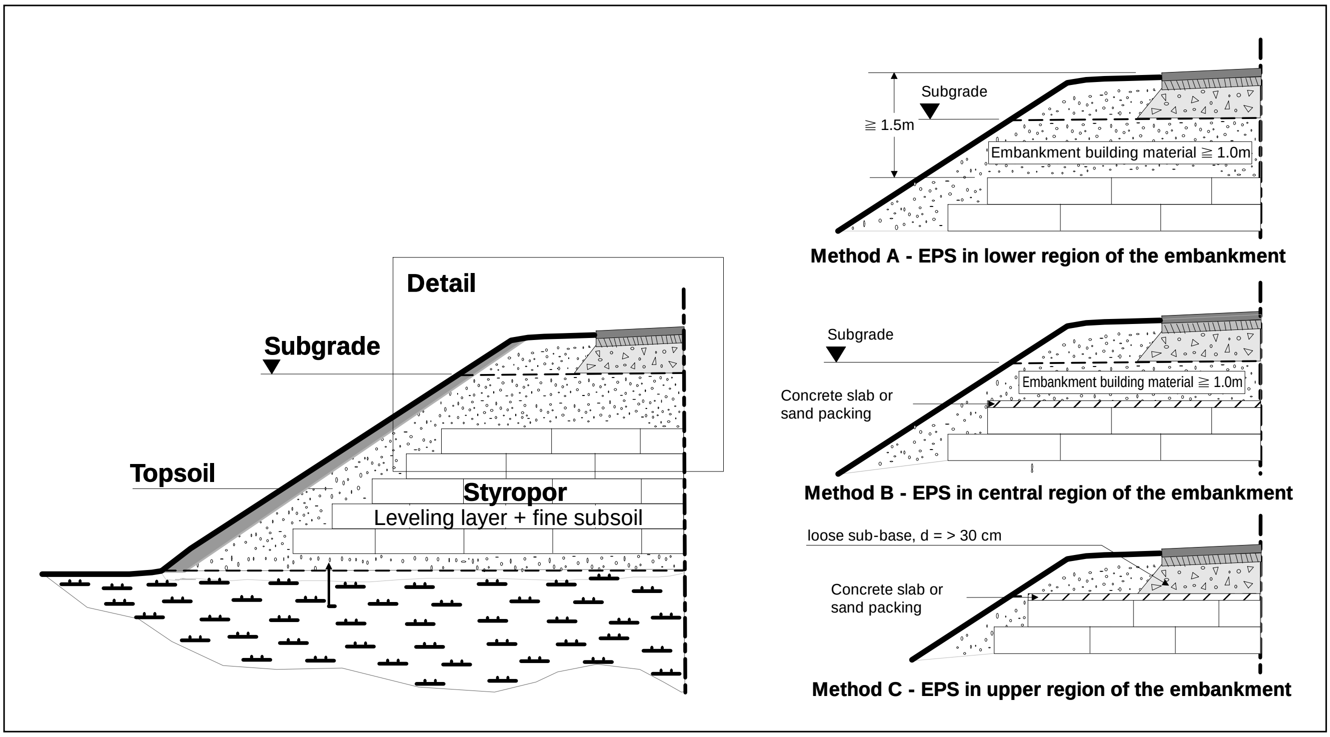


Fig. 11 EPS embankment construction method according to the code of practice of the German Institute for Road and Transport Research.

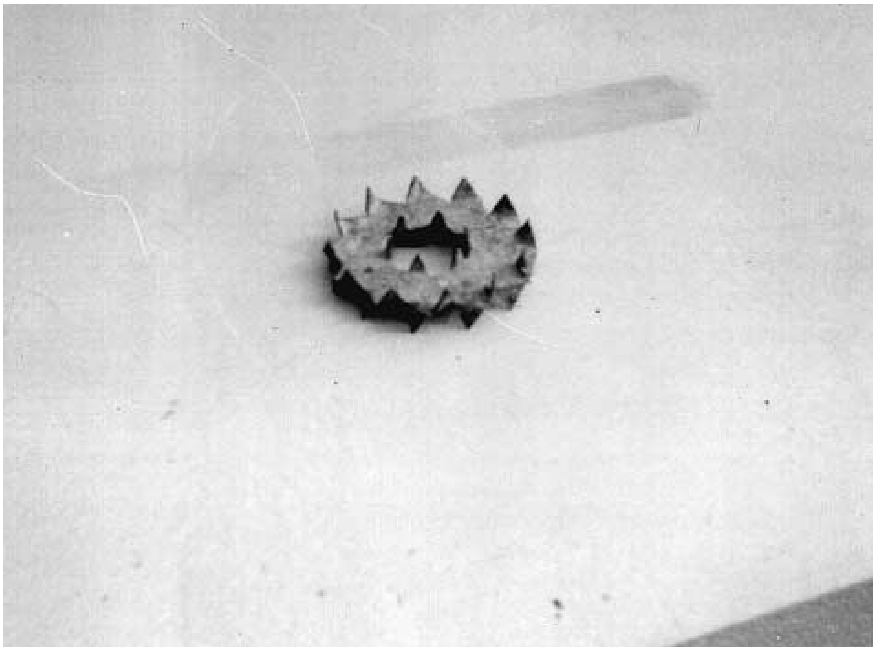


Fig. 12 Fixing the EPS blocks together by means of a spike grid

In Holland – mainly in the polder regions – this construction technique has been increasingly used as an economic alternative since 1985. In 1988, on just one construction project alone (Capelle a/d Ijssel), 35,000 m^3 of EPS foam were used for embankment construction.

In the period from 1990 to 1991 in Sweden, between the towns of Stora Höga and Ljungskile (about 100 km north of Gothenburg) part of the European Route 6 was converted to a four-lane highway. Here 40,000 m^3 of EPS foam were used owing to difficult soil and terrain conditions.

Since 1985, the EPS construction technique has been successfully applied (Fig. 15) in the extremely difficult subsoil conditions of Japan (about 70 % of the area of Japan consists of impassable mountains, a large part of the rest is moor and bog). This has been based not only on experience from abroad, but also on the country's own basic research [8].

In the Federal Republic of Germany the EPS method was tested on a practical scale in the course of a research project conducted by the Federal Institute for Highways [5].

By simulating sustained traffic loads the performance of the entire structure was measured, with the aim of obtaining a reliable method for designing different variations of the superstructure.

These findings together with the practical experience gained from abroad were gathered together by the Lightweight Building Materials Study Group of the Working Committee for Highway Construction on Poor Load-bearing Subsoils of the German Institute for Road and Transport Research and published as a set of regulations (code of practice) [6].

Since 1995 the Geofoam technique has also been finding increasing application in Germany as an economic alternative [9].

6 Summary

The low resistance to shear of unstable soils that are subjected to excessive loads, leads to subsidence and deformation which can often take place over many years.

Road construction – especially in the area adjoining existing structures – frequently requires measures to be taken that involve the soil being replaced, but, on grounds of cost and environmental protection, these are becoming increasingly more difficult.

A largely subsidence-free construction is obtained in poor subsoil conditions when practically no additional loads are applied to the unstable subsoil; this means that the weight of the fill material should be extremely small. Rigid Styropor foam (EPS) fulfills this requirement. Styropor was first employed (mainly in Scandinavia) in the mid-1960s as a frost protection layer in highway and railroad construction. The years of positive experience which followed formed the basis for the development of a technique of building roads on unstable subsoils using the "EPS Geofoam method". This construction method then won a place in road-building technology when, starting with Norway in 1972, blocks of EPS were used as a lightweight material for the first large stretch of highway. EPS was later used in other countries where difficult subsoil conditions predominate, such as the polder regions of Holland, in southern France, the USA, Canada and Japan. In Germany too, primarily in areas where poor soil conditions exist, the EPS method of construction is being used increasingly as an economic alternative.

Fig. 13 Method for steep-sided embankment construction with EPS without banking slope

Styropor®

Expandable polystyrene (EPS)

Range
Properties
Processing
Applications

Styrenic Polymers

BASF

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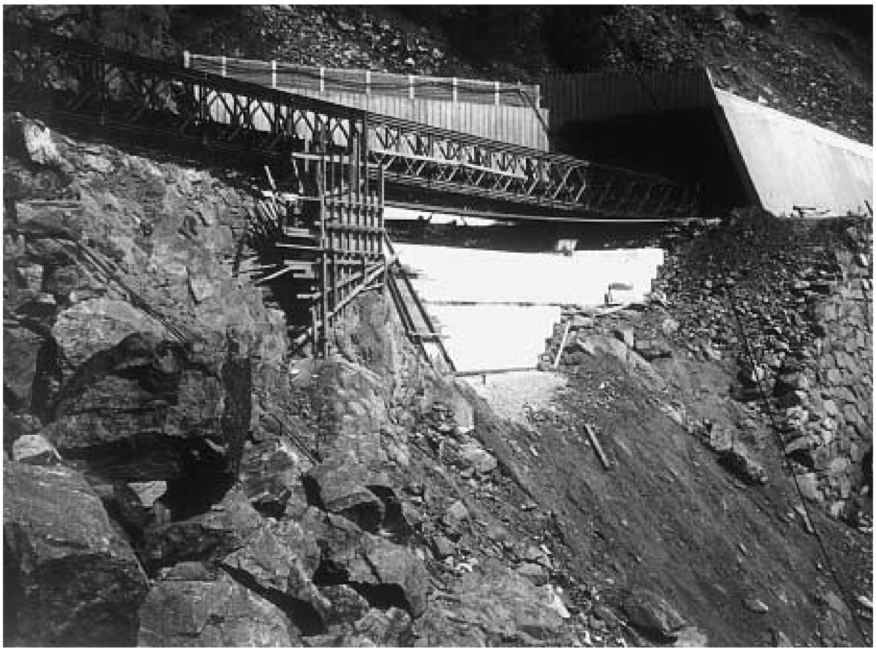

Fig. 14 Reconstruction of a mountainside road damaged by landslide using a vertical EPS construction method (h = 5 m, Sougdahl, Norway)

Fig. 15 EPS substructure (18,000 m^3) at an approach to the Kasai Nagisa Bridge, Tokyo

Note

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6 Highway construction/ Ground insulation

Frostproof highway construction – Theoretical investigation of thermal properties

The theoretical frost resistance of various road designs was compared with the help of computer simulation.

The calculations apply to:

a) the thermal properties of the road designs

b) the loadbearing capacity of the road designs and the loading on the subsoil.

Eight possible frost-resistant designs (see Fig. 1), which meet current German road-building technical regulations and recommendations, were selected for the study. The thermodynamic properties were compared by carrying out heat-flow analyses in which the depth of frost penetration and frost penetration times were determined. In doing so, the following assumptions were made:

a) Road surface temperature: average monthly temperatures as in Table l; water content of the subsoil 22 % by mass.

b) Road surface temperature: constant frost at –12 °C, –16 °C, and – 20 °C; water content of the subsoil 22 % by mass.

c) Road surface temperature: constant frost at – 20 °C; water content of the subsoil 14 % and 30 % by mass.

Table I
Average monthly temperatures

Time	Temperature °C	Length Days
30. November	+ 6	1
December	+ 2	31
January	0	31
February	– 9	29
March	+ 8	31

Calculating heat flow

A computer simulation tool written by BASF was used to work out the temperature profile in a layered structure as a function of depth; the program employs an algorithm based on a set of thermodynamics equations.

The following boundary conditions were used for each design:

a) layered structures as in Fig. 1

b) physical properties of the material as in Table II

c) temperature at depth of 8 m assumed to be a constant 6 °C

d) initial temperature profile on November 30 as in Table III.

The data given has been endorsed by the German road research institute (BASt) in Cologne.

The initial temperature profile and the average monthly temperatures given in Table I are based on observations of BASt on the test stretch at Obererlenbach, Germany.

The values given for the water content of the subsoil are based on observations by Dr. Jessberger of Ruhr-Universität, Bochum, Germany.

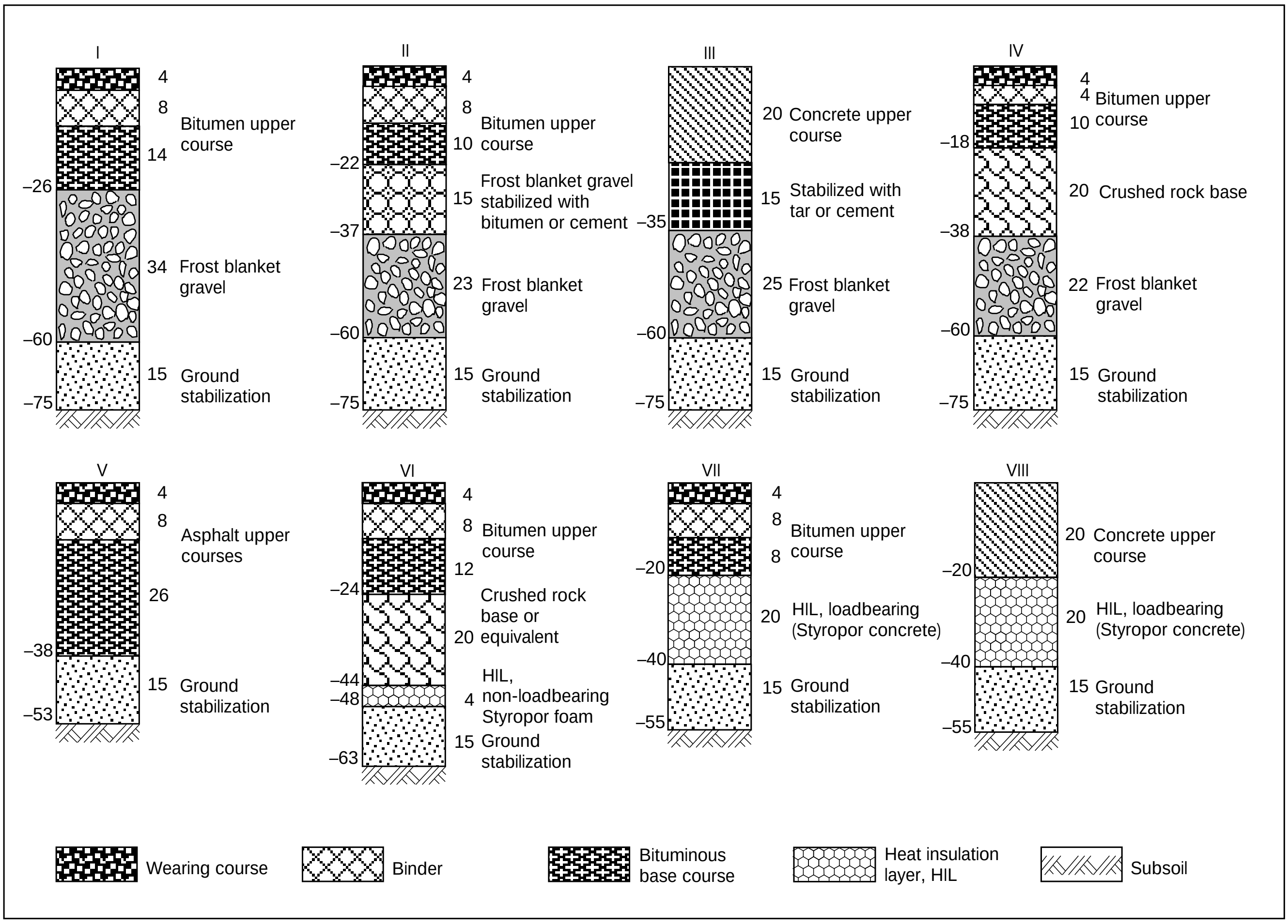

Fig. 1 Selection of possible frost-resistant structures
Suggested for heavy traffic: 5000 –10000 vehicles per 2-land highway in 24 hours or daily average of 500 –1000 HGVs over 5 t

Table II Physical properties of the material

Construction material	Density (dry) kg/m³	Thermal conductivity Ï W/(m · K)	Specific heat capacity c kJ/(kg · K)	Water content % (by mass)	% (by vol.)
Bituminous upper course	2400	1.74	0.84	2	
Concrete upper course	2370	1 63	1.09	5	
Frost blanket gravel 0/30	2000	0.79	0.92	5	
Crushed rock	2000	0.58	0.84	5	
Frost blanket gravel cement reinforced	2000	1.74	0.88	5	
Ground stabilization (limestone)	1650	0.87	0.84	15	
loadbearing heat insulation layer (Styropor concrete®)	650	0.15	1.26	18	
Frost-sensitive subsoil (course clay)	1600	0.42	0.84	22	
non-loadbearing heat insulation layer (Styropor foam boards)	40	0.03	1.38		10
Water	1000	0.58	4.18		
Ice	916	2.21	2.09		

Table III Initial temperature profile

Depth m	Temperature °C
0	6.0
1.0	8.5
2.0	11.2
3.0	12.8
4.0	12.5
5.0	12.2
(8.0)	(6.0)

Results of the analysis

a) Road surface temperature: Average monthly temperatures as in Table I; water content of the subsoil 22 % by mass.

Table IV shows computed values for each of the 8 structures. The figures given are: the maximum depth of frost penetration and the time taken to reach this depth (depth taken to the nearest boundary layer); the minimum temperature at this boundary layer; the temperature at the road surface.

Table IV Maximum frost depth (to nearest layer boundary)

Structure No.	Time Day	max. frost depth cm	Temperature	
			layer boundary °C	road surface °C
I	92	90	–0.190	+8.0
II	94	90	–0.106	+8.0
III	94	90	–0.145	+8.0
IV	96	90	–0.048	+8.0
V	94	76.5	–0.181	+8.0
VI	91	47	–0.181	–9.0
VII	91	40	–0.158	–9.0
VIII	91	40	–0.182	–9.0

VI = non-loadbearing heat insulation layer (Styropor foam boards)
VII, VIII = loadbearing heat insulation layer (Styropor concrete)

As can be seen from Table 4, the 8 structures fall into three groups according the frost penetration depth: the conventional designs (I to IV), the asphalt-topped structure (V), and those that use Styropor (VI, VII & VIII).

Table 5 contains, for each of the 8 structures, the computed minimum temperature at a depth of 75 cm (which happens to be the depth of the soil stabilization in structures I through IV), the time taken to reach this minimum temperature, and the temperature at the surface.

Table V Temp. at road surface and min. temp. 75 cm deep

Structure No.	Time Day	Min. temp. at 75 cm depth °C	road surface °C
I	92	–1.311	+8.0
II	91	–1.226	–9.0
III	91	–1.525	–9.0
IV	92	–1.146	+8.0
V	94	–0.177	+8.0
VI	93	+2.961	+8.0
VII	95	+1.391	+8.0
VIII	95	+1.366	+8.0

Figures 2 & 3 are plots of the function ϑ (t), the computed daily temperatures at the upper and lower boundaries of the soil stabilization layer of construction types 1, V, VI & VII (see also Fig. 1). The average daily road surface temperatures for the months December to March (see Table 1) have also been plotted alongside.

Table VI

Structure No.	Type of construction
I	conventional
V	asphalt upper courses
VI	non-loadbearing heat insulation layer
VII	loadbearing heat insulation layer

b) Road surface temperature: constant frost at –12 °C, –16 °C, and – 20 °C; water content of the subsoil 22 % by mass.

Fig. 4 shows the time taken for frost to penetrate (ie, soil to reach ϑ = 0 °C) down to the lower boundary of the soil stabilization layer of construction types I, V, VI & VII for road surfaces temperatures of –12 °C, –16 °C, and – 20 °C.

c) Road surface temperature: constant frost at – 20 °C; water con tent of the subsoil 14 % and 30 % by mass.

To get more information about the comparability of frost-resistant constructions, the heat flow was recomputed for subsoil water contents of 14 % and 30 % with the road surface temperature at – 20 °C in both cases.

Fig. 5 shows a plot of the frost penetration times (down to the lower boundary of the soil stabilization layer of construction types I, V, VI & VII) against the water content of the subsoil.

It can be clearly seen that a higher water content favours the flow of heat from the earth’s interior, thereby delaying frost penetration.

Structures with drier subsoils are more susceptible to frost penetration.

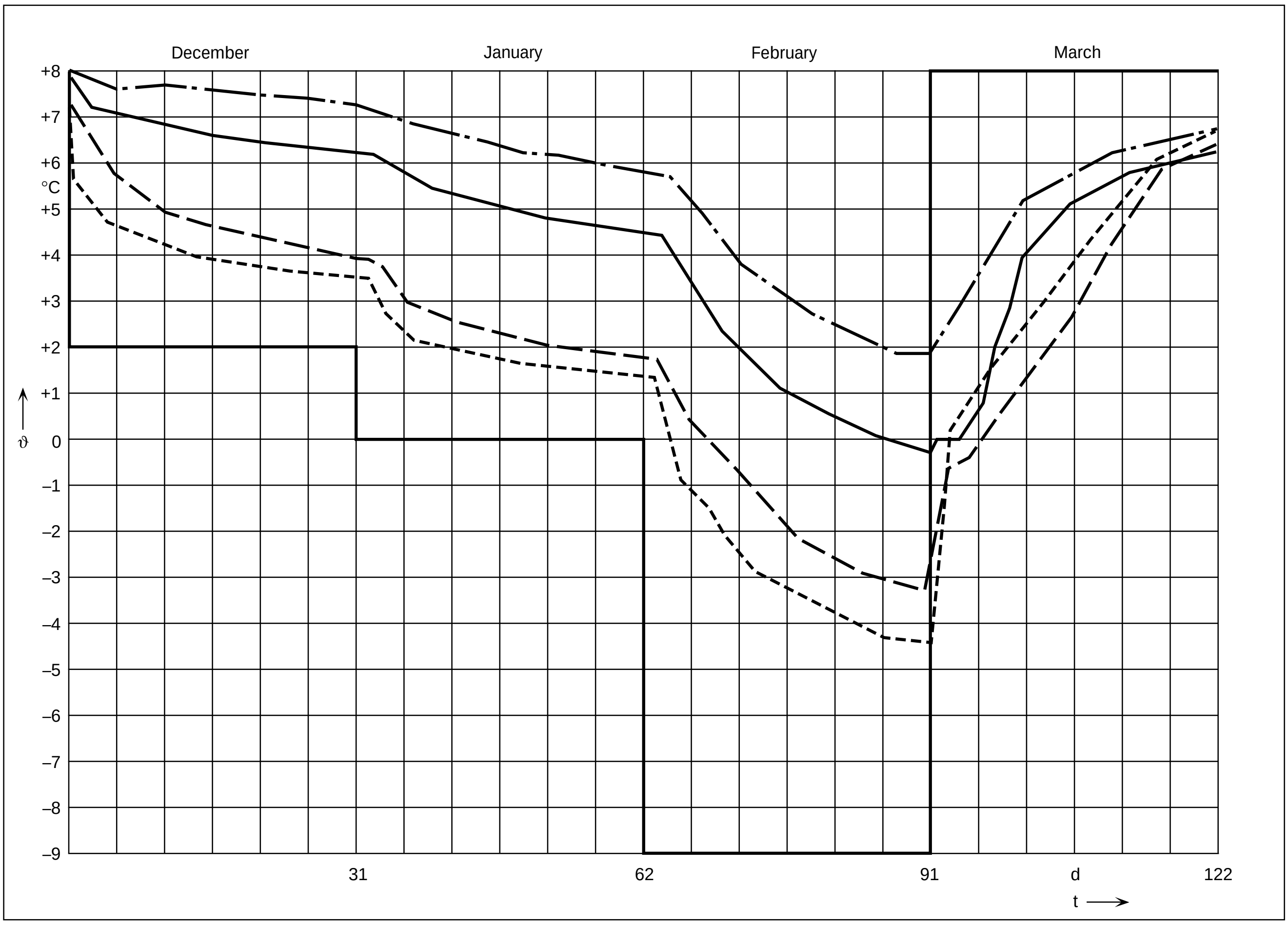

Fig. 2 ϑ *(t) at top of stabilization layer: I (60 cm* –·–·– *), V (38 cm* - - - - - *), VI (48 cm* — — — *), VII (40 cm* ——— *)*

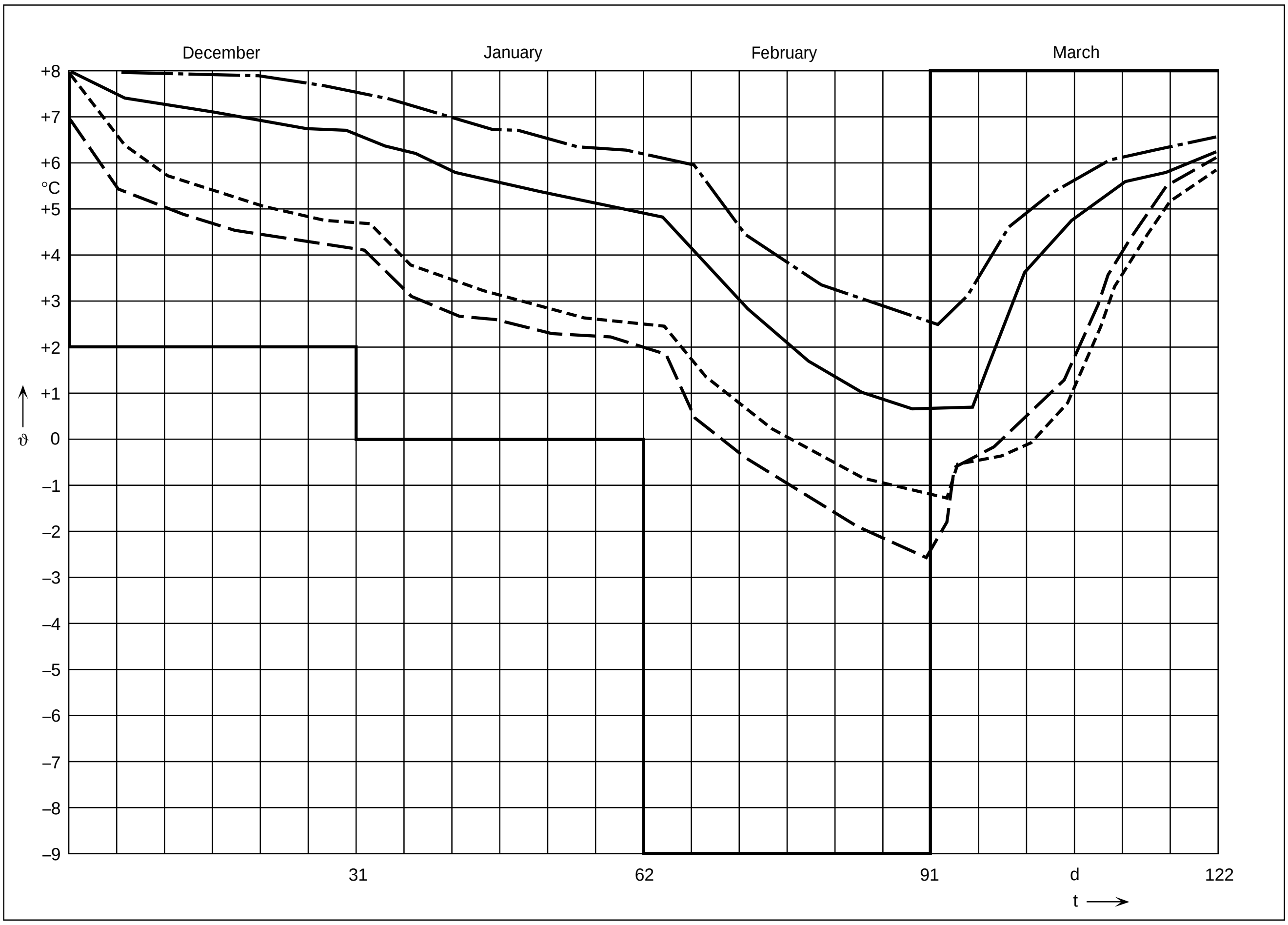

Fig. 3 ϑ *(t) at bottom of stabilization layer: I (75 cm* –·–·– *), V (53 cm* - - - - - *), VI (63 cm* — — — *), VII (55 cm* ——— *)*

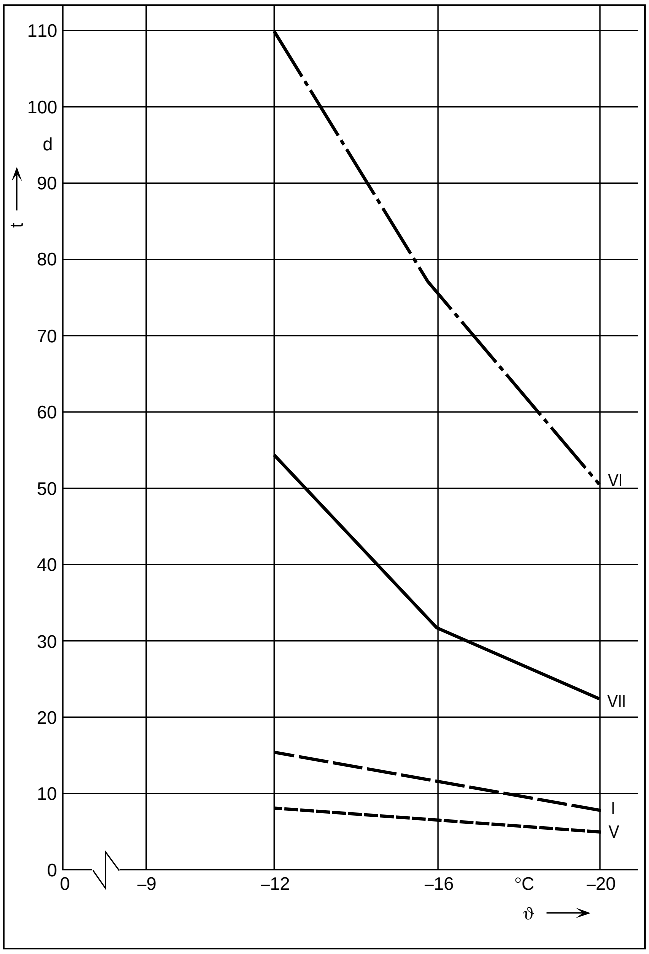

Fig. 4 Time taken for frost to penetrate down to the lower boundary of stabilization layer for constant road surface temperatures of –12 °C, 16 °C and – 20 °C.

Conclusions

Computer simulation was used to obtain theoretical values of the frost penetration depths and times for eight frostproof road designs. These results are a measure of the road's frost penetration resistance. The eight road designs can be placed into four groups according to their frost resistance:

a) Non-loadbearing heat insulation layer comprising Styropor foam boards (VI).

b) Loadbearing heat insulation layer comprising Styropor concrete (VII, VIII).

c) Conventional structures (I to IV).

d) Asphalt-topped (V).

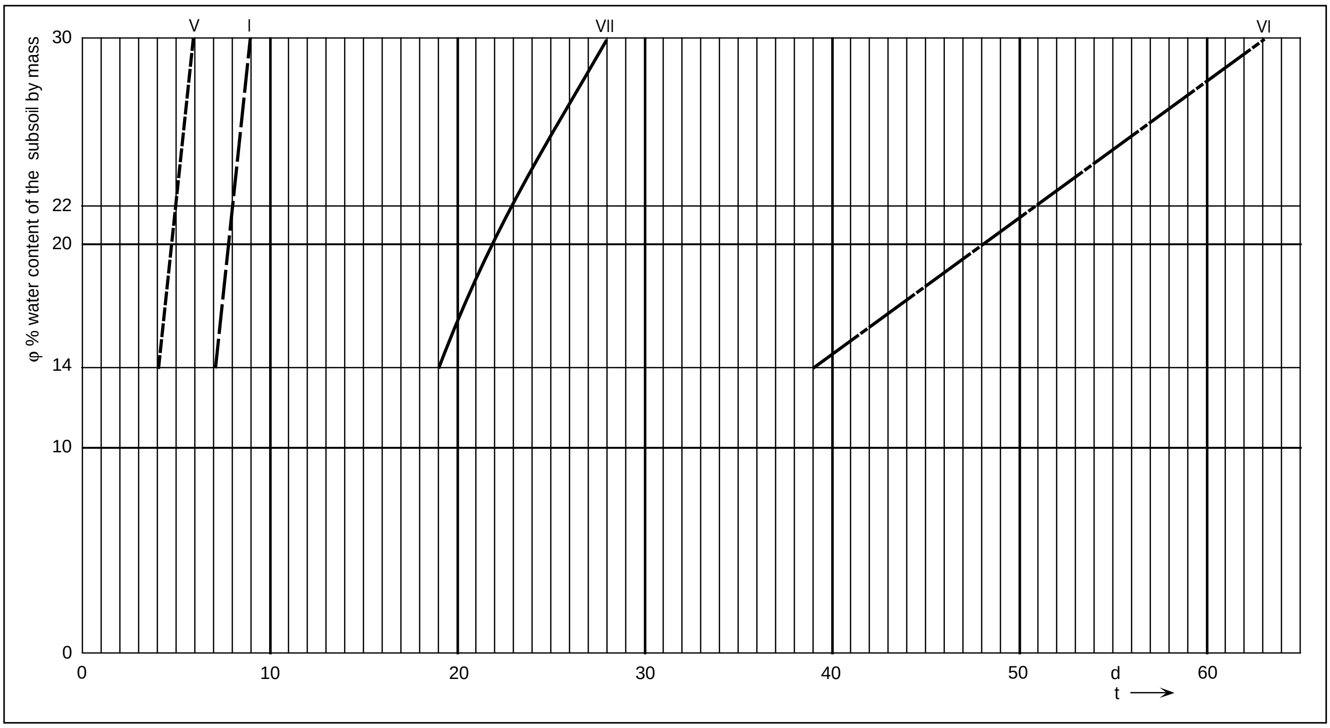

Fig. 5 Design I (ϑ = 0 °C at 75 cm depth), Design V (ϑ = 0 °C at 53 cm depth) Design VI (ϑ = 0 °C at 63 cm depth), Design VII (ϑ = 0 °C at 53 cm depth) Frost penetration times down to the lower boundary of the stabilization layer as a function of water content of the subsoil.

Note

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6 Highway construction Ground insulation

Insulation of livestock buildings; Design examples

General

At one time the only way to guarantee adequate heat insulation was to build livestock sheds with thick, solid walls. Today, wall thicknesses have been reduced to what is structurally necessary and heat loss kept down by use of light thermally insulating materials. Adequate ventilation ensures that moisture levels stay within tolerable limits.

Modern shed designs are quick and economical to erect. They consist mostly of a supporting structure filled in with heat insulating panels. Because most of the components are prefabricated off-site in purpose-built factories, the weather does not affect the progress of the building work; this makes fixed-price contracts easier to obtain.

Almost all other conventional shed designs require an extra layer of heat insulation material. The lightweight walls often used for sheds require greater insulation because of their low ability to retain heat.

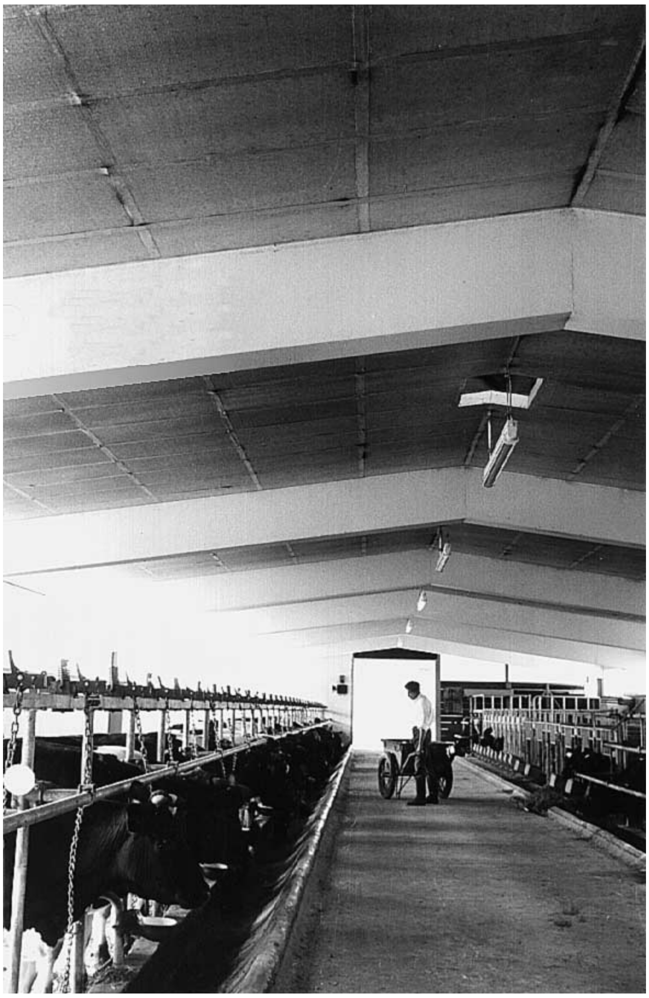


Fig. 1
Typical cattle shed

Walls*

The following table gives the heat transfer coefficient, k, for a number of wall designs with various thicknesses of thermal insulation. K-values for walls with no insulation (zero thickness) are also given. The table clearly shows the heat insulation performance of the various building materials used, along with the k-values that can be obtained with various thicknesses of foam board.

Table 1 Heat insulation of shed walls

Serial No.	Wall material	Thickness of Styropor foam board	Heat transfer resistance	Heat transfer coefficient
		d	$1/\Lambda$	k
		cm	$m^2 \cdot K/W$	$W/(m^2 \cdot K)$
1	Solid brick (DIN 105) 24 cm thick Density 1800 kg/m^3 $\lambda = 0.79$ W/(m · K) plastered on both sides	0 2 3 4	0.34 0.83 1.08 1.32	1.97 1.00 0.80 0.67
2	Solid brick (DIN 105) 24 cm thick Density 1200 kg/m^3 $\lambda = 0.52$ W/(m · K) plastered on both sides	0 2 3 4	0.50 0.99 1.24 1.48	1.54 0.87 0.71 0.60
3	Lightweight concrete/twocell hollow block DIN 18151 24 cm thick Density 1200 kg/m^3 $\lambda = 0.49$ W/(m · K) plastered on both sides	0 2 3 4	0.53 1.02 1.28 1.51	1.44 0.85 0.70 0.59
4	As in 3, but 30 cm thick	0 1 2 3	0.65 0.90 1.14 1.39	1.22 0.94 0.77 0.64
5	Lightweight concrete/twocell hollow block DIN 18151 24 cm thick Density 1600 kg/m^3 $\lambda = 0.56$ W/(m · K) plastered on both sides	0 2 3 4	0.47 0.96 1.21 1.45	1.57 0.88 0.73 0.62
6	As in 5, but 30 cm thick	0 2 3 4	0.58 1.07 1.32 1.57	1.35 0.81 0.66 0.58
7	Lightweight concrete/solid block (DIN 18152) 24 cm thick Density 1400 kg/m^3 $\lambda = 0.64$ W/(m · K) plastered on both sides	0 2 3 4	0.41 0.90 1.15 1.39	1.73 0.94 0.76 0.64
8	Sand-lime/solid block (DIN 106) 24 cm thick Density 1800 kg/m^3 $\lambda = 0.99$ W/(m · K) plastered on both sides	0 3 4 5	0.28 1.02 1.26 1.51	2.23 0.85 0.70 0.59

** In the following diagrams of wall cross-sections, the outside of the building is always on the left*

Serial No.	Wall material	Thickness of Styropor foam board	Heat transfer resistance	Heat transfer coefficient
		d	$1/\Lambda$	k
		cm	$m^2 \cdot K/W$	$W/(m^2 \cdot K)$
9	Lime-sand/cored block	0	0.39	1.81
	(DIN 106)	2	0.88	0.97
	24 cm thick	3	1.13	0.78
	Density 1400 kg/m^3	4	1.37	0.65
	$\lambda = 0.70$ W/(m · K)			
	plastered on both sides			
10	Aggregate concrete	0	0.14	3.31
	24 cm tick	3	0.88	0.97
	Density 2400 kg/m^3 B $\geq$ 160	4	1.12	0.78
	$\lambda = 2.04$ W/(m · K)	5	1.37	0.66
	plastered on one side			
11	Dense natural stone (granite, basalt)	0	0.16	3.06
	50 cm thick	3	0.90	0.94
	Density 3000 kg/m^3	4	1.14	0.77
	$\lambda = 3.49$ W/(m · K)	5	1.39	0.64

Fig. 2 Typical pig rearing unit

Explanation of heat insulation terms used by DIN 4108:

$\frac{1}{\Lambda}$ = Heat transfer resistance
(Heat insulation factor)
Unit: $m^2 \cdot K/W$
k = Heat transfer coefficient
(known as the k-value)
Unit: $W/(m^2 \cdot K)$

In terms of heat insulation, it does not matter whether the heat insulation layer is on the inside or the outside of the building. Insulation on the outside gives better heat retention; a vapour barrier is usually unnecessary. On the other hand, weather protection is necessary (eg, reinforced polymer-dispersion-based plaster or cladding boards). Sheet made of plastic, metal, fibre cement and similar material is also possible, as is corrugated sheeting and shingle cladding, etc. Figs. 3 to 6 show examples.

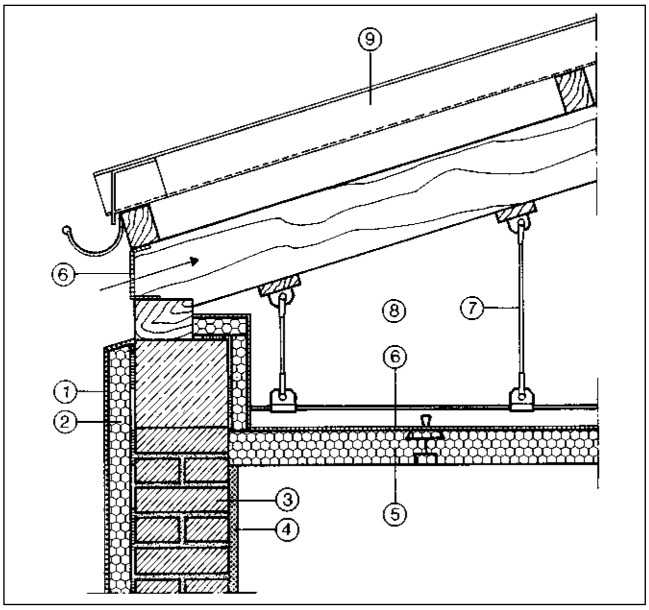


Fig . 3 Insulation on the outside of the shed wall; shed ceiling is suspended

Outside wall

① Reinforced dispersion-based plaster
② 4 cm Styropor foam board
③ 24 cm solid brick (DIN 105)
④ 1.5 cm lime cement plaster
$\frac{1}{\Lambda} = 1.31\ m^2 \cdot K/W$
$k = 0.67\ W/(m^2 \cdot K)$

Ceiling

Suspended fire-retardant Styropor foam ceiling
⑤ 9 cm Styropor foam
⑥ Wire mess or similar
⑦ Aluminium strut
⑧ Ventilated roof
⑨ Corrogated fibrated concrete
$\frac{1}{\Lambda} = 2.1\ m^2 \cdot K/W$
$k = 0.41\ W/(m^2 \cdot K)$

Insulation is often easier to apply to the inside of the building; Figs. 7 – 9 & 13 show examples of this. In contrast to human living accommodation, sheds require a vapour barrier on the inside due to the high humidity. For example, this can take the form of an aluminium foil pre-laminated to the foam board. The gaps between the boards are covered over with adhesive tape. It is advisable to protect the insulation at places vulnerable to accidental mechanical damage (eg, by farm machinery) by installing protective skirting or spur posts.

Figs. 10 & 11 show lightweight wall designs. In these cases there must be adequate ventilation behind the outer cladding – boards in Fig. 10, fibrated cement in Fig. 11 – to remove any moisture formed by condensation or driving rain (gaps!).

Because condensation will easily form on all cold surfaces due to the high humidity found in sheds holding livestock, careful consideration must be given to cold bridges. The places especially at risk are where steel or concrete framework, as well as peripheral tie beams and supports, penetrate the interior insulation. For interior insulation, the vapour barrier must also extend into window reveals as Figs. 8 & 19 show.

Styropor foam is so easy to apply that in many cases you can install it yourself. The foam board is available in many thicknesses and also comes laminated with a large variety of materials. It can be shaped with all the usual woodworking tools and can even be cut with a knife.

The foam boards can be secured in place by bonding, nailing, screwing or battening. With concrete walls, plaster baseboards are often placed into the formwork before the concrete is poured and become fixed as the concrete sets.

Dispersion-based adhesives are recommended for fixing the boards to absorbent, even, surfaces; for uneven surfaces (eg, bare brickwork), adhesive mortar should be used.

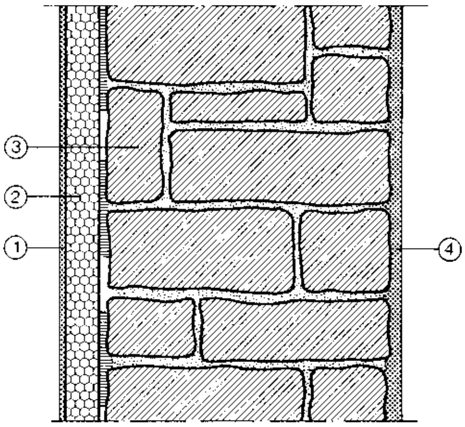


Fig. 4 Old rough-stone shed wall with new exterior insulation

① Reinforced dispersion-based plaster with fabric reinforcement
② 5 cm Styropor foam board
③ 50 cm rough-stone masonry
④ 2 cm lime cement plaster

$\frac{1}{\Lambda} = 1.39$ m^2 · K/W
k = 0.64 W/(m^2 · K)

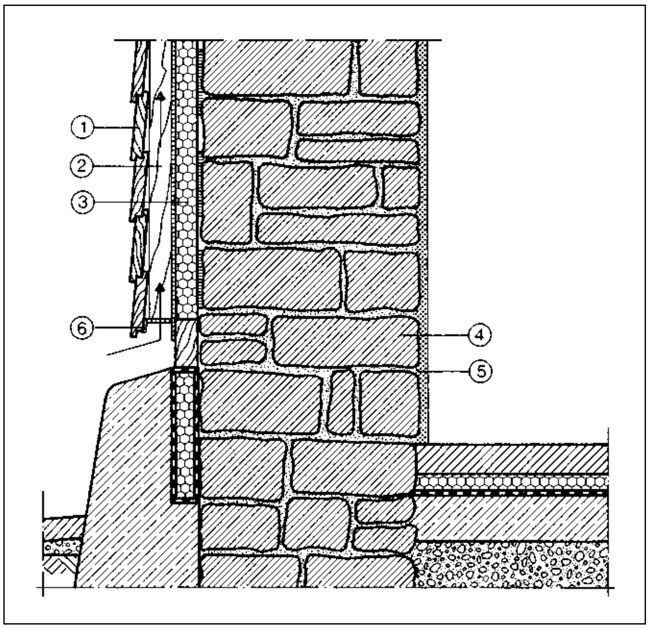
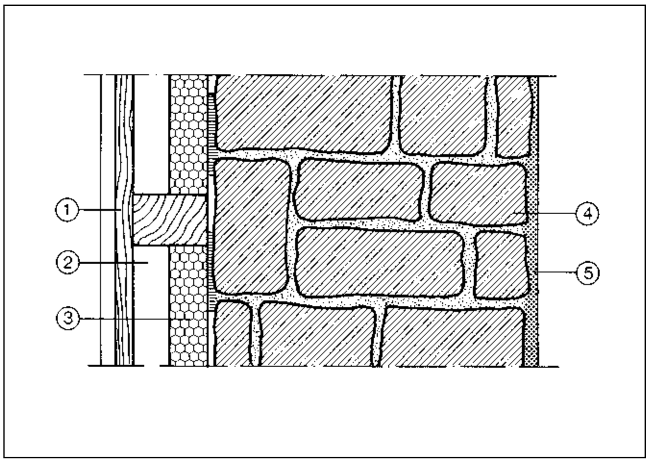


Fig. 5 Old shed wall as in Fig. 4, but with insulation layer protected by a ventilated outer cladding



Horizontal section of old shed wall (see Fig. 5)

① 2 cm cladding board set on wooden battens
② Ventilation
③ 5 cm Styropor foam board
④ 50 cm rough-stone masonry
⑤ 2 cm lime cement plaster
⑥ Opening with mesh cover

$\frac{1}{\Lambda} = 1.39\ \text{m}^2 \cdot \text{K/W}$

$k = 0.64\ \text{W/(m}^2 \cdot \text{K)}$

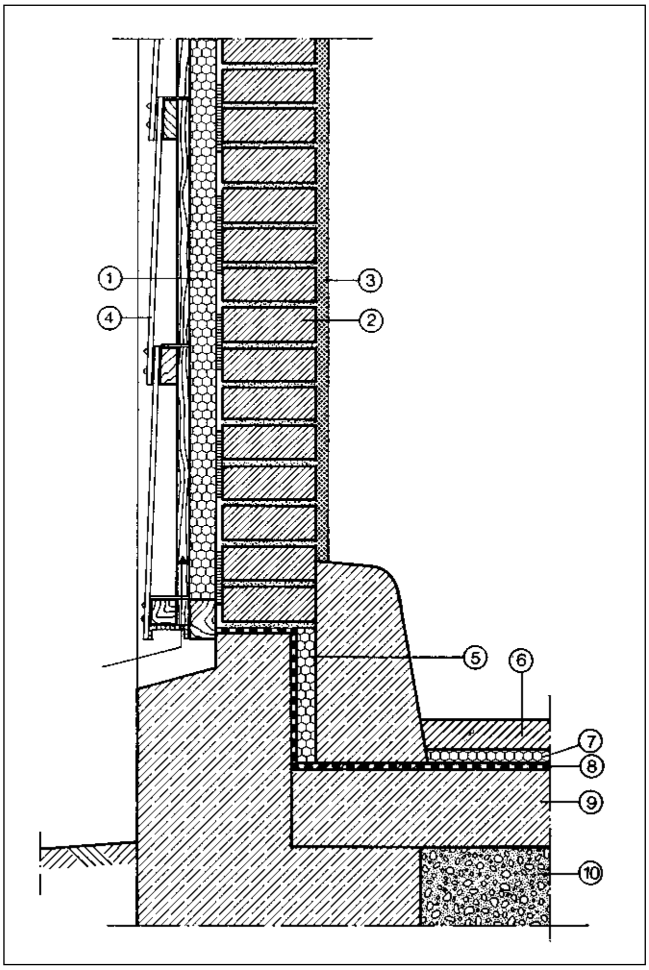


Fig. 6 Shed wall with outer insulation

Wall

① 5 cm Styropor foam board
② 17.5 cm lime-sand solid brick (DIN 106)
③ 2 cm lime cement plaster
④ Fibrated concrete sheet outer cladding
⑤ Base insulation made from Styropor foam board

$\frac{1}{\Lambda} = 1.43\ \text{m}^2 \cdot \text{K/W}$

$k = 0.63\ \text{W/(m}^2 \cdot \text{K)}$

Floor

⑥ 6 cm cast reinforced concrete
⑦ 3 cm Styropor foam board covered with film
⑧ Moisture barrier
⑨ 15 cm aggregate concrete
⑩ Filter layer of gravel or crushed

$\frac{1}{\Lambda} = 0.78\ \text{m}^2 \cdot \text{K/W}$

$k = 1.05\ \text{W/(m}^2 \cdot \text{K)}$

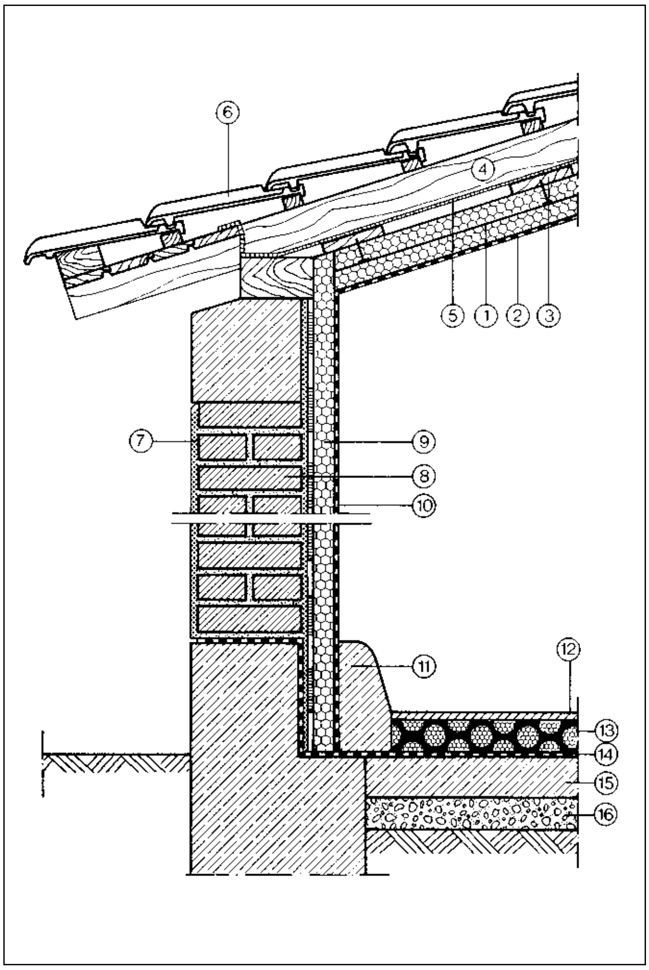


Fig. 7 Insulation on the inner side of the wall and ceiling

Roof

① 9 cm Styropor foam board
② Vapour barrier*

$\frac{1}{\Lambda} = 2.20\ \text{m}^2 \cdot \text{K/W}$
$k = 0.42\ \text{W/(m}^2 \cdot \text{K)}$

③ Open formwork
④ Rafter system (ventilated roof)
⑤ Vire cloth or similar
⑥ Roofing tiles and battens

Wall

⑦ 2 cm lime cement plaster
⑧ 24 cm lime-sand solid brick (DIN 106)
⑨ 5 cm Styropor foam board
⑩ Moisture barrier
⑪ Spur stone

$\frac{1}{\Lambda} = 1.51\ \text{m}^2 \cdot \text{K/W}$
$k = 0.59\ \text{W/(m}^2 \cdot \text{K)}$

Floor

⑫ Protective screed
⑬ Styropor® concrete
⑭ Moisture barrier
⑮ 10 cm aggregate concrete
⑯ Filter layer of gravel or crushed rock

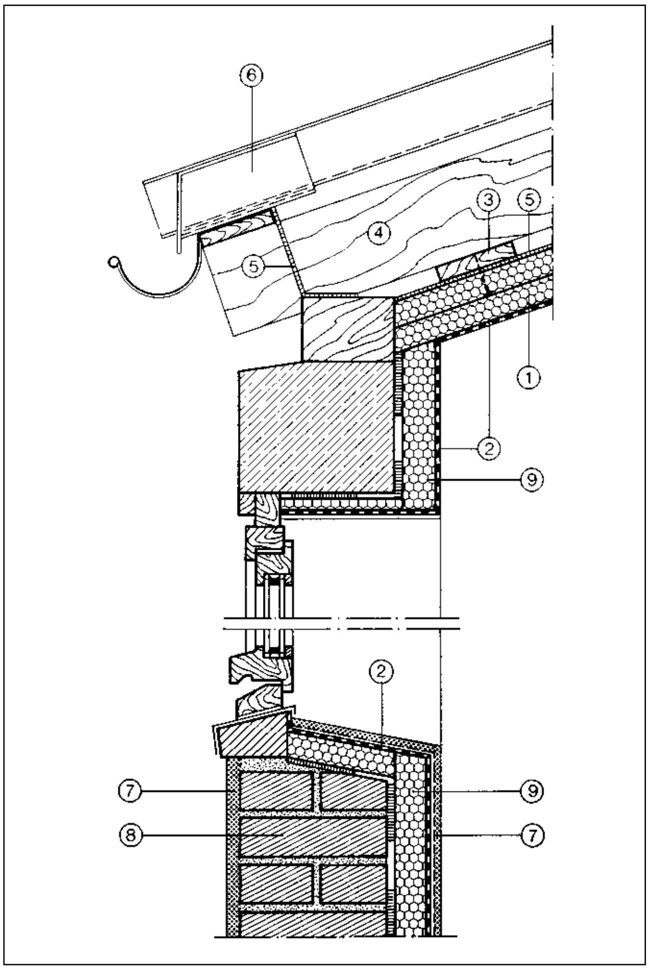


Fig. 8 Shed wall with internal insulation and double-glazed wood frame window

Roof

① 9 cm Styropor foam board

$\frac{1}{\Lambda} = 2.20\ \text{m}^2 \cdot \text{K/W}$
$k = 0.42\ \text{W/(m}^2 \cdot \text{K)}$

② Vapour barrier
③ Open formwork
④ Rafter system (ventilated roof)
⑤ Wire cloth or similar
⑥ Corrugated fibrated concrete cladding

Wall

⑦ 2 cm lime cement plaster (plaster support use inside)
⑧ 24 cm solid brick (DIN 105)
⑨ 4 cm Styropor foam board, with vapour barrier between battens

$\frac{1}{\Lambda} = 1.32\ \text{m}^2 \cdot \text{K/W}$
$k = 0.67\ \text{W/(m}^2 \cdot \text{K)}$

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* *Not necessary if there is sufficient ventilation.*

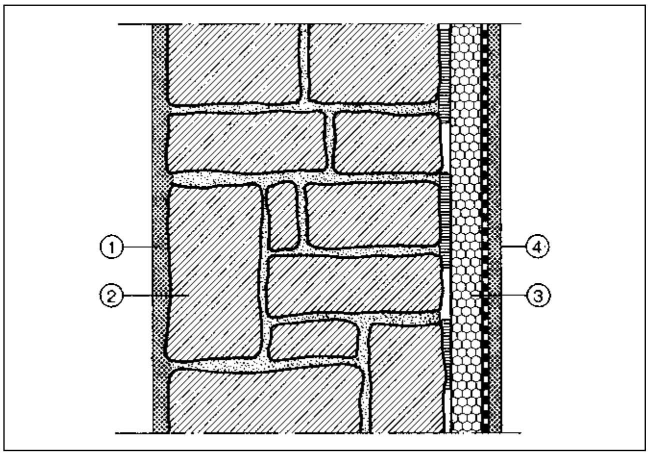

Fig. 9 Rough-stone shed wall with interior insulation

① 2 cm lime cement plaster
② 50 cm rough-stone masonry
③ 5 cm Styropor foam board, with vapour barrier between battens
④ Lime cement plaster on top of plaster support

$\frac{1}{\Lambda} = 1.39\ \text{m}^2 \cdot \text{K/W}$
$k = 0.64\ \text{W/(m}^2 \cdot \text{K)}$

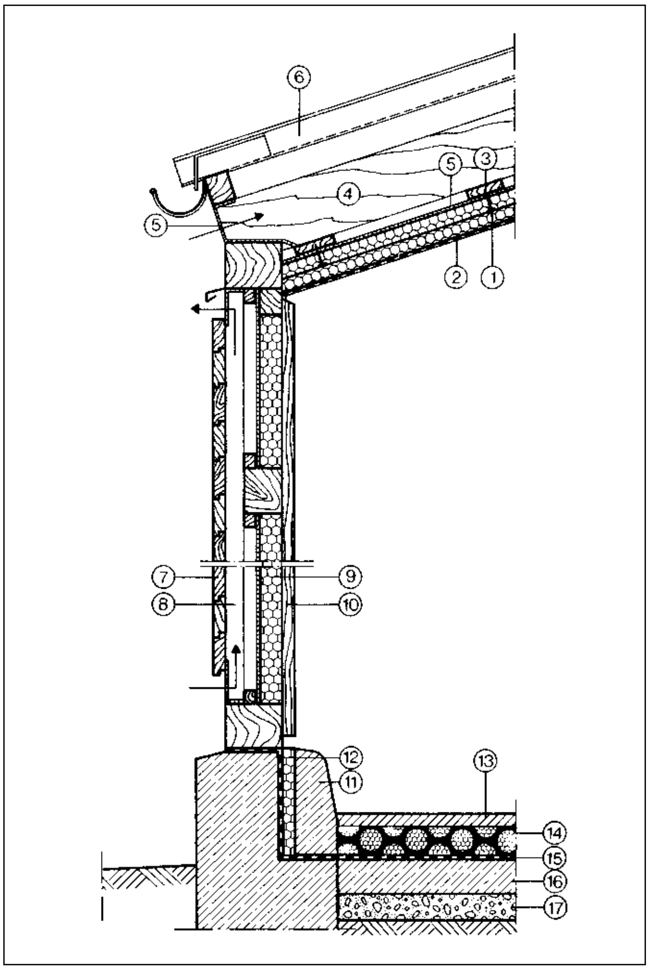

Fig. 10 Insulation of a wooden shed

Roof

① 9 cm Styropor foam board
② Vapour barrier

$\frac{1}{\Lambda} = 2.20\ \text{m}^2 \cdot \text{K/W}$
$k = 0.42\ \text{W/(m}^2 \cdot \text{K)}$

③ Open formwork
④ Rafter system (ventilated roof)
⑤ Wird cloth or similar
⑥ Corrugated fibrated concrete sheet

Wall

⑦ Outer cladding made from shuttering board
⑧ Ventilated cavity
⑨ 8 cm Styropor foam board
⑩ Inner cladding made from shuttering board
⑪ Concrete spur stone
⑫ Base insulation made from 3 cm Styropor foam board

$\frac{1}{\Lambda} = 2.14\ \text{m}^2 \cdot \text{K/W}$
$k = 0.44\ \text{W/(m}^2 \cdot \text{K)}$

Floor

⑬ Cement screed
⑭ 10 cm Styropor concrete
⑮ Moisture barrier layer
⑯ Aggregate concrete
⑰ Filter layer of gravel or crushed rock

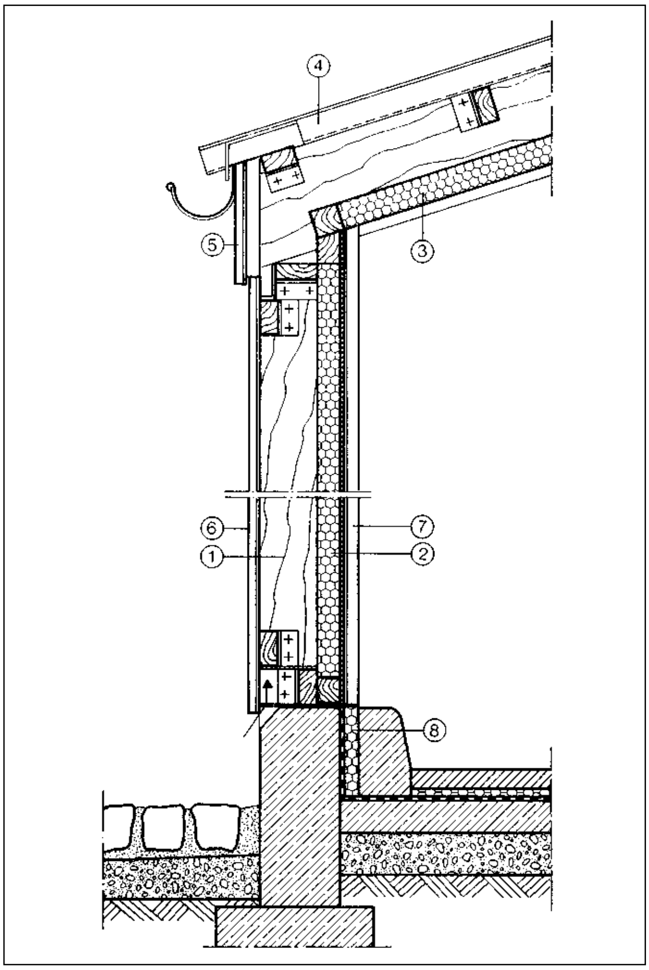

Fig. 11 Prefabricated shed

Fig. 12 Heat insulation in the roof of a poultry house

① Girder system (2-joint timber frame)
② Wall-high composite element with Styropor foam board and surrounding edge band
③ Large composite element, similar to ②
④ Roof covering (corrugated fibrated concrete sheet)
⑤ Fibrate concrete board
⑥ Outer fibrated concrete cladding
⑦ Inner fibrated concrete cladding
⑧ Base insulation made from 3 cm Styropor foam board

Roofs

Sheds usually have ventilated roofs because these are economical and easy to construct.

Wind-induced pressure differences and convection currents cause a stream of air to flow through the roof space (the space between the insulation layer and the roof membrane) and carry away any water vapour that has diffused through the layer of insulation (Figs. 3, 7, 8, 11, 13). It is therefore important to take into account the siting of the building with respect to the prevailing wind direction, as well as the location of ventilation openings on eaves and ridges.

When it comes to getting rid of moisture, the air flow through the roof-space of flat and low-pitched roofs only has a limited effect. This is why, when the humidity levels in the shed are particularly high, a vapour barrier (eg, aluminium foil) is applied to the room-side of the insulation layer. Styropor foam board laminated with aluminium has been well proven for this purpose. As is shown in the section drawings, the insulation in the roof is thicker than on the walls. There are three reasons for this: firstly, the heat retention effect is entirely due to the layer of insulation; secondly, the heat radiated through the roof is greater than through the walls; thirdly, the heat transmitted to the outside is greater due to the higher temperature gradient found in the warmer upper parts of the shed. These reasons also explain the greater risk of condensation under the ceiling than on the walls.

Fig. 3 shows a suspended ceiling. The support struts are of a standard light alloy design. Note here that any gaps must be carefully sealed.

Mesh (size not more than 8 – 10 mm) must be used in appropriate places to prevent rodents (eg, rats and mice) making their nests in the foam insulation. Only water-based wood preservative must be used; that containing oil or solvents attacks the Styropor foam.

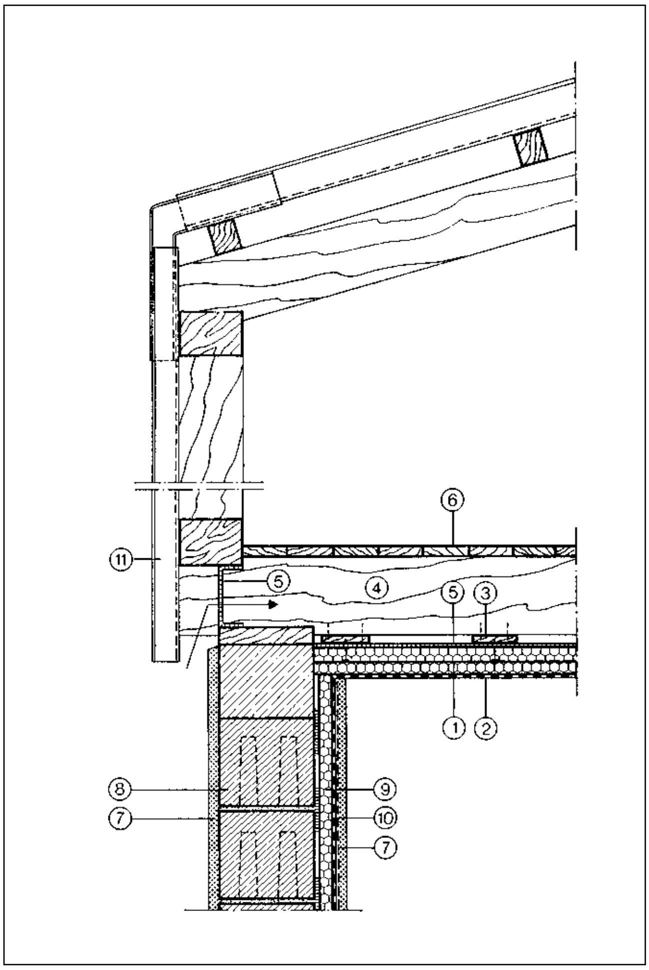

Fig. 13 Shed with straw loft; ventilated ceiling; insulation applied to inside of exterior wall

Ceiling

① 9 cm Styropor foam board
② Vapour barrier

$$\frac{1}{\Lambda} = 2.20\ \text{m}^2 \cdot \text{K/W}$$

$k = 0.46\ \text{W}/(\text{m}^2 \cdot \text{K})$

③ Open formwork
④ System of binders and joists (ventilated ceiling)
⑤ Wire cloth or similar
⑥ Wooden floor boards

Wall

⑦ 2 cm lime cement plaster (plaster support used inside)
⑧ 24 cm lightweight concrete/two-cell hollow block (DIN 18151)
⑨ 4 cm Styropor foam board between wooden battens
⑩ Vapour barrier

$$\frac{1}{\Lambda} = 1.51\ \text{m}^2 \cdot \text{K/W}$$

$k = 0.59\ \text{W}/(\text{m}^2 \cdot \text{K})$

⑪ Timber construction cladded with corrugated fibrated concrete board

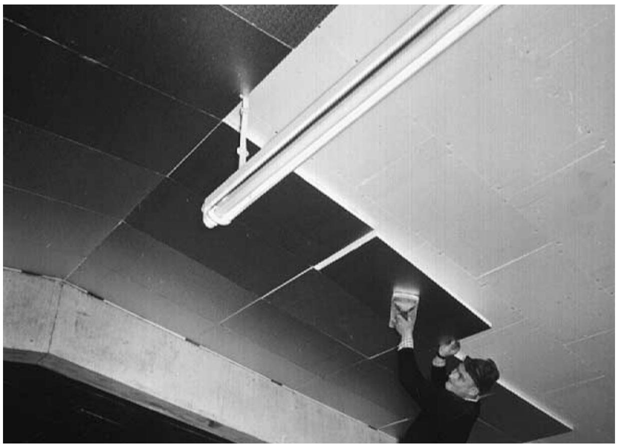

Fig. 14 Insulating a roof with Styropor foam board

Fig. 15 Gaps are sealed with adhesive tape against passage of water vapour

Shed floor

The shed floor should also be insulated against heat loss – not just under the pens where the cattle are housed, but also under the feeding and mucking-out areas. Here the insulation is 2 – 4 cm thick.

The main purpose of underfloor insulation in the accommodation pens is to prevent excessive loss of body heat from resting cattle and to keep the area comfortably warm. Heat insulation is installed particularly when no straw is used. Here, Styropor concrete has proved to be extremely effective.

Fig. 16 Styropor concrete as a heat insulation layer in shed construction

Doors and windows

It would be nonsensical not to bother insulating the door and windows. Fig. 18 shows a well-proven design of door with an inner core of insulation. Doors can be easily rebated to minimize heat loss through the gaps.

Condensation easily forms on closed shed-windows. This can only be cured by installing double-glazed windows, which are relatively expensive. Apart from heat loss, the run-off from condensation not only dirties the surrounding area of wall, but also forms a starting point for further damage.

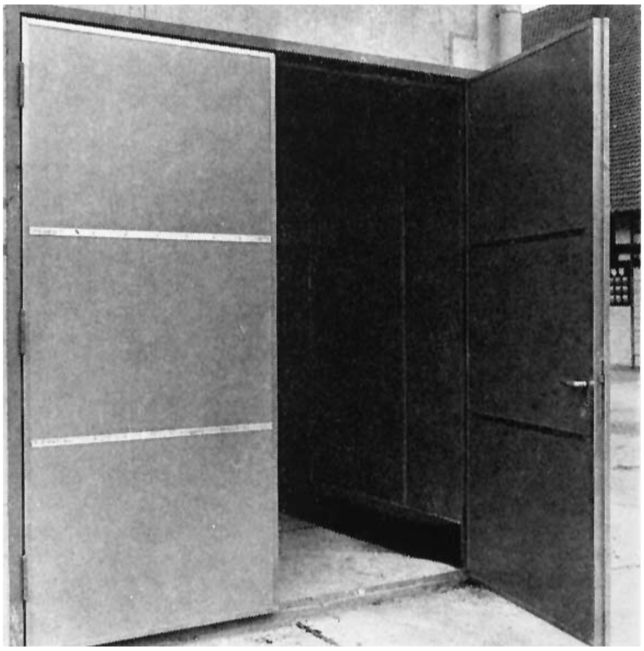

Fig. 17 Heat insulating aluminiumclad shed doors

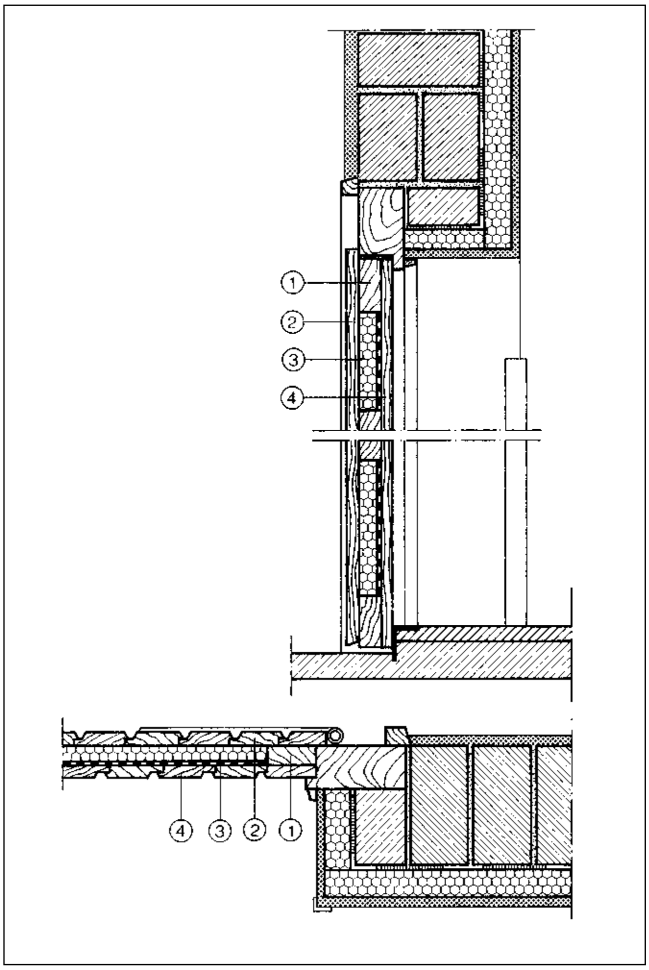

Fig. 18 Heat insulated shed outer door

① Timber frame
② 2.5 cm outer boarding
③ 4 cm Styropor foam board
④ 2.5 cm inner boarding

k = 0.66 W/(m^2 · K)

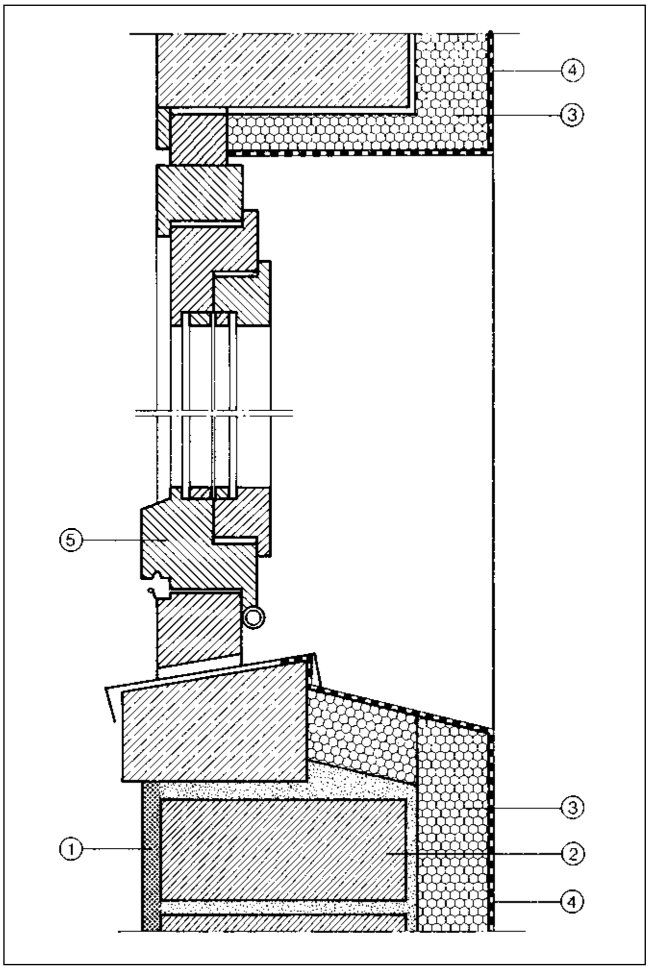

Fig. 19 Wall and window in detail

Wall

① 2 cm lime cement plaster
② 24 cm vertical coring brick (DIN 105)
③ 4 cm Styropor foam board
④ Moisture barrier

$\frac{1}{\Lambda}$ = 1.48 m^2 · K/W
k = 0.60 W/(m^2 · K)

⑤ Double-glazed wooden-framed window

Note

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49482 February 1992

6 Highway construction/ Ground insulation

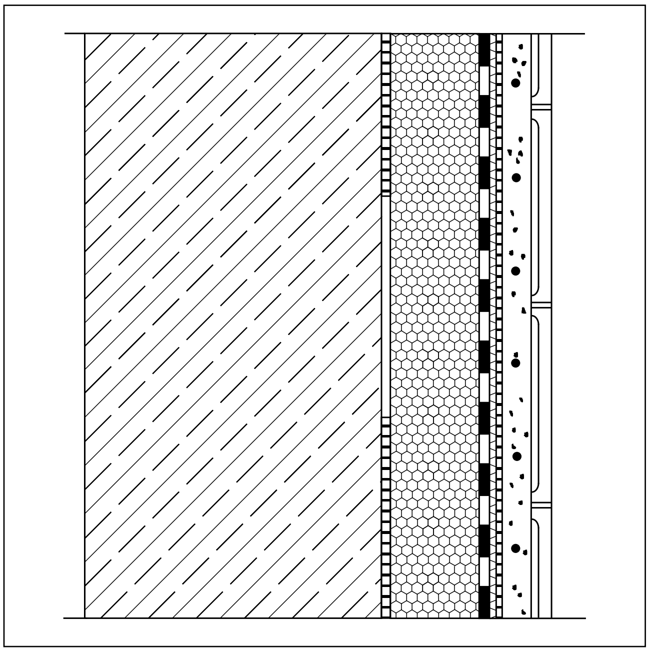
Swimming pools – general

When planning the construction of small swimming pools the same principles apply as for much larger indoor ones. Special attention must be paid to the insulation and ventilation.

The water temperature in the pool is usually between 22 °C and 27 °C. The surrounding air temperature must always be kept a few degrees above that of the water (even when the pool is not in use) to avoid the formation of condensation on walls and ceilings.

Good thermal insulation permits the pool to be run economically. The thickness of the insulation layer depends on local factors.
At the same time, the formation of condensation within the walls must also be prevented. This means that a vapour barrier is necessary on the warm side of the construction.

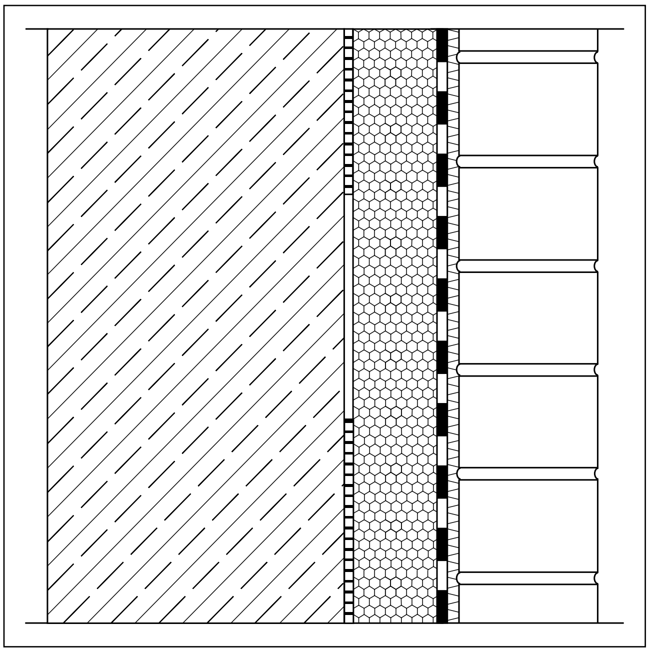
Here are some examples:



Outer wall

from exterior to interior:

- Concrete
- Construction adhesive
- Styropor foam boards, laminated on the room side with bituminous roofing membrane
- Aluminium roof-sealing membrane, overlapped and bonded with hot bitumen
- Hot bitumen coat, sand-surfaced
- Mortar, multilayered, with reinforcement
- Ceramic wall tiles

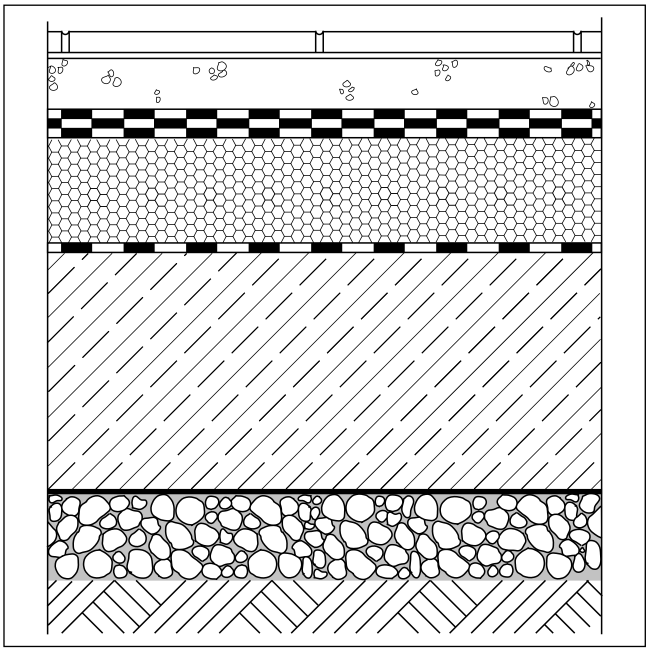


Alternative:

Clinker block construction

Special note: The vapour barrier is punctured when reinforcements for the plaster are anchored into the supporting wall; these openings in the barrier layer must be carefully sealed.

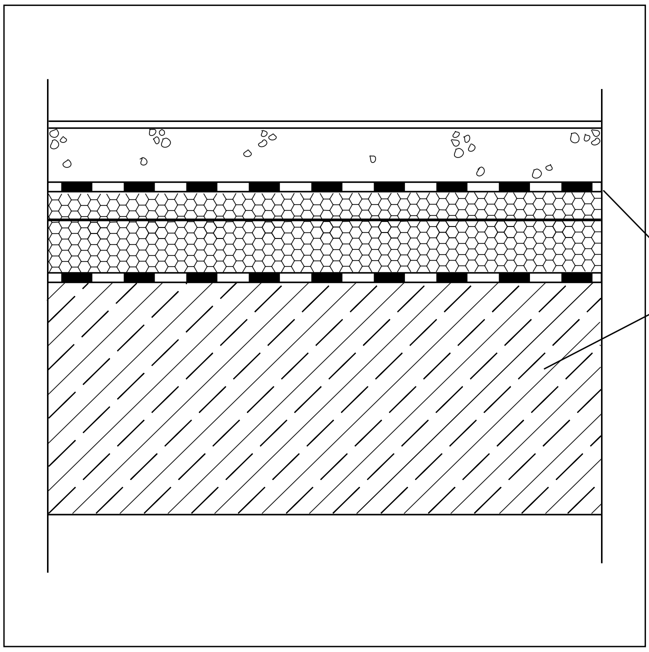
If the thermal insulation layer is to be applied to the outer side, a wall facing should be chosen for the room side under which it is easy to apply a vapour barrier; provided, of course, that it is not already an effective vapour barrier itself.



Floor

From top to bottom:

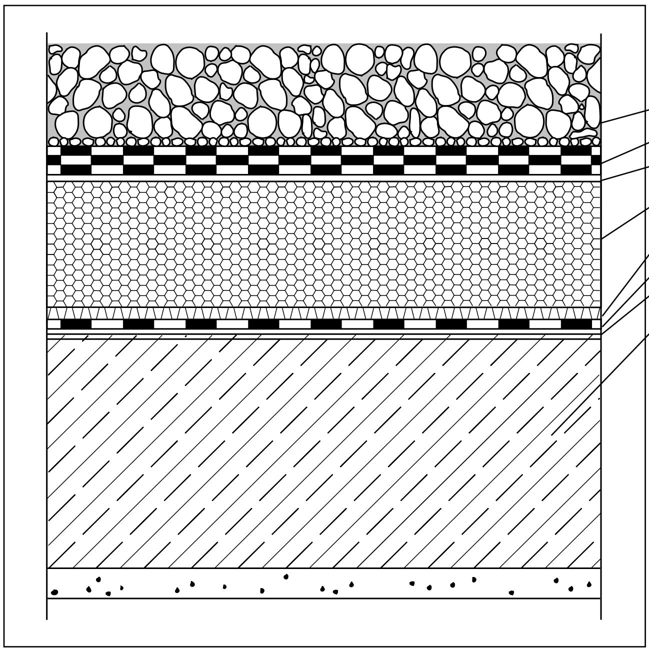
- Tiles laid in bed of mortar
- Cast plaster, 35 mm
- Damp course (also acts as a vapour barrier)
- Styropor foam board, laminated on the upper side
- Substructure built according to local conditions, possibly with a barrier against rising damp



Intermediate reinforced concrete floor

beneath a living area;
from top to bottom:

- Floorcovering
- Screed, at least 35 mm
- Protective sheeting (eg, polyethylene)
- Styropor foam boards of appropriate thickness – possibly footstep sound insulation board
- Vapour barrier
- Reinforced concrete floor

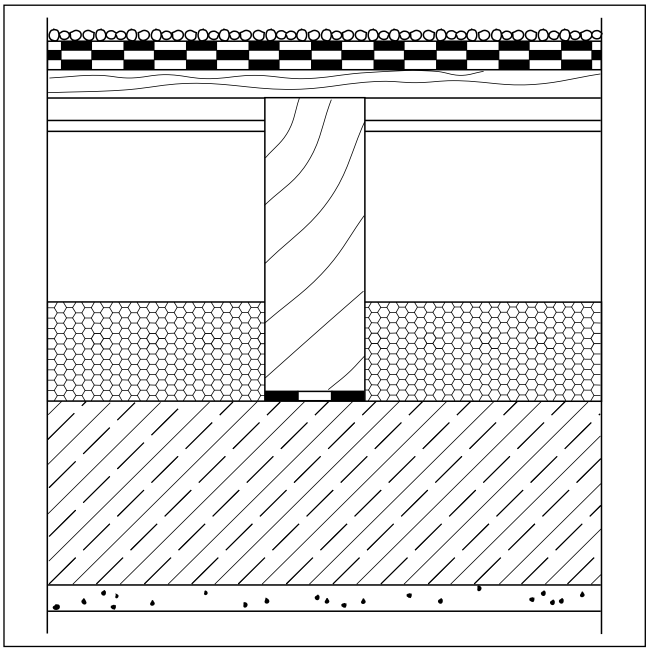


Solid non-ventilated flat roof

from top to bottom:

- Surface protection
- Roof covering or sealing
- Pressure equalizing layer
- Styropor foam board, type PS 20
- Vapour barrier
- Levelling layer
- Precoat of cold bitumen
- Reinforced concrete ceiling
- Surface finish (eg, paint) or facing

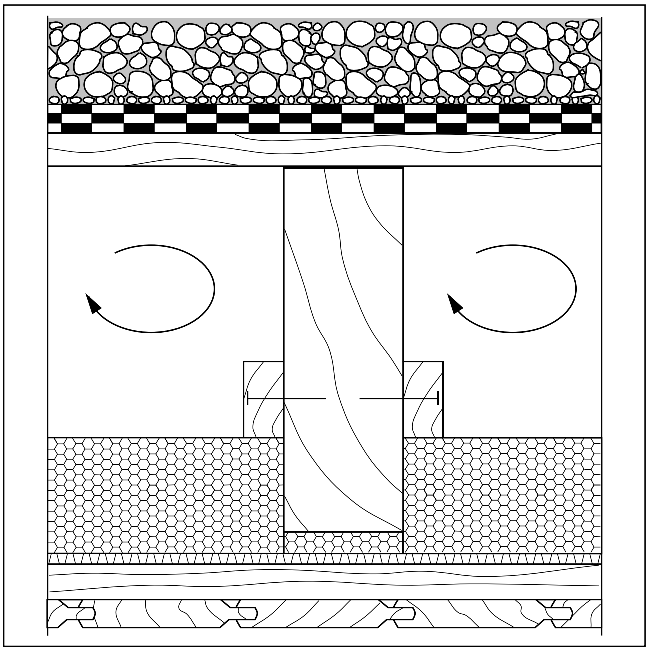
This is the usual type of construction; however, the thermal insulation layer is thicker – about 70 –100 mm thick.
The vapour barrier must be applied very carefully. Only materials that can cope with high atmospheric humidity should be used for the underside of the ceiling.



Ventilated flat roof with fireproof suspended ceiling

from top to bottom:

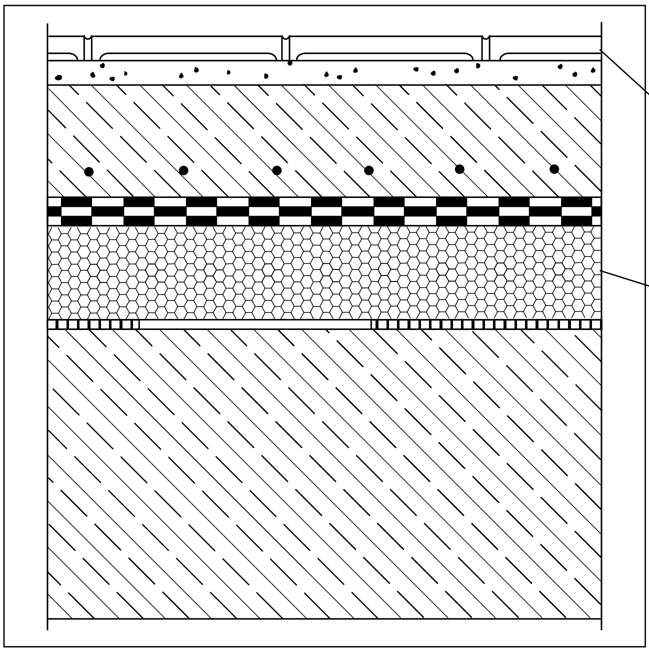
- Surface protection
- Roof covering or sealing
  (first layer of bituminous roofing membrane is nailed down)
- Board formwork
- Ventilated cavity (between the two structures)
- Styropor foam boards, Type PS 15 SE
  (flame retardant), 70 –100 mm thick.
- Reinforced concrete slab, depending on local conditions
- Surface finish (eg, paint) or facing



Ventilated flat roof with fireproof lightweight suspended ceiling

from top to bottom:

- Surface protection
- Roof covering or sealing
  (first layer of bituminous roofing membrane is nailed down)
- Board formwork
- Ventilated cavity (between the two structures)
- Styropor foam boards, Type PS 15 SE
  (flame retardant), 60 – 80 mm thick,
  underside laminated with aluminium foil – joints are carefully sealed with self adhesive aluminium foil strip
- Wooden facing



Swimming bath

Walls from inside to outside,
Floor from top to bottom:

- Tiles laid in mortar bed;
  inner concrete shell of the bath is reinforced
- Protective paper
- Sealing made of suitable plastic sheet or bituminous sealing membrane
- Bond with hot bitumen
- Styropor foam boards, Type PS 30, inner side laminated with bituminous fibre-glass wool.
- Substructure built according to local conditions

Special note: A density of Styropor foam must be chosen that corresponds to the expected loads encountered (due to the construction and the water pressure). In most cases Type PS 30 is sufficient.

General: It is especially important that at all joints (eg, floor-to-wall, wall-to-ceiling) the water vapour barrier membrane overlaps well and is totally impermeable. Under certain conditions it is recommended – or even necessary – to allow for expansion of these barrier layers.

There are of course other suitable designs possible. The ones given here are merely to show what basic factors have to be taken into consideration.

Note

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6 Highway construction/ Ground insulation

Inserts for joints

Joints between parts of structures or building elements fulfil various different purposes, to which their designs must be suited. Although the principal types of joint – settlement joints, expansion joints, isolation joints, and sliding joints – have different functions, many joints used in practice must serve more than one purpose.

1 Settlement joints

The extent of settlement depends mainly on the bearing capacity of the soil under the structure and the loading intensity. If different parts of a structure are likely to experience settlement to different degrees, it is necessary to provide vertical settlement joints. This situation can be expected when, for instance, loading intensities are not the same for the whole structure, or when an existing building is extended.

Styropor board used in settlement joints must fill the whole joint gap, completely separating the neighbouring parts of the structure. The board can be spot-bonded to the face of the existing structure. The joint must be protected externally against driving rain, e.g. by jointing section of the kind shown in Fig. 1.

2 Expansion joints

While settlement joints provide largely for relative movement vertically, in the plane of the joint, expansion joints allow horizontal movement normal to the plane of the joint, which may decrease or increase the joint gap.

Longitudinal expansion and contraction are most commonly due to temperature changes, to whose effects massive elements, such as roof slabs, are especially prone. However, differential settlement can also affect expansion joints, which must therefore satisfy a number of requirements in practice.

The position and execution of an expansion joint should take into account all the following points:

- The joint must continue through all the entire building element.
- The joint gap must be wide enough to accommodate the maximum expansion expected.
- Any filling must not offer appreciable resistance to expansion of the neighbouring parts of the building element.
- The filling must not cause thermal bridging.

There is no difficulty in meeting either of the last two requirements if the filling consists of expanded Styropor. Often, standard board of low density (15 kg · m^{-3}) is sufficiently compressible, but precompressed Styropor board, designated PS T, whose primary use is for reducing impact noise, offers considerably less resistance to short-term compressive stresses. The long-term behaviour of standard Styropor board of density 15 kg · m^{-3} is shown in Fig. 5.

In blockwork walls, the Styropor board can be placed in the opening dry, in close contact with the blocks. In poured concrete walls, the board can be placed in the form, but then care has to be taken that none of the mortar or cement paste can pass round it. The joints between the panels of Styropor board can be sealed with adhesive tape, but the use of board with rebated edges or two layers of board with staggered joints is also effective.

The outside of expansion joints may be protected from the weather by appropriate jointing sections (cf. Fig. 1) or elastoplastic sealant. Where protection against water under pressure is required, elastomeric water stops must be used, e.g. of the type shown in Fig. 2.

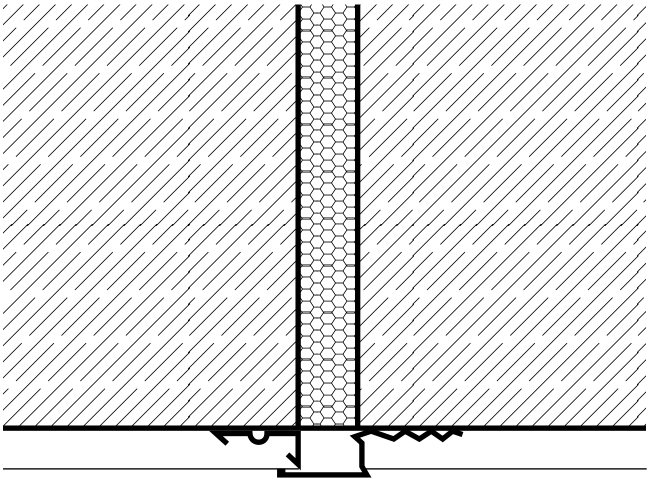

Fig. 1 Settlement joint protected by jointing section

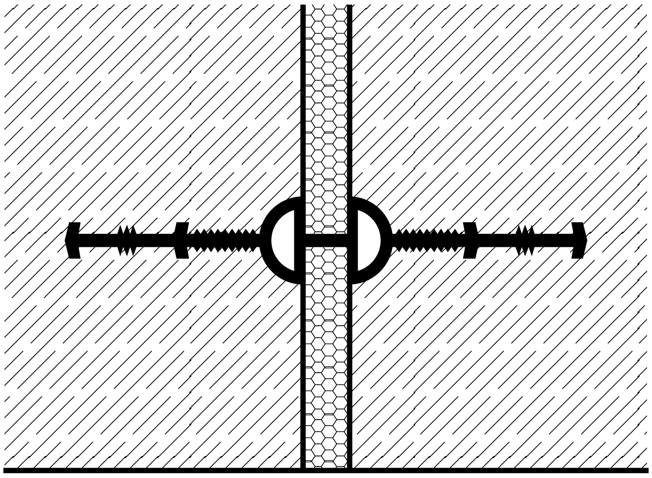

Fig. 2 Water stop fitted in an expansion joint

3 Isolating joints

Isolating joints are used primarily to reduce sound transmission, e.g. through otherwise solid separating walls (between semidetached or terraced houses – cf. Fig. 3).

The joint must extend as far as the roof, and may not be bridged at floors and ceilings. The purpose of the Styropor-board filling is to prevent the joint from becoming accidentally bridged by mortar or rubble during construction.

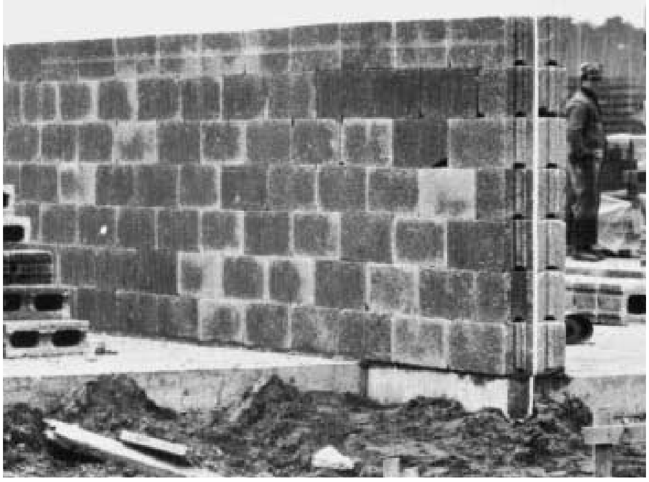

Fig. 3 Isolating joint between leaves of a separating wall

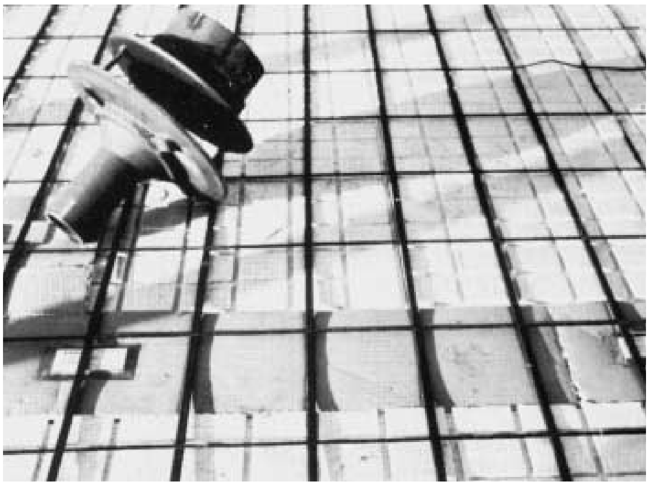

Fig. 4 Pad bearings with Styropor board infill

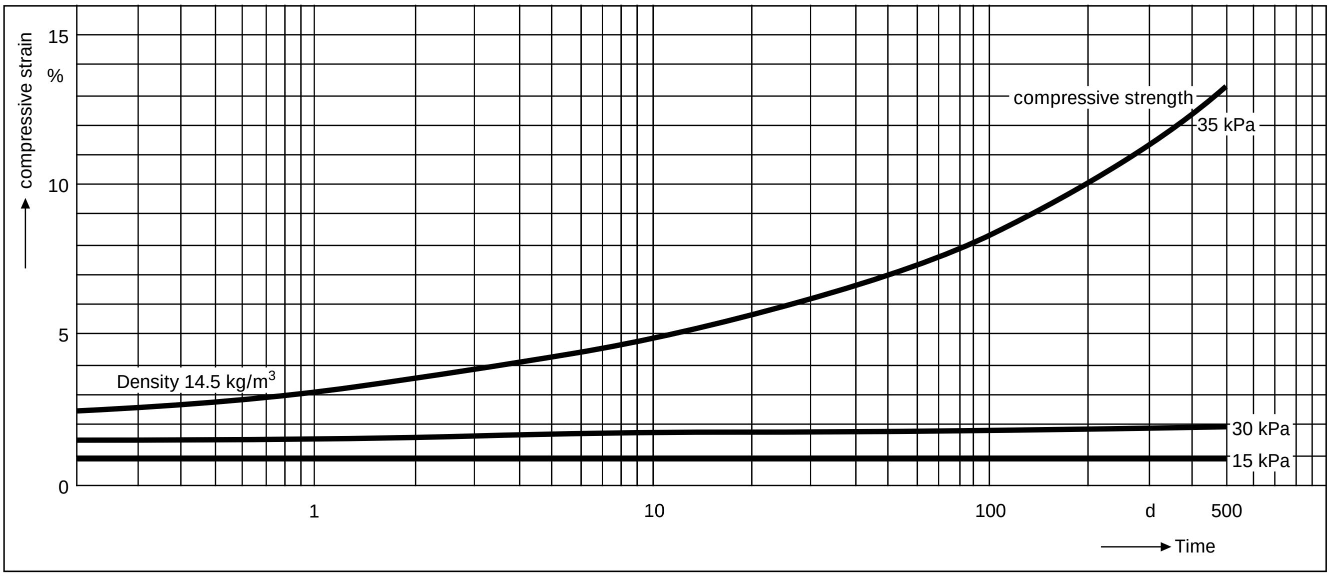

Fig. 5 Compressive strain ε *of Styropor board of density 14.5 kg·m*$^{-3}$ *vs time* ***t*** *for various values of stress* σ

4 Sliding joints

The joint between a monolithic horizontal building element such as a reinforced concrete roof slab and its support (e.g. a ring beam) must allow some horizontal movement. To reduce frictional resistance, various pad bearings or strip-pad bearings made from synthetic elastomers may be used. Styropor board may be used to fill the joint gap around and between the bearings. It is placed in position before the concrete is poured (cf. Fig. 4) and carries most of the weight of the wet concrete. Subsequently, the weight is borne by the bearings, and the friction between the expanded Styropor and the hardened concrete is negligible.

5 Styropor board for filling joints

Precompressed Styropor board suitable for impact-sound duty should always be used in isolation joints and expansion joints in which the filling is likely to be highly compressed from time to time. For all other joints, standard Styropor board of the lowest available density, e.g. 15 kg·m^{-3}, is suitable. However, if the filling is not covered, the equivalent flame-retardant grade must be used.

The panels of Styropor board should always be tightly butted, to avoid penetration of the joints by cement paste or mortar. Where complete separation is particularly important, it is best to use panels with rebated edges, though taping the joints or using two layers with staggered joints can be equally effective.

Where vertical joints of large area are to be filled, it is usual to spot-bond the Styropor board to one face.

If fresh concrete is applied to both sides of Styropor board, a bond may be formed at each interface. This tends to inhibit movement, and it has proved advantageous to remove the Styropor filling afterwards, leaving an open joint.

Styropor board is a particularly good filling for joints in buildings or other structures because it is non-absorbent and can be cut, shaped, and trimmed accurately and with simple tools.

Note

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7 Packaging

Model building using expanded Styropor foam

Drawings and models are both proven aids to planning, but models have the illustrative power peculiar to three-dimensional representations. Models can serve many purposes:

- architectural models give visual impressions of building projects;
- planning models can be used to optimize the flow of materials and the positions of machines;
- design models show proportions, colours, and handling of articles;
- packaging models serve as prototypes for pilot runs of packaging for specific articles.

There is also a special kind of model (called a pattern) used in casting metals. If the pattern is made from expanded Styropor it can be used for investment casting, i. e. it remains in place when the metal is poured.

The techniques used to construct all these kinds of model from expanded Styropor are essentially the same, but the information given here refers solely to making packaging models.

The expanded Styropor used in making a model costs very little, because of its very low density. It can also be worked easily and quickly, with tools that could not be simpler but are found very versatile in practice. Models of any shape can be made in a very short time.

Since the material used for modelling, expanded Styropor, is the same as that used for packaging, a full-scale model (reduced scales are uncommon) not only represents the shape and size of the series moulding but also gives an approximation to its function as a rule. Measurements of strength and performance – e.g. drop, crushing, and shaking tests – carried out on the model give a reliable indication of how useful the intended packaging will be. The model provides a pattern for the mould-maker to work from, while its mass provides a basis for quoting a price for the mouldings. Not least of the functions of a model is to provide an invaluable aid in discussions between the maker and the user of the packaging. Almost immediately after he receives an inquiry the packaging manufacturer can respond by providing a sample that is also a working model. Any special wish of the buyer or necessary modification can easily be reproduced in the model at minimal cost, so the risk of investing in moulding tools that have to be discarded without use in production is reduced enormously.

Techniques in model construction

Models can be made by shaping from the solid, i. e. from a rectangular block, or by assembling simple components that are easy to make. In either case, one or more of the techniques

- hot-wire cutting,
- machining,
- and cutting with blades

will be used, while assembly from parts will normally involve

- bonding with adhesive.

The starting material is Styropor block or board of appropriate dimensions and density. The density should be the same as that of the mouldings that are being modelled.

Before work can be started on a model, the basic design features must be decided on. These are the contours and the density of the expanded Styropor necessary for providing the requisite protection of the article to be packed. If a subsequent production run is intended, the design should also take into account those features that are necessary for straightforward moulding and high rates of output. The following preparations are therefore advisable:

- Calculate the density, contact area, wall thickness, and the dimensions of any ribs needed for the requisite degree of protection for the article in question (cf. TI 510, TI 610, TI 710, and DIN 55471 Part 2).
- In accordance with the shape and strength of the article, decide which parts of it are to be in contact with the packaging. If the package is to absorb shock loads, position the ribs providing cushioning at places where the article is strongest.
- To facilitate moulding, avoid varying wall thicknesses as far as possible; have no undercuts; divide mouldings so as to make best use of the platen areas of the moulding machine to be used; ensure that mouldings can be stacked but remain well ventilated when nested; if possible, choose a common value for the density.
- To facilitate use of the packaging, divide mouldings so as to simplify packing and unpacking; provide aids to handling such as openings for handholds; provide any necessary openings for ventilation; place raised lettering or symbols (recycling symbol, material code, “top” and “bottom”, company logo, etc.) where they can be seen easily.

Hot-wire cutting

A taut wire heated electrically to a temperature of 180 – 200 °C is kept pressed against the expanded Styropor, which, being thermoplastic, softens and collapses in the immediate vicinity of the wire. The optimum wire temperature depends on several factors, but since the appearance of the cut surfaces is a reliable indicator of any departure from the optimum, this is the practical criterion. If the current through the wire has been properly adjusted, short threads are drawn from the cut surface, as seen on the left of Fig. 2, and the cut is very narrow. If the current is too large, the wire overheats and makes a broad cut, as seen on the right of Fig. 2.

When a sudden change in direction is made – to make a sharp edge, for instance – it may be best to cut off the current to avoid local overheating.

The wire used for cutting is generally high-tensile resistance wire, such as Cr-Ni 30 Special, of diameter 0.5 – 0.8 mm. Accessories for cutting curves use stiffer bent wire of diameter about 1.5 mm or ribbon about 2.5 mm wide and 0.5 mm thick.

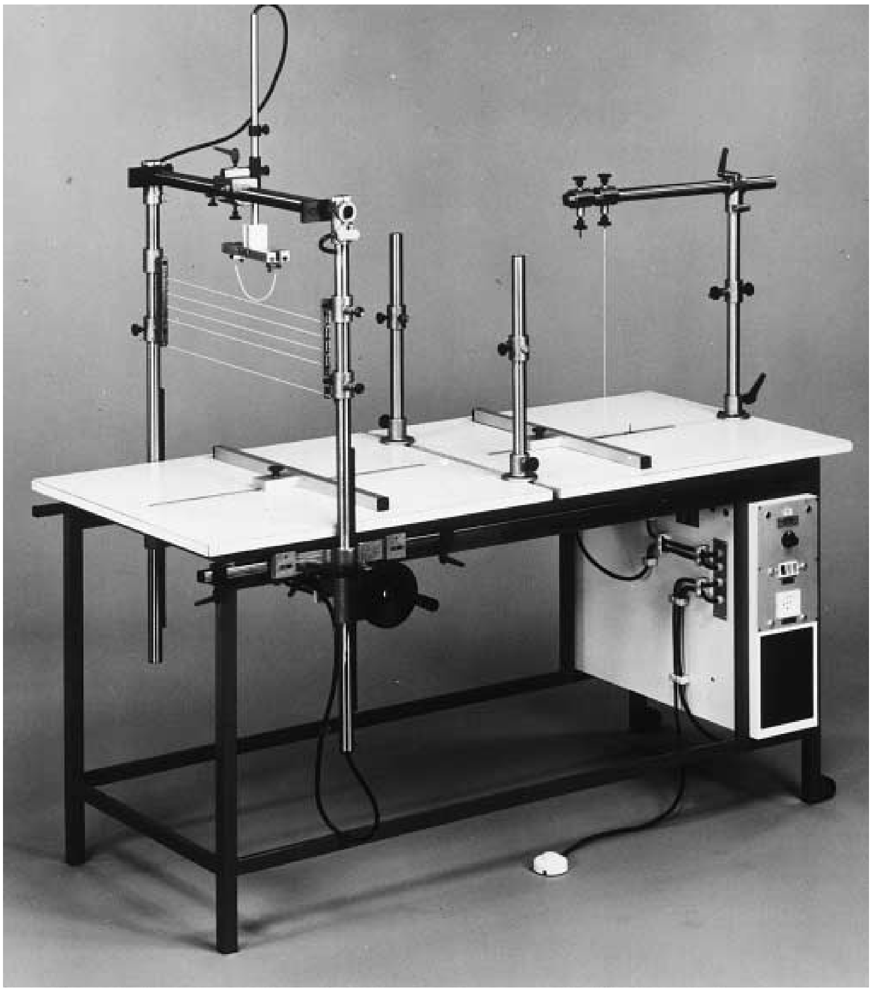

Fig. 1 Hot-wire cutting equipment

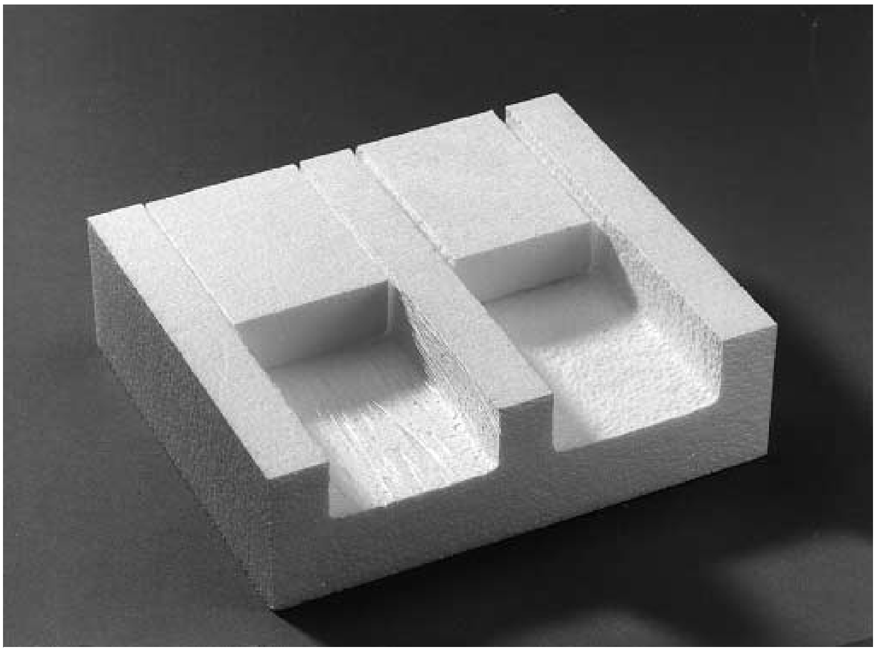

Fig. 2 Surfaces cut with (left) wire at the correct temperature and (right) wire that was too hot

To compensate for differences in wire thickness and length, the current through the wire is regulated by varying the applied potential difference, which for safety reasons may not however exceed 25 V a.c. or 60 V d.c.

4. Equipment for hot-wire cutting

Various types of equipment are available commercially (cf. Fig. 1). They differ mainly in the arrangements for mounting the cutting wires and guiding the block of expanded Styropor. The principal requirements for multipurpose assemblies are:

- a rigid construction and an adequate working surface;
- variable mounting arrangements for the cutting wires – horizontal, vertical, and any chosen angle;
- constant but adjustable tension in the cutting wire, maintained by springs;
- means for easy parallel displacement of the cutting wires, either in steps or variable;
- means for easy displacement and rotation of the workpiece, or of the cutting wires, or of both; it is also advantageous to be able to raise one side of the assembly so that the working surface is tilted;
- accessories for mounting curved cutting wires of various shapes (cf. Fig. 3); it should be possible to use the wires in fixed positions or to rotate them and to take them off for use by hand;
- infinitely variable wire tension and current variable to suit the length and resistivity of the wire used;
- foot controls, so as to leave both hands free when working.

Hot-wire cutting equipment should be installed in a room that is well lit and ventilated and accessible from all sides.

Machining

There is a variety of machine tools suitable for use with expanded Styropor, ranging from simple milling machines to numerically controlled equipment of the type used in computer-aided manufacturing. However, even the hand-held rasp works on the same principle, i.e. the removal of material in small fragments. Whatever type of tool is used, working conditions will not be acceptable unless there is an effective arrangement for drawing off and collecting this swarf. In this respect, milling machines with hollow cutters through which the swarf is sucked have proved useful. Any milling machine used should also run vibration-free and afford rapid exchange of cutters.

Machined models have several special advantages:

- they can be given complicated shapes without having to be made in parts;
- inside radii, grooves, slots, shoulders, etc. can be formed without difficulty if the appropriate cutters are available;
- their finish is pleasing in appearance.

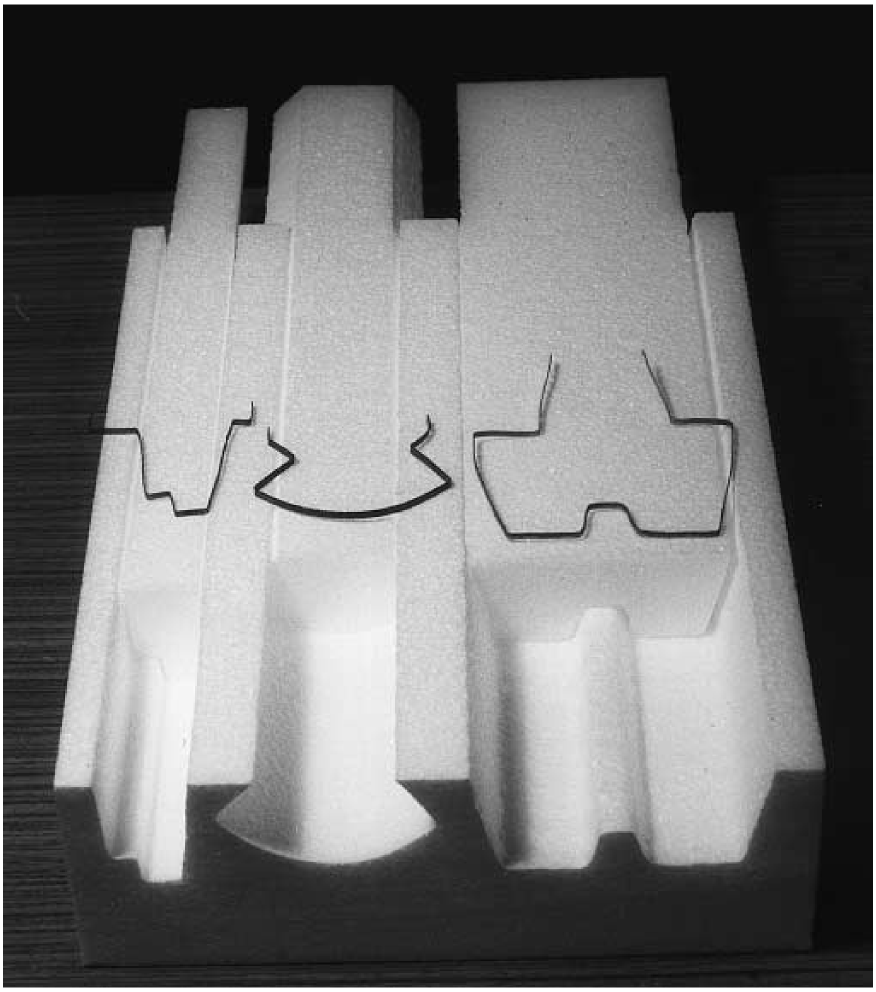

Fig. 3 Channels with curved profiles cut out with bent wires

Fig. 4 Holes cut with cork borers

Cutting with blades

Parting material that is not very thick and cutting to make minor corrections is best done with sharp blades.

Holes up to 30 mm in diameter can be cut cleanly and simply with well-sharpened cork borers (cf. Fig. 4).

Bonding with adhesive

The most usual way of joining parts of models is bonding with adhesive. The choice of adhesive is important, since several types attack expanded polystyrene.

If the area of the bond is small, an aqueous **polymer dispersion** such as BASF's Propiofan® 5 D can be used. The viscous dispersion is applied thinly with a spreading comb to both the surfaces to be joined and the parts are clamped or pinned together until the adhesive is dry. Since this takes some time, it holds up further work. The quickest and most reliable procedure is to leave the finished model in a drying oven (with forced circulation) at a temperature of about 70 °C for 3 – 4 h.

Faster working is possible if a **contact adhesive** is used, e.g. Terokal 2397 (TEROSON GmbH, Heidelberg). Like the polymer dispersion, it is spread thinly on both surfaces, but these are not brought together immediately; instead, they are left to dry until *just slightly tacky* to the feel, which takes 10 – 20 min, and then pressed together firmly. The bond is immediate, and no correction of position is possible.

Bitumen mastic adhesive, e.g. EC 226 (3M Adhesives), also gives firm bonds immediately and fills the joint too. It is used in the same way as contact adhesives such as Terokal 2397. However, the joints are very prominent, since black lines can be seen.

Comparison between models and their moulded counterparts

Moulded parts have an outer skin, which will generally be missing from the corresponding models. Moulded parts are normally in one piece, but the corresponding models are often assembled from several pieces (as in Fig. 5). These are differences that lead to models performing less well when subjected to certain stresses (especially in bending and at notches).

Manufacturers of cutting equipment and machine tools

Hot-wire cutting equipment

Germany

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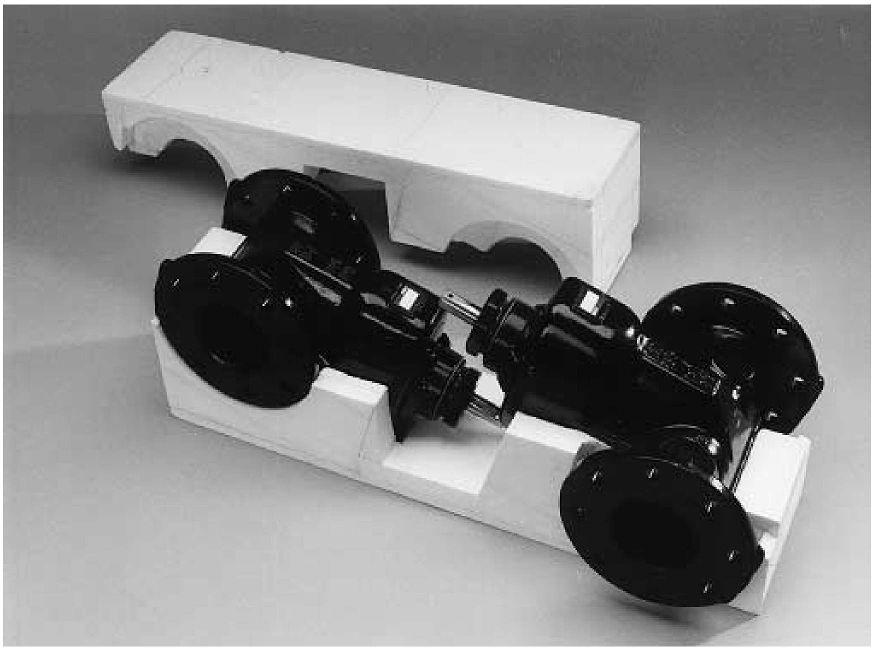

Fig. 5 Model constructed by bonding several parts with adhesive

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Pantel & Brömser GmbH
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Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

Styropor®

20696 May 1998

7 Packaging

Packaging properties conditioned by the material and processing

Styropor foam is a lightweight, versatile and economic packaging material. Its versatility means it can be tailored to the changing complex requirements of packaging technology and adapted to fit the contours of all types of products. The foam's physical properties can be adjusted and maintained within narrow limits during manufacture.

The design of a Styropor moulding is able to be **modelled, tested** and **optimized** before it finally goes into mass production. The most important applications are stackable packaging for heavy goods, as well as shock absorption and thermal insulation.

We have produced a packaging questionnaire (TI 2-415) to help you specify precisely what the task of the packaging is. In seeking a satisfactory solution to your packaging problem, it is also helpful to take into account those properties that are affected by the material and processing technology; these are summarized in Tables 1 & 2 overleaf.

Table 1 Material-dependent packaging properties of Styropor foam

Properties	Applicational advantages and options	Examples
Closed cell structure	Load bearing capacity of the air exploits the PS cell structure to the full: high stiffness and strength despite low weight	Low raw material consumption
	The air-filled cells have a cushioning and heat insulation effect	
	Does not absorb moisture	Watertight mouldings
Low weight; density mostly between 20 and 30 kg/m^3	Low freight costs	Advantageous if goods are sent through the post or by air
	Low and constant tare weight; for many goods the tare can be neglected	The tare can be set on the weighing scales; filling fruit, vegetable or fish crates is easy
Density-dependent, uniform strength properties	The packaging's protective and strength requirements are quantifiable. That means:Optimization of the material; protection for the packaged articles; low incidence of damage to goods and low replacement costs	
Compressive strength	Load-bearing packaging with good buckling resistance and stack stability	Stackable fruit and vegetable crates; Fish boxes; Heavy-goods packaging: engines and gear boxes; machine parts; heavy household appliances
Defined stock absorption properties	Quantifiable and therefore safe cushioning effect	Packaging for electrical, audio, video equipment, measuring instruments, glass, porcelain, etc.
Low specific cushioning factor (G-value)	Small cushion thicknesses mean overall size of the packaging is smaller	
Increase in specific shock energy absorption at higher densities	Low amount of material needed for cushioning elements; high protection for corners and edges subjected to knocks and blows	
Wet strength	Strength properties unaffected by moisture or wetness; roughly similar to cellulosic packaging material	Transport palettes for plants, fruit and vegetable crates; fish crates
	Empties and packing pieces can be stored outside as long as the packed goods are not sensitive to moisture	Saving in warehouse space
Low-temperature strength	Not brittle at low temperatures	Packaging for deep-frozen goods
Heat insulation properties $\lambda = 0.03$ W/(m·k)	Computable thermal insulation properties; protection against rapid changes in temperature; guarantees low temperature differences in the packaged item	Packaging for temperature-sensitive, easily perishable food (seafood, milk products, ice-cream, frozen food), hot ready-meals, pharmaceuticals, biological preparations
Heat deformation resistance of 80 °C at loads of up to about 2 N/cm^2	Combination with shrink wrapping film; transport of heated goods	Shrink-wrapped packaging; transport of hot food
With a few exceptions: resistant to chemicals; dust-free, hygienic; authorized for use as food packaging	Does not affect the packaged goods or the surroundings; foam is not damaged by the packed articles, aggressive atmosphere or moisture	Food packaging; secondary packaging for chemicals, pharmaceuticals, cosmetics Disposal of waste is environmentally sound
Attractive appearance; coloured packaging available	Impressive presentation of goods, emphasises product quality	Attractive packaging for food and display purposes
Environmentally friendly	Ground up packaging waste has other uses	Soil loosening, drainage, composting, regrind used in block and part moulding. Conversion to polystyrene by sintering or melting
	Usual methods of disposal can be used	Landfill; energy recovery through incineration

Table 2 Processing-dependent packaging properties of Styropor foam

Properties	Applicational advantages and options	Examples
Large degree of design freedom	Packaging for objects with complicated shapes and/or non-level surfaces.	Auto and machine parts; tools; small household appliances; glass and porcelain
	Recesses to safely grip one or more similar or dissimilar objects in a single package. Rationalization of the packaging; savings on packaging labour costs	Integral packaging for small appliances; multi-packs for replacement parts; tools with accessories; multi-buy packs for toys and gifts; bottles
	Features for ease of handling	Stacking aids, grip holes, built-in weak points for break-off packaging
	Embossed features on the outer surface of mouldings	Marking for advertizing and sales promotion: company logos, trademarks, symbols to identify goods, dispatch labelling
	Material-saving design features	Strengthening elements: ribs, swellings, edge reinforcements, chamfered instead of square edges
	Strength where it is needed	Concentration of material at load-bearing points or in highly-stressed places; moulded-on cushioning ribs or bosses
	Recesses in mouldings for bulky goods	Integral packaging for household oil burners, vacuum cleaners, lamps, overhead projectors
	Ability to incorporate strengthening or supplementary packaging elements	Combination packaging: stackable heavy-goods packaging; if static loads on packaged goods otherwise too high; attachment of wooden supports, cardboard enclosures, sealing tape, etc.
	Elements for combination packaging	Edge and corner protectors (also with self-adhesive coat) for large household appliances, machine components, furniture
The moulding's shape has only a small influence on the cycle time	The application advantages described previously are valid for varying batch sizes	Packaging for all types of mass-produced goods
Short cycle times and long tool life; multi-cavity moulds possible	Option of adjusting production to match the quantities required by the customer	Short scheduling and production time; savings in warehousing costs
Uniform quality as regards strength and dimensional stability	Packed goods fit snugly, constant dimensions, more protection	Mouldings suitable for automated packing lines
Subsequent treatment of moulding's outer surface	Printing, coating, flocking	Lettering, logos, symbols and decorations for informational, advertizing and sales-promotion purposes
Numerous possibilities for shaping the foam using simple tools and machines	The foam can be hot-wire cut or milled; parts can be fabricated by bonding pieces together	Packaging models, packaging for high-value one-off products such as measuring instruments or works of art

Note

BASF Aktiengesellschaft
D-67056 Ludwigshafen, Germany

49484 May 1998

7 Packaging

® = Registered trademark

Packaging questionnaire

It is often the case that packaging specifications are not given in enough detail. All important parameters must be considered so as to fully exploit the properties of Styropor foam and arrive at the optimal solution. A packaging questionnaire can serve in this respect as a memory aid and form the basis of technical discussions between the packaging manufacturer and his customers.

1 Properties of Styropor foam packaging

Closed cell foam structure

Low weight

Moulded packing pieces can be dimensioned with confidence given the uniform density of the Styropor foam.

Compressive strength for stackable packaging and packaging for heavy goods

No loss of strength when wet

Good low-temperature resistance

High shock absorption

Good thermal insulation

Resistant to chemicals, with few exceptions

Clean and hygienic; approved as a food packaging material

Complex shapes are easy to produce

Guaranteed high output of mouldings with uniform quality

Packing pieces can be printed on, written on and flocked

Can be used in combination with other materials

2 Information for determining the packaging task[1]

Packaged goods

Description of the packaged goods

Accessories

Overall dimensions

Weight

Weight or quantity per packaging unit

solid, pourable, liquid

Manufacturer of the packaged goods and/or user of the packaging

Transportation and storage

Transportation aids (eg, palettes, containers – with dimensions)

Number of packages per transport aid

Position of the packaged goods during transportation

Position of the packaged goods during storage

Transport route from
to
via

Mode of transport (eg, road, rail, sea, air)

Special climatic conditions

Special loading and unloading conditions

Protection tasks

Shock absorbing

Packaged goods' susceptibility to breakage (permitted deceleration on impact) – in multiples of the freefall acceleration.

Critical causes of impact (drop, shunt impact)

Maximum drop height
during loading onto the transport

Special mechanical surface sensitivity (eg, low scratch resistance)

Load bearing (stackable)

Load carrying ability of the packaged goods

Weight of the packaged goods per box kg

Box dimension l = cm
b = cm
h = cm
d = cm

Height of stack:

during storage cm

during transportation cm

Thermally insulating

Nature of the packaged goods

Weight of the packaged goods in an outer packaging kg

Required period goods must be kept insulated h

Permissible maximum temperature of the packaged goods °C

Permissible minimum temperature of the packaged goods °C

Average ambient temperature during insulated storage period °C

Temperature of the packaged goods at start of insulated storage period °C

Temperature of the packaged goods at end of insulated storage period °C

Weight of accompanying cooling/heating element, eg,
ice, kg
dry ice, kg
ice packs kg

Temperature of the cooling/heating element at the start of the insulated storage period °C

Humidity and corrosion

Is the packaged article (or its components) susceptible to corrosion or sensitive to humidity?

What are the sensitive components made of?

Would the means of transport or the surrounding area be damaged in the event of a breakage?

Other requirements

Special transport and storage risks

Special rules for transport and handling

Presentation of the packaged article

Rationalization of the packaging, seal, transport etc.

Clear presentational arrangement of the goods in the packaging

Labelling

Type of packaging

Transit or storage packaging

Integral packaging

Combination packaging (eg, foam mouldings and shrink wrap)

One-trip or reusable packaging

Use of Styrofill®/Ultrafill®

Other

Economic aspects

Reasons for discontinuation of previous packaging (eg, breakage rate, rationalization, price).

Aspects that favour use of Styropor foam (see 1st. section)

Monthly requirement at start
later on

Existing alternative solutions

Price limit

Delivery times/dates

Note

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[1] *The questionnaire must take into account the various types of packaging tasks. However, only information necessary for solving a particular packaging problem should be entered.*

Technical Information

34388 March 1995

Styropor® 450

BASF Plastics

7 Packaging

Packaging moisture-sensitive goods

Contents

1 Moisture-sensitivity of goods

The cost of each measure designed to add to the protection of packed goods has to be weighed against the estimated losses if the measure is *not* undertaken. This applies as much to protection against damage caused by moisture as to any other form of protection.

The first step is to estimate roughly the extent to which the goods may be affected by moisture. Broadly speaking, goods can be placed in one of four classes:

- goods that spoil if they *lose* moisture (e.g. some foodstuffs, flowers);
- goods that are unaffected by moisture (e.g. glass, ceramics, most plastics);
- goods only slightly affected by moisture (e.g. domestic appliances, furniture);
- goods harmed by moisture (some metal articles, spare parts, instruments).

The limits of each class cannot of course be defined exactly, but in any case the protection to be provided also depends on how long the goods are to be in transit and stored and the climates to which they may be exposed.

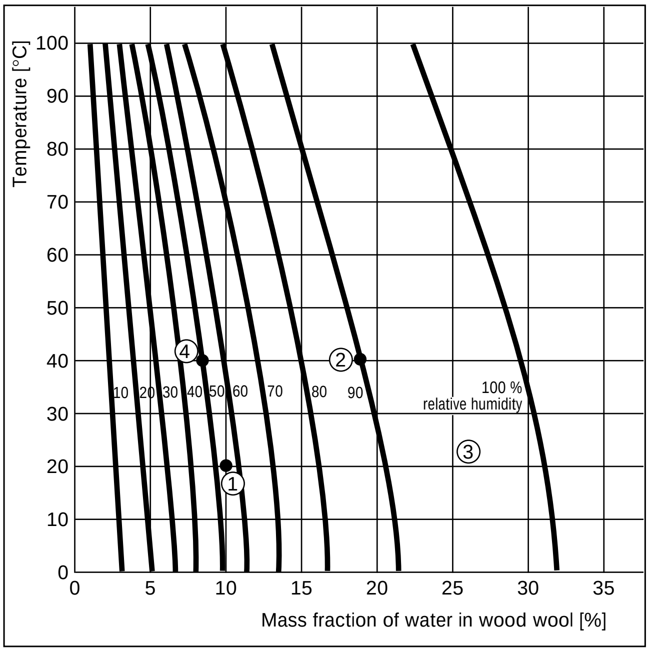
Goods in the first two classes can be transported and stored in either open or closed expanded Styropor containers without special moisture protection. Those in the second two are the subject of the discussion following.

2 Damage caused by moisture

Most metals are prone to *corrosion* in moist atmospheres.* High *relative humidity* tends to increase corrosion, particularly if the atmosphere is polluted by certain common products of combustion or if the unprotected surface of the metal carries traces of any of numerous possible contaminants. However, the nature and surface treatment of the metal each play an important role.

At ordinary temperatures, steel is considered to be at risk in atmospheres of relative humidity greater than 70%. However, near cold metal surfaces, rapid local cooling can easily reduce the temperature of the air to below its *dew-point temperature*, resulting in the formation of a film of water on the metal and consequent corrosion.

Fig. 1 Equilibrium values of the mass fraction of water in wood wool at standard atmospheric pressure



Many non-metallic materials absorb water vapour and swell in so doing. The result may be blistering, distortion, or weakening of adhesive bonds. Fungal growth is also likely if the substrate contains enough water to be congenial to micro-organisms. In general, frequency of damage to goods made of organic materials increases with the *absolute humidity* within the packages. A dry internal climate is therefore something of a panacea.

3 Moisture in packaging material

Packaging materials with high and low *equilibrium moisture contents* affect the internal climates of packages in ways that differ in principle. This is a matter that has nothing to do with water physically absorbed (e.g. rainwater soaked up when material is left in the open), although the effects of such water may be grave – it can weaken many materials, it inevitably increases the humidity of the internal climate, and from some materials it can leach out ingredients harmful to the packed goods.

3.1 High equilibrium moisture contents

In general, cellulosic materials – either packed goods or packaging materials – have high equilibrium moisture contents. For instance, the mass fraction of water in wood or wood wool can be 30% or more, depending on how fresh the wood is and the atmosphere in which it is kept.

The mass fraction of water in wood wool that has reached equilibrium at a temperature of 20 °C in air of relative humidity 55% (point ① in Fig. 1) is only 10%. If this wood wool were brought into a climate of temperature 40 °C and relative humidity 90% (point ②), it would take up moisture from the air until its water content was 19%.

Similarly, wood wool that had a high equilibrium moisture content – say, 25% at 25 °C (point ③) – would lose water vapour until its moisture content was only 8.5% if brought into a climate of temperature 40 °C and relative humidity 50% (point ④).

Within the confines of a package, dry wood or wood wool tends to reduce the relative humidity of the air, and it may have a stabilizing effect if moisture diffuses in. On the other hand, moist wood or wood wool loses water, thereby increasing the relative humidity of the air; if the air is already nearly *saturated*, condensation is likely, particularly on metal surfaces. Of course, the effect of water taken up or given off depends on the mass of the packaging material relative to the volume of air within the package as well as climatic conditions.

If a material tending to high equilibrium moisture contents is exposed to variable temperatures and relative humidities, it may take up water at one point only to give it off later; this cycle can be repeated many times.

3.2 Low equilibrium moisture contents

Expanded Styropor is a packaging material whose equilibrium moisture content is extremely low, but, because of the way it is made, it inevitably contains appreciable proportions of water when it is removed from the mould.

The pressure within the cells of fresh expanded Styropor is less than atmospheric pressure, but it soon starts to increase as air dif-

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* *Terms printed in italics in §§ 2–4 are defined in § 6, Definitions, on page 5.*

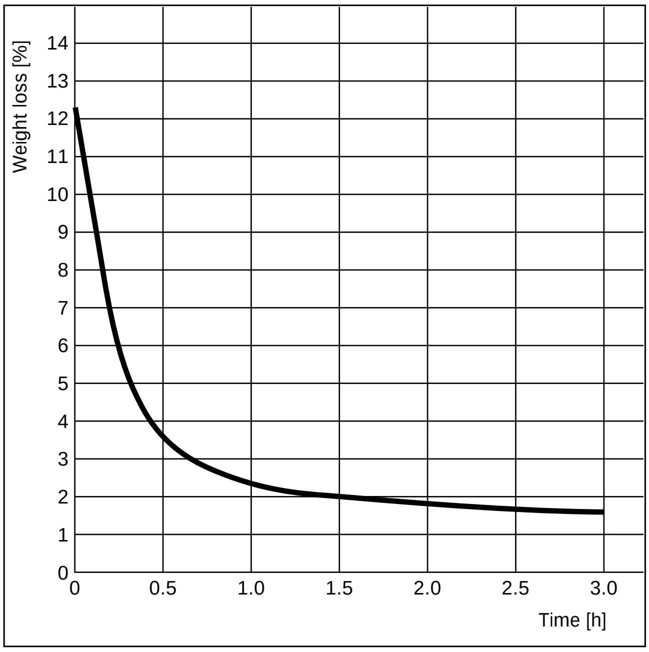

Fig. 2
Drying curves: Styropor foam; density: 20 kg/m^3; forced-circulation oven at 70 °C

fuses in, and after 12 – 24 h the mouldings have practically attained their normal strength. After this, drying is carried out. Actual rates of loss of water and other volatile substances depend on temperature and rate of air circulation, but the form of the drying curve is always as shown in Fig. 2: initial rapid loss followed by a long period of very slow change. The mass fraction of water at equilibrium is less than 1%, but at such levels it is difficult to follow any changes.*

After the moisture content of expanded Styropor has attained its equilibrium value under given conditions, changes may take place as conditions alter, but these certainly do not exceed 0.15 % of the mass of the material. So expanded Styropor cannot affect the internal climate of a closed package as do cellulosic materials – losing water to a drier atmosphere, gaining it from a humid one. In that respect it is passive.

3.3 Permeability of packaging materials

The internal climate of a package is influenced by factors other than water held by the packaging material: the rate of passage of water vapour through these materials is important too. Regardless of how much water vapour the packaging material can adsorb, it is also permeable to water – even metal foils are permeable to some extent.

The rate of passage of water vapour through a packaging material increases with its area, temperature, and the difference between the *partial pressures* of the water vapour on either side of it; it decreases with the thickness of the material. It naturally depends on the nature of the material too, and in the particular case of expanded Styropor it decreases with increasing density.

3.4 Effects of properties of expanded Styropor

It is often thought that because expanded Styropor contains little water it affords protection against corrosion and other effects of moisture. This is an illusion, but disappointment in this respect is frequently ascribed to inadequate drying nevertheless. The fact is that thorough initial drying and a low equilibrium moisture content are necessary but not sufficient conditions for a dry internal climate.

The additional conditions required are package walls whose permeability to water vapour is almost negligible and vapour-tight seals. By itself, expanded Styropor cannot satisfy the first of these conditions: if it is thick enough, it can slow the entry of water vapour appreciably but not stop it.

3.5 Moisture contents of Styropor packaging in practice

For economic reasons, it is not desirable to dry Styropor mouldings beyond certain limits, and in practice, mouldings in which the mass fraction of water is 3 – 5 % meet most packaging requirements. There are several reasons why this is justified:

- Styropor mouldings are watertight but not vapour-tight. Under conditions that could easily be encountered in practice, a mass of water greater than that present in a typical moulding can (as vapour) enter a sealed package in a few days.**
- Like most other packaging materials, expanded Styropor alone cannot exclude water vapour to the degree required by particularly sensitive goods, which need a really dry atmosphere. Only enclosure with a desiccant, surrounded by almost impermeable material, can protect them properly. But then the moisture in the outer packaging material is of little concern.
- When fresh expanded Styropor is dried, it loses water (together with other volatile substances) very quickly at first, but the rate of loss of mass soon diminishes. Prolonged drying times increase costs without commensurate reductions in moisture contents.

Losses of water from Styropor mouldings are hard to follow exactly, since other volatile components vaporize at the same time, though not at the same rate (their mass fraction in fresh mouldings can be about 3 %). These may constitute a high proportion of the residual volatile matter when little water is left.

4 Shielding against moisture

4.1 Treatment of goods

Protecting goods from the effects of normal levels of moisture is essentially the responsibility of the manufacturer in the first place. He may choose inherently stable materials or protect them chemically (e. g. anodized aluminium) or with coatings. The list of possible measures is a very long one. However, it may be more economic to provide protection only while the goods are in transit or held in stock, especially if these are the only times when they are at risk.

4.2 Precautions before and during packing

It has been estimated that about three in ten cases of moisture damage to packaged goods can be ascribed to mistakes made in packing or just beforehand.

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* *Changes in mass are inconclusive, because up to 3 % of other (harmless) volatile components may be present initially.*

** *At a temperature of 20 °C, with relative humidities of 85 % and 0 % at opposite faces of Styropor board 30 mm thick and of density 30 kg · m^{-3}, the rate of transfer of water vapour is 0.6 g · m^{-2} · h^{-1}.*

Goods exposed to rain, fog, or other ways of “getting wet” obviously have to be dried before they are packed. Too little thought is given however to commoner – and therefore more important – sources of dampness troubles: cold storerooms and warm, badly ventilated packing rooms.

If a cold article is brought into a considerably warmer room in which the air is very humid or even moderately humid, it is likely that moisture will immediately deposit on its surface. Whether or not the condensed water will evaporate again within a short time depends on a number of factors, of which the size of the article and its thermal conductivity are among the most important. The greater the mass of the article relative to its surface area, the longer its temperature will remain below that of the room, since thermal capacity increases with mass. The greater the conductivity of the article, the more likely it is that its surface temperature will remain below that of the air in contact with it for an appreciable time.

In principle, the same considerations apply to packaging materials brought from a cold room to a warm, humid one. Considerable condensation is only likely if the temperature difference is comparatively large and the relative humidity in the packing room is very high, but since the area exposed may well be large, it can be enough to increase the moisture content of the packaging material markedly. The effect of such condensation is greatest if the packaging material is absorbent, otherwise – as in the case of expanded Styropor – the water remains on the surface and very soon evaporates.

The remedies are simple:

- keep the atmosphere in a packing room moderately cool and dry;
- bring in both the goods to be packed and the packaging materials needed early enough to come into equilibrium with the atmosphere in the packing room.

Proper control of the atmospheres in packing rooms also takes care of another potential source of highly corrosive moisture: sweaty fingers.

4.3 Shielding against moisture in Styropor packaging

Goods only slightly affected by moisture receive adequate protection in closed expanded Styropor containers, provided transit and storage times are not too long; special precautions are not necessary. This form of packaging is primarily intended to protect the goods against bangs and jolts, rapid temperature changes, and abrasion, but it also provides an effective shield against dust and water.

Unlike cellulosic materials, such as paper, fibreboard, etc., expanded Styropor does not adsorb water vapour, but it is not an effective barrier to it. When prolonged transit and storage are not expected, it is advisable to seal moderately moisture-sensitive goods in polyethylene film before placing them in Styropor containers.

Where goods require greater shielding from water vapour than ordinary polyethylene film can provide, they should be sealed in special multilayer plastic film or plastic-coated metal foil. Since however even these only provide improved vapour control, not complete exclusion of water vapour, an appropriate desiccant should be sealed in too if the goods are to remain in the package for very long.

Enough desiccant must be used to absorb

- all the water vapour in the air within the sealed film,
- any water adsorbed by the article or packaging material sealed in with it, and
- the water vapour that can be expected to pass through the film during the lifetime for which the package is designed.

Manufacturers of desiccants for use in packaging provide aids for determining how much desiccant to use in particular cases, and some national standards give similar guidance.*

An indicator that changes colour with changes in air humidity can be placed behind a window in the protective foil. There is normally a printed guide correlating the present colour with relative humidity. Such devices are reversible, i.e. they only indicate present values and do not show whether a given limit has been exceeded previously.

5 Summary

In protecting against moisture damage, *measures must be optimized economically:* their costs must be commensurate with losses likely in view of the nature of the goods and conditions of transport and storage.

Protection begins in the manufacturer’s works: correct choice of materials and their treatment (e.g. with surface coatings) can avoid damage during transport and storage.

Moisture damage can originate in packing rooms: taking goods and packaging materials from cold storerooms into packing rooms filled with warm, humid air is a certain recipe for forming condensation. Overheated, poorly ventilated rooms also lead to sweaty fingers, one of the commonest causes of metal corrosion in brand-new articles. If packages are kept for long in a warm, humid atmosphere, condensation can even take place on the cooler articles within them, since most packaging materials (including expanded Styropor) offer comparatively little resistance to the diffusion of water vapour.

The remedy is to keep both goods and packaging in the packing room for some time before they are needed, to allow them to come into equilibrium with the atmosphere there.

The *equilibrium moisture content* of expanded Styropor is very low – the mass fraction of water eventually comes down to less than 1% – and after it has been reached, hardly any moisture can be adsorbed.
The internal climate of a package is not influenced by dry expanded Styropor.

Expanded Styropor is *watertight, not vapour-tight*. It slows the ingress of water vapour from the atmosphere by diffusion but cannot stop it. Water vapour penetrates expanded Styropor at rates that depend on the thickness and density of the material and the difference between the vapour pressures outside and inside the package. Even the average pressure difference is unpredictable, so the extent of vapour penetration cannot be calculated satisfactorily.

Closed expanded-Styropor packaging does not constitute an adequate shield against water vapour. Goods sensitive to moisture should be sealed in *vapour-control film*.
The highest degree of protection (needed if transit and storage times are protracted) is given by enclosing a *desiccant* with the goods.

Excessive drying of fresh expanded Styropor is uneconomic. The cost of reducing the mass fraction of water in expanded Styropor much below 5% cannot be justified; this level does not affect most goods; those that might be affected need to be sealed in film anyway, to shield them from atmospheric water vapour.

** BS 1133, Packaging Code – Section 19: 1986, Use of desiccants in packaging.*

Table 1: Absolute humidity, γ_{WS}, vs temperature, ϑ, of saturated air under standard-state pressure (1000 hPa)*

ϑ/°C	γ_{WS}/g·m^{-3}	ϑ/°C	γ_{WS}/g·m^{-3}	ϑ/°C	γ_{WS}/g·m^{-3}	ϑ/°C	γ_{WS}/g·m^{-3}
–10	2.2	1	5.1	11	9.9	21	18.2
–9	2.3	2	5.5	12	10.6	22	19.2
–8	2.5	3	5.9	13	11.2	23	20.4
–7	2.7	4	6.3	14	12.0	24	21.6
–6	3.0	5	6.7	15	12.7	25	22.8
–5	3.2	6	7.2	16	13.5	26	24.2
–4	3.5	7	7.7	17	14.3	27	25.5
–3	3.8	8	8.2	18	15.2	28	27.0
–2	4.1	9	8.7	19	16.2	29	28.5
–1	4.4	10	9.3	20	17.1	30	30.1
0	4.8						

* *Calculated from humidity ratios at saturation given in 1993 ASHRAE Handbook, pp. 6.2 – 6.3. The humidity ratio (mass of water vapour relative to the mass of dry air) is independent of pressure.*

Determining residual water in expanded Styropor is difficult. Fresh expanded Styropor contains up to 3% of other volatile components (mainly expanding agent), which makes the simplest method – loss of mass on drying – only an approximate, though useful, guide to water contents.

Water has no effect on the strength of expanded Styropor. If goods to be packed require moisture or are immune to it, the water content of expanded Styropor has no relevance to packaging.

6 Definitions

absolute humidity, γ_w
The mass of water vapour, m_W, in a given sample of moist air divided by the volume of the sample, V:

$$\gamma_W = m_w / V$$

It may be less than but cannot exceed the absolute humidity of saturated air (q.v.) at the same temperature (cf. Table 1). Moist air is a uniform mixture of gaseous components; it has no droplets of water.

corrosion
Defined in DIN 50900 as “an interaction of a metal with its surroundings that causes measurable changes to the metal and may lead to damage”. It generally involves an electrochemical reaction, but sometimes results from direct chemical reactions or physical changes.

dew-point temperature
The temperature at which moist air is saturated with water vapour (q.v.). When the temperature falls to the dew point, vapour may begin to condense as droplets of water.

Example:

- The dew-point temperature of air whose temperature is 30 °C and relative humidity (q.v.) 80% has a dew-point temperature of just under 26 °C (cf. Table 1), i.e. this is the temperature at which the air becomes saturated.

equilibrium moisture content
The mass fraction of bound water in a substance in equilibrium at a given temperature with moist air of given relative humidity (q.v.).

It decreases with temperature and increases with the relative humidity of the air (cf. Fig. 1). A packaging material is often described as “dry” when it has come into equilibrium (either by losing water or gaining it) with the moist air in contact with it. It can however still lose water if it is moved into a drier atmosphere as well as gain it in a more humid one.

partial pressure
The pressure that a component of a mixture of gases (such as air) would exert if it were present alone and occupied the same volume as the mixture. The pressure of the mixture is the sum of the partial pressures of its components, so in moist air of pressure p (atmospheric pressure),

$$p = p_A + p_W,$$

where p_A and p_W are respectively the partial pressures of dry air and the water vapour. At any given temperature, the difference between the partial water-vapour pressures of atmospheres whose relative humidities (q.v.) are Φ_1 and Φ_2 is

$$\Delta p_W = p_{WS}(\Phi_1 - \Phi_2),$$

where p_{WS} is the saturation vapour pressure (q.v.) of water at that temperature.

Example:

- Inside a sealed package, the temperature is 15 °C and the relative humidity 70%; the corresponding vapour pressure is 12 hPa. If the package is brought into a ship’s hold where the temperature is 30 °C and the relative humidity 50% (vapour pressure 21 hPa), the difference in partial pressures under which water vapour is driven to diffuse from outside to inside is 9 hPa.

relative humidity, Φ
The ratio of the partial pressure of water vapour in moist air to the partial pressure in saturated air (q.v.) at the same temperature and pressure.

$$\Phi = p_W/p_{WS} = \gamma_W/\gamma_{WS}.$$

Examples:

- If the absolute humidity of air at a temperature of 30 °C and a pressure of 1000 hPa is 21.1 g·m^{-3}, the relative humidity is 70%, since the absolute humidity of saturated air is 30.1 g·m^{-3} at this temperature and pressure.
- If saturated air at a temperature of 15 °C is (whose absolute humidity is 12.7 kg·m^{-3}) is warmed to 30 °C, its relative humidity is reduced to 42%.

Thus if air is warmed, its *relative* humidity sinks, if it is cooled, it rises.

saturated air
Moist air in which the partial pressure of the water vapour is equal to the saturation vapour pressure (q.v.) of water at the same temperature.

The absolute humidity of saturated air increases with temperature (cf. Table 1). If the temperature of saturated air is reduced, condensation takes place (on surfaces with which the air is in contact) until the lower absolute humidity of saturated air at the new temperature is reached.

Example:
Air at a temperature of 27 °C whose relative humidity is 70% is cooled to 15 °C; the quantity of water that must condense on surfaces is 5.1 $g \cdot m^{-3}$.

saturation vapour pressure
The pressure exerted by vapour in an enclosed space when it is in equilibrium with the liquid substance. It depends only on the nature of the substance and its temperature.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Technical Information

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Styropor®

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7 Packaging

Designing shock-absorbent expanded foam packaging

If a fork-lift truck sets a load down roughly or a package falls to the ground, e. g. during a loading or unloading process, valuable products are often damaged or even destroyed. The energy employed for the production of the packaged goods, often costly materials and the various working outlays associated with them are lost.

In this information leaflet it is intended to show that this transport damage is avoidable and the products can reach the recipient in perfect condition. By using expanded foam cushions made from Styropor the forces arising in impact and falling processes are cut down to such an extent that no damage to the packaged goods can occur. In doing so it is unimportant whether the packaged goods are electrical devices, machines, porcelain vases or wine bottles with high-quality contents. Due to the universal production process, tailor-made protective systems can be manufactured for all products. However, depending on the sensitivity of the goods to be packaged, their weight and the stresses in transport different sizes of cushions are necessary. The exact sizes can be simply and rapidly determined by means of standardized sizing methods.

In what follows the most important influencing variables are first of all described and then the method of calculation is explained with reference to some examples.

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Factors affecting the quality of a cushion

In order to bring a body with the weight $(m \cdot g)_1$ to a certain height h_1 an energy $E_1 = (m \cdot g)_1 \cdot h_1$ is required. This energy is released again during a fall from the height h_1 and causes a more or less maximum force to act on the body depending on the size of the stopping distance and the course of deceleration to the position of rest.

As can be gathered from Fig. 1.1 the maximum force acting on the body in the case of an ideal cushion, i. e. in the theoretically most favorable case, amounts to

$(h/d_0) \cdot (m \cdot g)$.

The modifying factor (h/d_0) with respect to the force acting at the position of rest is designated as the impact factor G or the G value.

In the case of the ideal cushion, doubling the stopping distance causes the maximum braking force or the G value to be halved (see Fig. 1.2).

In the case of an ideal spring (force ~ total thickness) the G value is already twice as large as for an ideal cushion of the same thickness (see Fig. 1.3). This is attributable to the less favorable course of the force. In a 50 % deformation of the cushion only 25 % of the energy of the fall is converted. The conversion of the remaining 75 % share of the energy therefore requires considerably greater forces. From these two illustrations the requirements for a good cushioning material can be derived:

- rise of the resistance to deformation to a certain value for a small deformation path,
- as constant a deformation resistance as possible over as large a deformation region as possible.

Expanded foams made from Styropor come closest to this requirement of all usual cushioning materials. As emerges from the force-deformation diagram in Fig. 1.4, resistance to deformation builds up very rapidly in expanded materials made from Styropor and change only relatively slightly up to about 60 % deformation. This results in extraordinarily low G values in correctly sized packaging.

In contrast with this in cushioning materials having a characteristic curve corresponding to Fig. 1.5 the difference in deformation resistance between the start of deformation and approximately 60 % deformation is very large. The G values achievable with this are therefore higher than those in expanded foams made from Styropor.

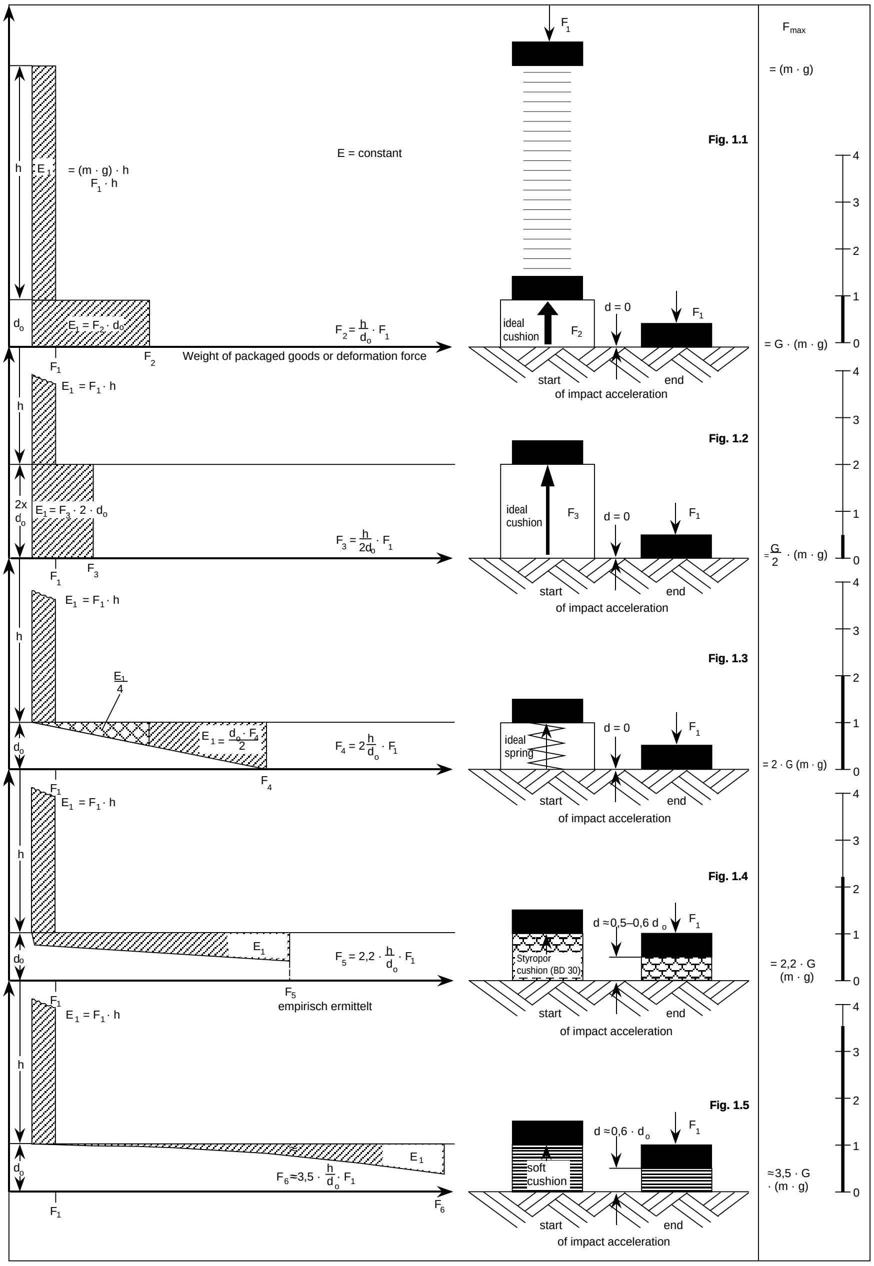


Fig. 1 Weight of packaged goods or deformation force

Effects of different cushion loads

The damping capacity of cushioning materials is also affected like specific physical properties by the specific loads. This behavior is illustrated in Fig. 2 with reference to the example of a diver.

- In the case of a “bellyflop” the dive depth, i. e. the stopping distance, is least. In doing so, however, the diver feels the action of a large force on his body.
- In the case of a vertical header the load on the body is initially at its lowest. In this case, however, the cushioning material, which is water, brakes the body only slowly so that at the end of the cushioning material there is abrupt damping with the action of a large force on the impact surface, i.e. the diver’s head.

- The most favorable behavior is obtained with a quite specific angle of dive. In doing this the body uses the available cushioning path for uniform braking. The braking forces or G values arising are at their lowest.

If changes occur in the starting conditions such as height of dive, weight of the diver and depth of water a change in the angle of dive is necessary in order to obtain the lowest possible load on the body. If the ratio of height of dive to depth of water (h/d) increases then a lower angle of dive (greater impact surface) must be chosen in order to transfer the gravitational energy to the available diving depth.

Sizing aid

In falls involving packages similar influencing variables are to be taken into account. However, by free choice of the bulk density of the expanded foam and of the geometric shape the cushioning properties can be better matched to the requirements. By means of extensive series of tests the damping properties were determined at different loads, cushion thicknesses, heights of fall and bulk densities and summarized in the form of cushioning diagrams (see Diagrams 1 to 3).

These diagrams are also recommended in DIN 55 471, Part 2, as a basis for sizing. The specified parameters have the following meaning:

- static surface load

  $$= \frac{\text{Weight of packaged goods in N*}}{\text{Area of support in cm}^2}$$

- impact factor G or G value (this factor is the maximum by which the dead weight of the packaged goods increases during the damping process).

  The maximum permissible G value for a particular packaged product is also know as the packaged goods sensitivity.

- h/d ratio

  $$= \frac{\text{Height of fall in cm}}{\text{Thickness of cushion in cm}}$$

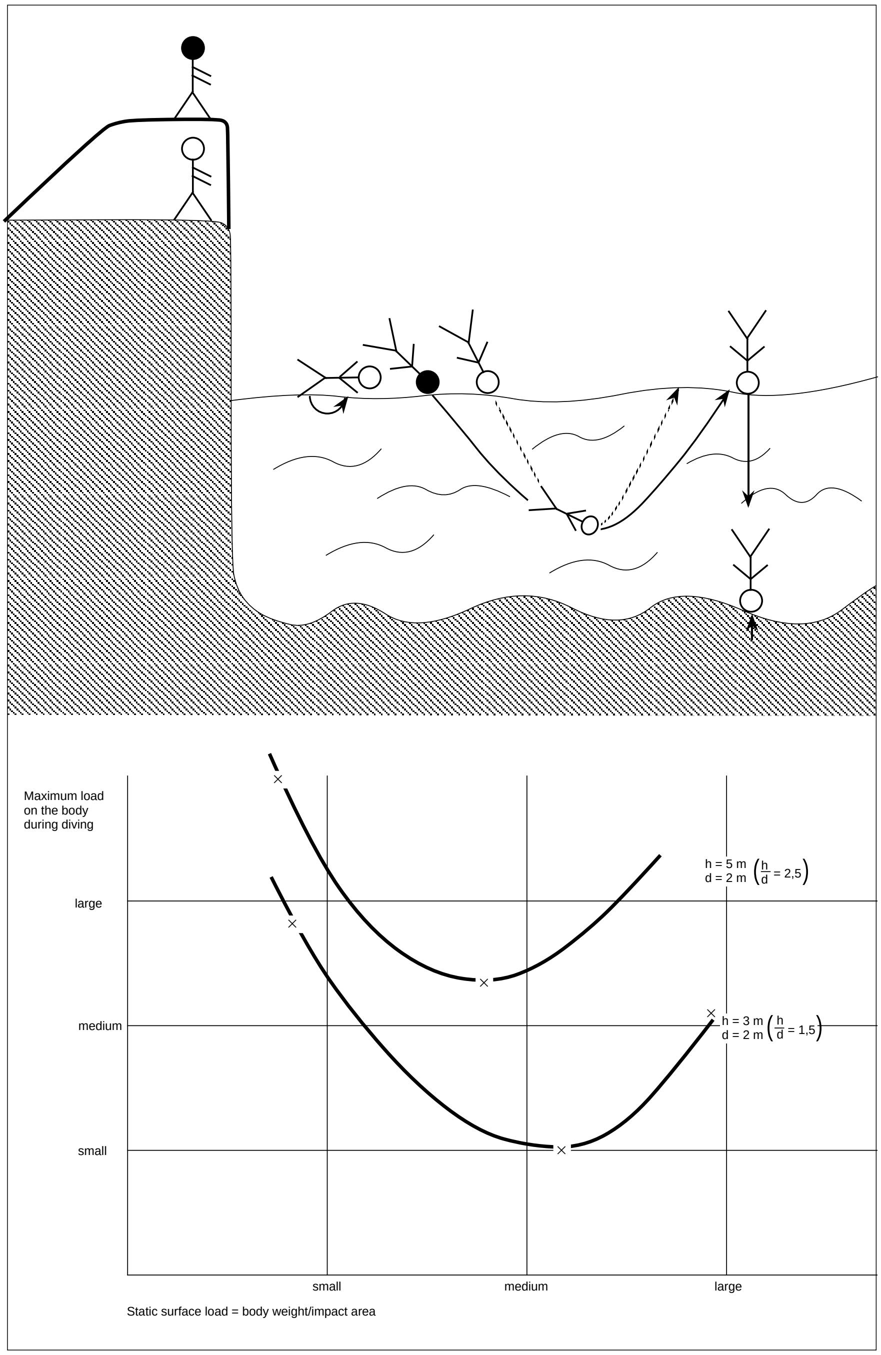


Fig. 2 Geometric and gravimetric influencing factors

From the cushioning diagrams (see page 7) for raw densities of 20, 25 and 30 it may be seen that the achievable impact factors at the same h/d ratio are independent of the bulk density**. This is only the case, however, for the bulk density range of BD 20 to BD 30 specified here.

The most favorable packaging sizes are obtained by selecting the characteristic values of the curve minima (optimum cushion load). Values at variance with the curve minima yield ever thicker cushion thicknesses for the same impact factor G.

Apart from the cushioning diagrams, easy-to-use sizing calculators are available for the calculation of expanded foam cushions made from Styropor (see Fig. 3). The sizing calculator is based on the curve minima of the cushioning diagrams. Structural values diverging from the optimum values can therefore not be determined using the sizing calculator.

$* \; 1\,N = \frac{1\,kg \cdot m}{s^2}$

The gravitational force of the mass of 1 kg amounts to 9.81 N

*** The existing small bulk density effects are described in TI 2-520*

Example calculations

Some calculation exercises are presented in the following table. If sizing in accordance with the optimum cushioning parameters is desired then up to two of the listed five variables can be determined. This is possible both with the aid of the cushioning diagrams as well as with the sizing calculator (see pages 4 to 6). If for particular reasons sizing with too low or too high a cushion load (left and right of the curve minima respectively) is desired, only one of the five listed variables can be determined. This calculation is possible only with the aid of the cushioning diagrams (see pages 4 to 5).

Calculation with the aid of cushioning diagrams

Exercises

Influencing variables	Symbol	Units	Optimum cushion load			Loads different from optimum	
			Example 1	Example 2	Example 3	Example 4	Example 5
Foam bulk density	BD	kg/m^3	20	20	20	20	20
Weight of packaged goods	m	kg	10	10	10	10	10
Cushioning area	A	cm^2	?	?	180	300	140
Cushion thickness	d	cm	?	4.2	3.6	4.2	?
Height of fall	h	cm	90	100	?	100	70
Impact factor G (Packaged goods sensitivity)	G	–	70	?	?	?	85

- ***from EPS 20 cushioning diagram***

with respect to	Impact factor	Static surface load σ in N/cm^2 m·9,81/A = σ	Value of h/d h / d = h/d
Example 1	70	*0.51*	*28*
Example 2	*60*	*0.62*	100/4.2 = 24
Example 3	*65*	10·9.81 / 180 = 0.55	*26*
Example 4	*77*	10·9.81 / 300 = 0.33	100/4.2 = 24
Example 5	85	10·9.81 / 140 = 0.70	*30*

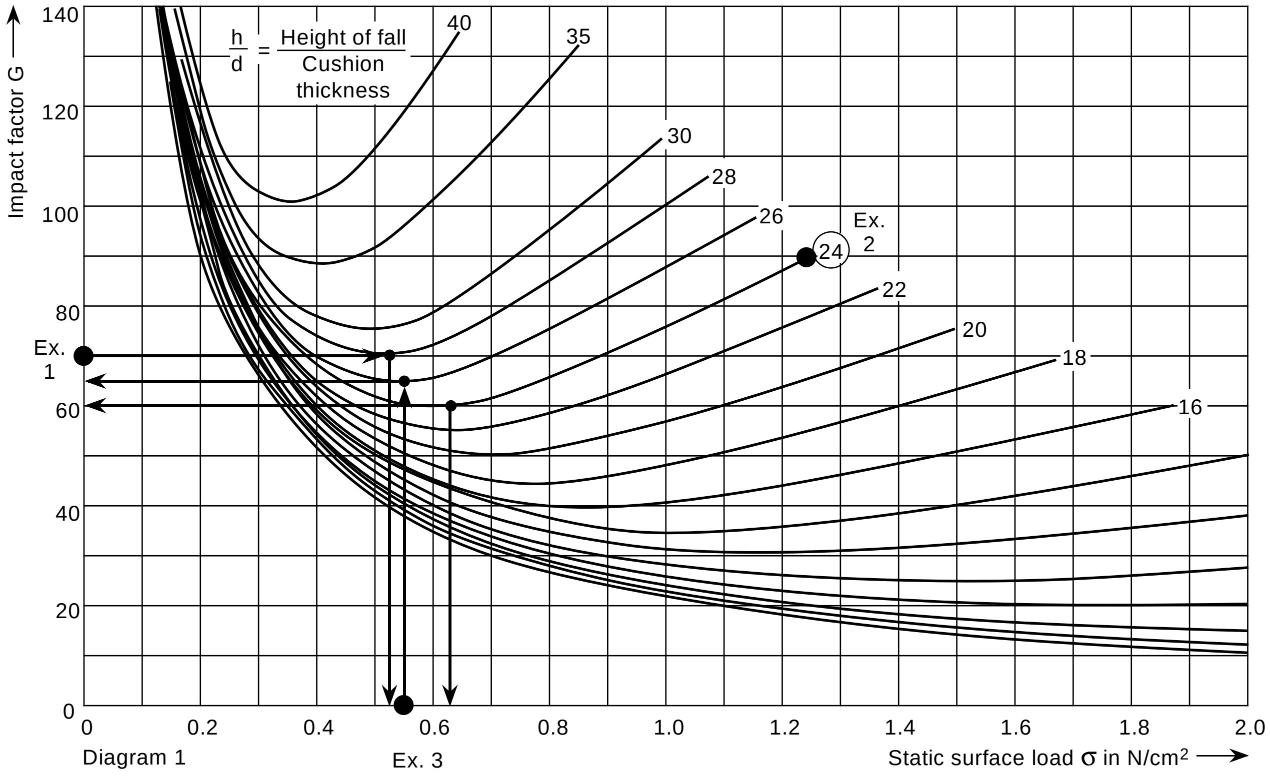
- ***Results***

with respect to	Calculations	Calculation hints
Example 1	A = 10·9.81/0.51 = *192 cm^2* d = 90/28 = *3.2 cm*	A = m·9.81/σ d = h/(h/d)
Example 2	A = 10·9.81/0.62 = *158 cm^2* G from cushioning diagram = *60*	A = m·9.81/σ –
Example 3	h = 3.6·26 = *94 cm* G from cushioning diagram = *65*	h = d·(h/d) –
Example 4	G from cushioning diagram = *77*	–
Example 5	d = 70/30 = *2.3 cm*	d = h/(h/d)

Cushioning diagrames for EPS 20 expanded foam

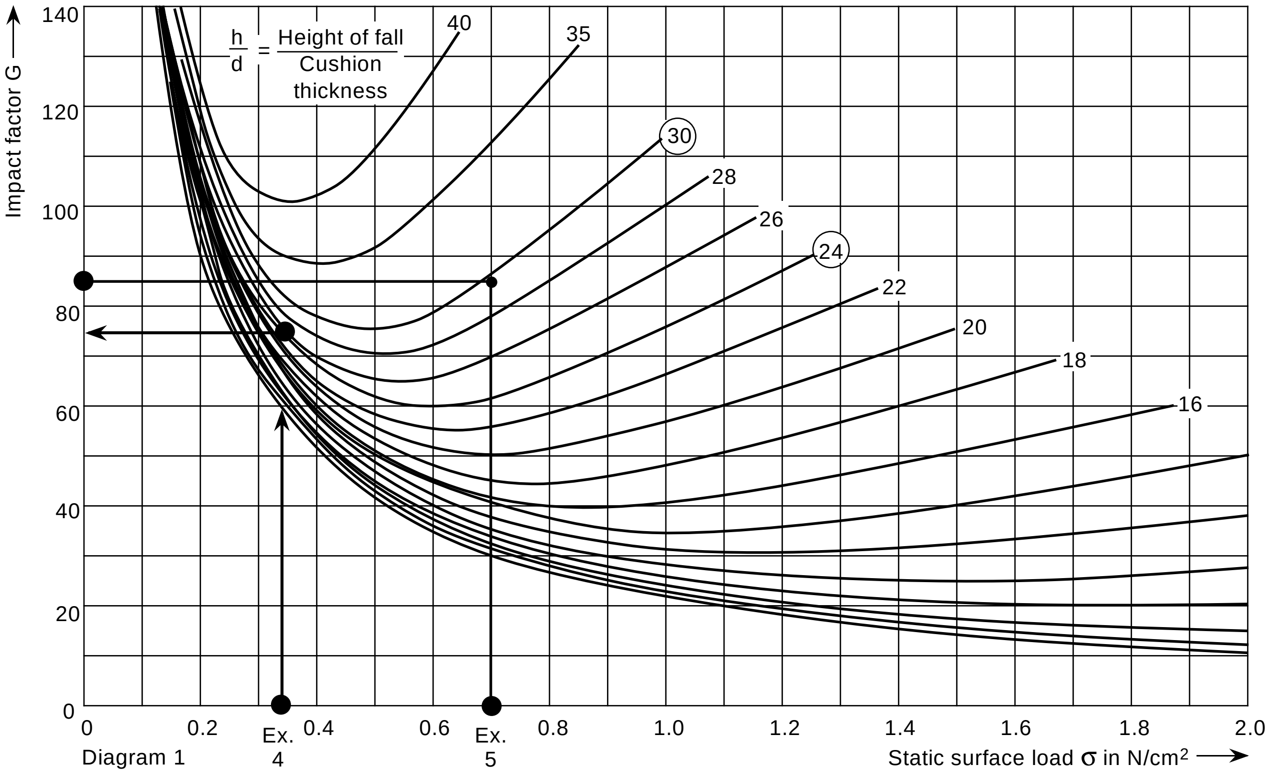
● Values for Examples 1 to 3 (optimim cushion load)

Starting point! ●



● Values for Examples 4 and 5 (cushion load different from optimum)

Starting point! ●



Calculations with the aid of the sizing calculator

Example 1 (optimum cushion load)

given: BD = 20 kg/m^3
m = 10 kg
h = 90 cm
G = 70

sought: A and d

with the sizing calculator:

- set the slider so that the red arrow points to G = 70
- Result: **d = 3.2 cm** (at h = 90 cm)
  (A/m) = 18.6 cm^2/kg
  A = m · (a/m) = 10 kg · 18.6 cm^2/kg = **186 cm^2**

Example 2 (optimum cushion load)

given: BD = 20 kg/m^3
m = 10 kg
d = 4.2 cm
h = 100 cm

sought: A and G

with the sizing calculator:

- set the slider so that d = 4.2 cm appears in the red window at h = 100 cm
- Result: **G = 60**
  (A/m) = 16 cm^2/kg
  A = m · (a/m) = 10 kg · 16 cm^2/kg = **160 cm^2**

Example 3 (optimum cushion load)

given: BD = 20 kg/m^3
m = 10 kg
A = 180 cm^2 A/m = 180 cm^2/10 kg = 18 cm^2/kg
d = 3.6 cm

sought: h and G

with the sizing calculator:

- set the slider so that 18.6 appears in the yellow window at RD 20
- Result: **G = 70**
  h = 100 cm (at d = 3.6 cm)

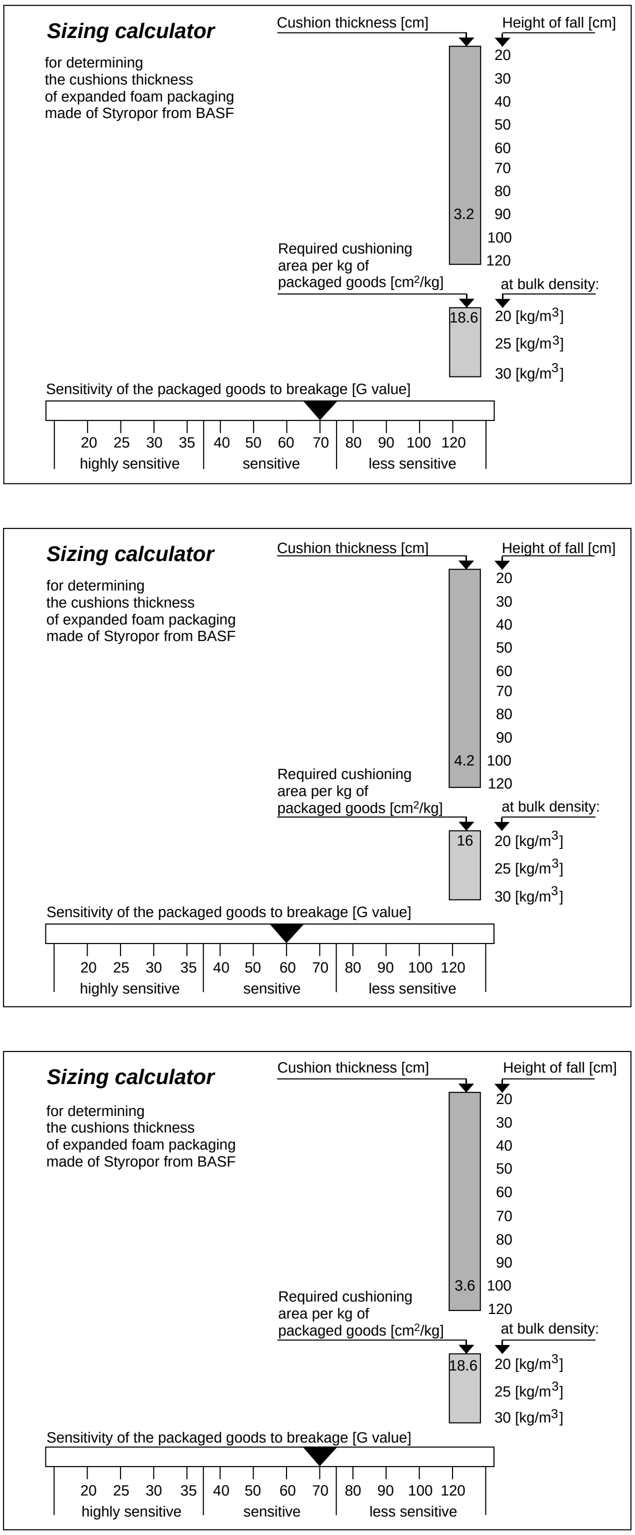


Fig. 3 Sizing calculator

Cushioning diagram for EPS 20 expanded foam

(see also DIN 55 471, Part 2)

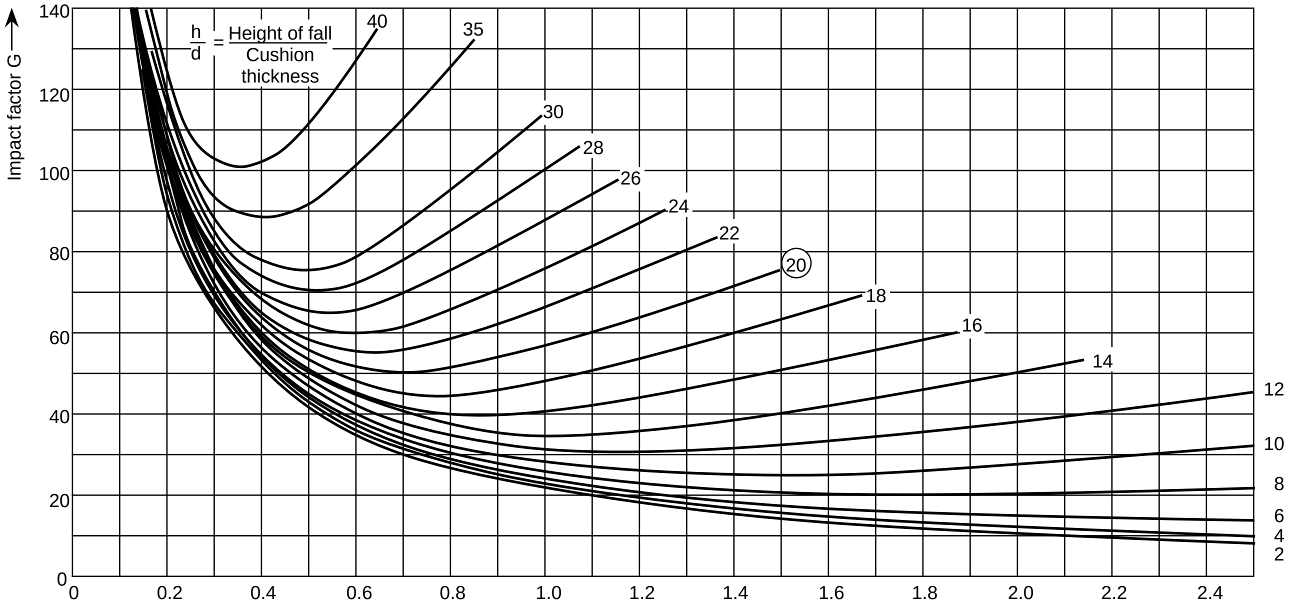


Diagram 1

Cushioning diagram for EPS 25 expanded foam

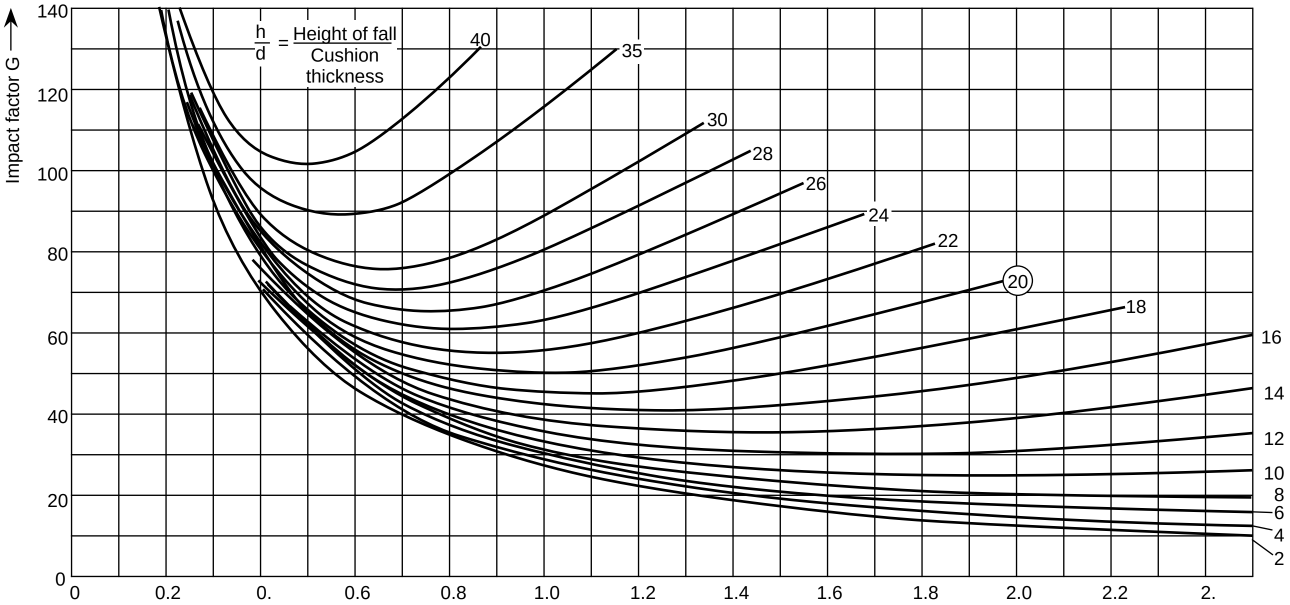


Diagram 2

Cushioning diagram for EPS 30 expanded foam

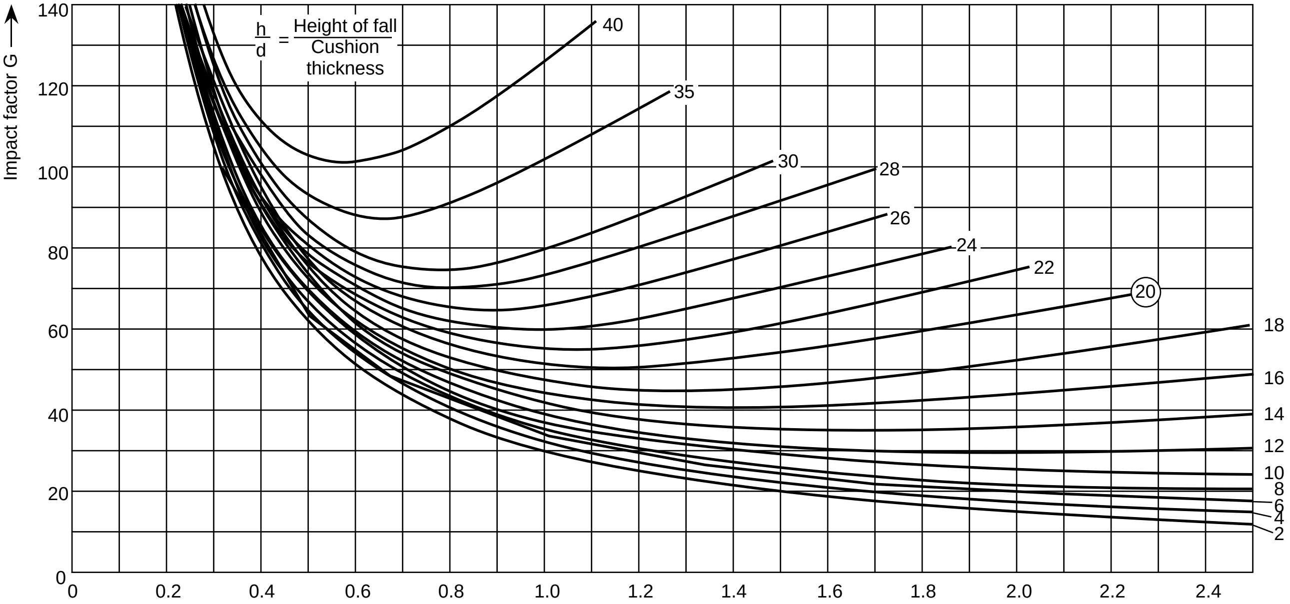


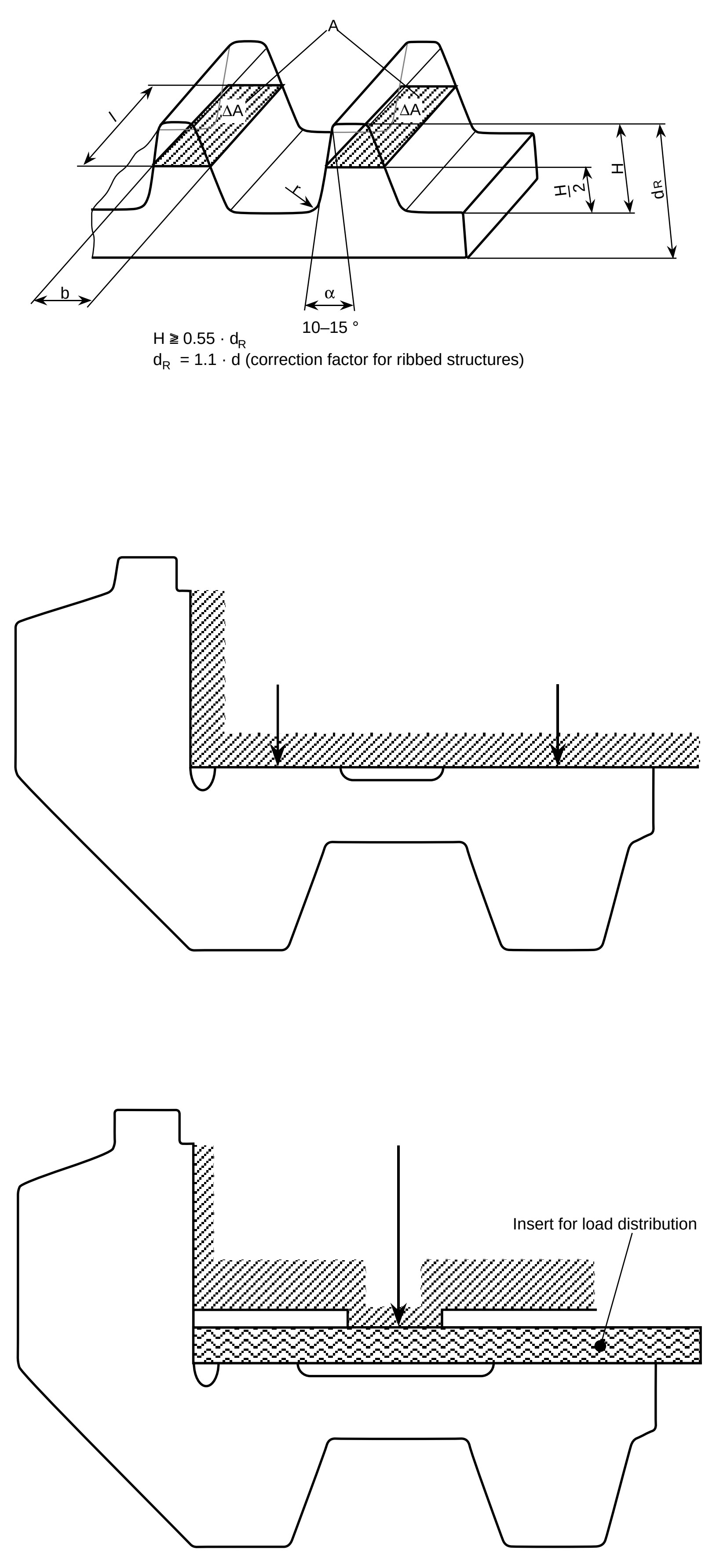
Diagram 3

Static surface load σ in N/cm² →

Cushion design

The calculated cushioning areas are in most cases smaller than the support areas of the packaging. Adaptation by means of recesses and rib or nubble constructions (see Fig. 4) is therefore necessary. In doing so the following requirements have to be observed.

- The rib or nubble heights (H) or the depths of the recesses must amount to at least 55 % of the calculated total cushion thickness.
- In ribbed and nubble structures the calculated cushion thickness has to be increased by the factor 1.1 (form factor).
- The cushioning area is the surface at the median height of the rib.
- The angle of slope of ribs or nubbles should be about 10 to 15° and the radius of curvature at the foot about 10 mm.
- The ribs or nubbles must have adequate flexural strength. From previous experience this requirement is met when the median rib width (b) is at least 0.6 times the rib height (H).
- In the rib or nubble arrangement care has to be taken that the forces coming into effect (G value x weight of packaged goods) when there is loading due to a fall are conducted in rectilinear manner from the packaged goods to the impact surface. If for structural reasons this is not possible load distributors must be inserted into the packaging. By means of these measures excessively high shearing strains and hence formation of fractures on the packaging are avoided.



$H \geqq 0.55 \cdot d_R$

$d_R = 1.1 \cdot d$ (correction factor for ribbed structures)

Insert for load distribution

Fig. 4

Packaging design

By means of packaging calculations information is obtained about the required cushion thicknesses, cushioning areas and expanded foam bulk densities. In addition to these important structural parameters, however, still further requirements (production, storage, packaging process, compressive load-bearing capacity) must also be observed and taken into account in the final definition of the construction of the packaging. The four most common types of packaging are illustrated in Figure 5.

- Smooth outer surfaces with internal ribbing (1). In this case no outer packaging is necessary, but rather only fastening by means of adhesive tapes or film or cardboard bands.
- Optimum ability of the packaging to adapt to the contours of the packaged goods using externally ribbed packaging (2). With this, secure fixing of the packaged goods is achieved even under high transport stresses.
- Packaging parts protecting corners and edges especially for furniture and large devices (3). Universally applicable shockproof cushions.
- Partial packaging with two end shells or a base and covering part (4). Particularly low-cost shockproof cushion for combination packaging together with, e. g. corrugated board folding boxes.

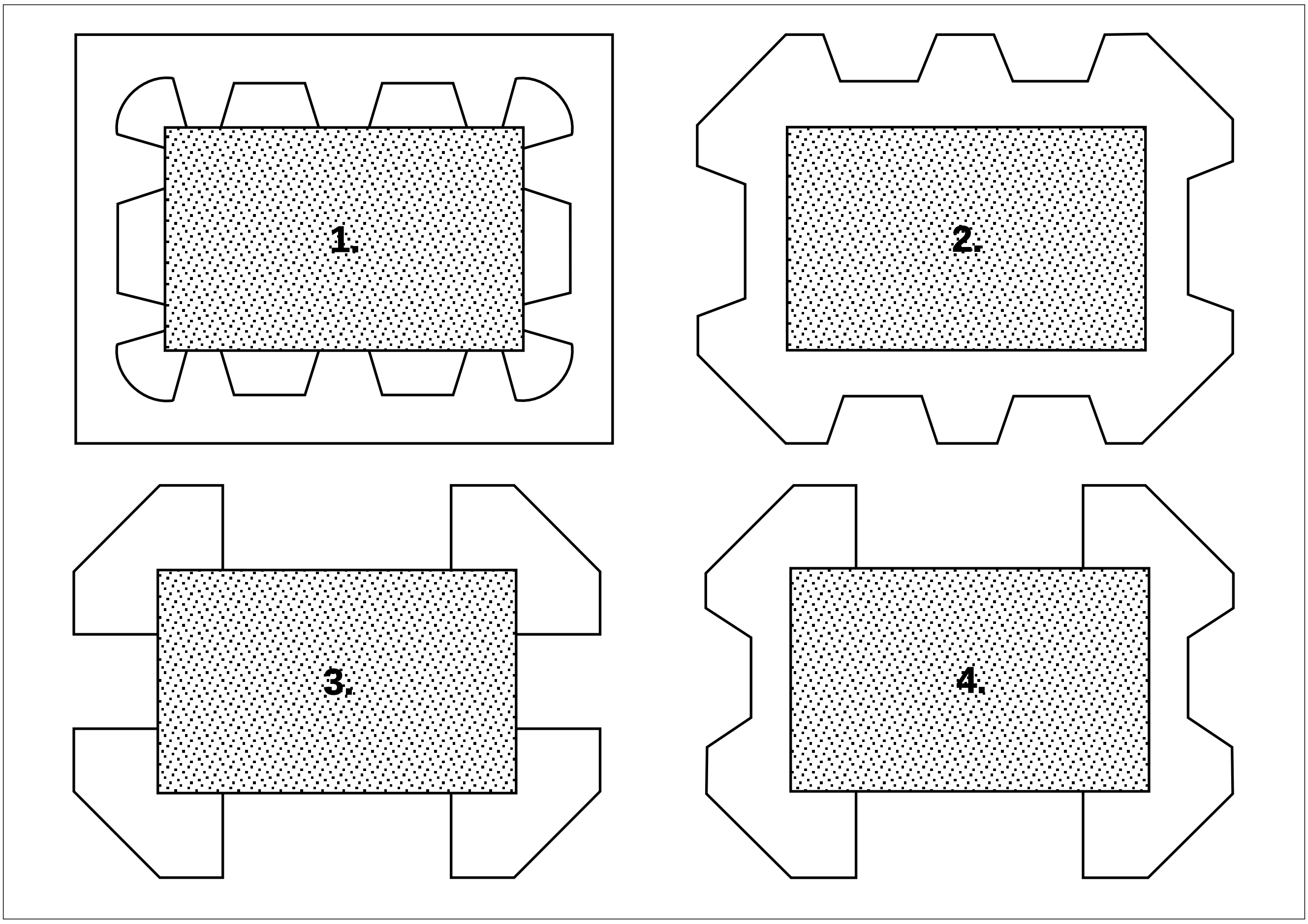


Fig. 5 Structures for shock-absorbent packaging
1. internal cushioning ribs, 2. external cushioning ribs, 3. shockproof corners, 4. support frames.

Procedure for designing packaging

We recommend that the design of shock-absorbent packaging having ribbed or nubble structures be carried out as illustrated in the calculation record (page 13).

- Lay down the bulk density (BD) or calculate it in accordance with the transport, storage and handling loads to be expected.
- Ask the user of the packaging for details of the weight (m) of the packaged goods, the sensitivity (G value) of the packaged goods and the permissible height of fall (h) or set these jointly with him.
- Determine the cushion thickness (d) and the cushioning area (A) with the aid of the sizing calculator or the cushioning diagrams.
- If the calculated cushioning area is smaller than the package support area it is necessary to calculate
  - the rib thickness (d_R)
  - the rib height (H) and
  - to carry out a subdivision of the cushioning area (DA) while observing the described requirements. After that either the
  - rib length or the rib width of the individual cushioning elements is to be fixed and the rib width or the rib length respectively to be calculated. In the case of very small cushioning areas we recommend the choice of nubbles having a square cross section with $l = b = \sqrt{\Delta A}$ since in this way the requirement that $b \geq 0.6 \cdot H$ can be most readily fulfilled.

When calculating packaging units for lightweight, sensitive packaged goods, particularly small cushioning areas are obtained. Fulfillment of the requirement for adequate flexural strength of the rib or nubble elements is facilitated by the following measures:

- set a small number of ribs
- choose the cross section of the rib so that it has a low ratio of length to breadth
- reduce the rib height to the lower limiting value ($0.55 \cdot d_R$)
- choose a lower bulk density
- if need be check with the users of the packaging whether the fixed boundary values can be increased (G value) or reduced (height of fall)

Sizing of a shock-absorbent expanded foam packaging unit made from Styropor (Example calculation 1, see page 7)

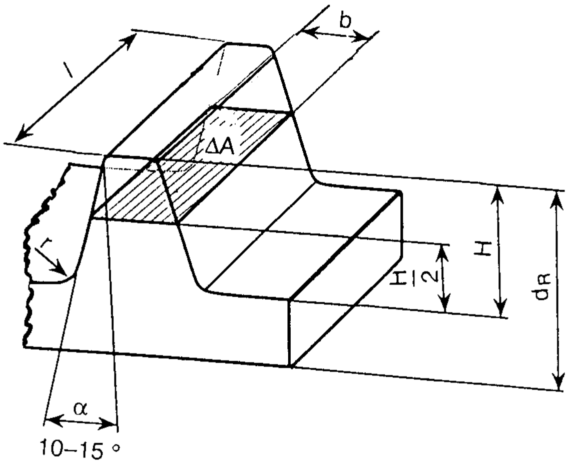
Variables	**Symbol**	**Units**	**Lateral surface**						**Calculation hints**
			All:						
Foam bulk density	BD	kg/m^3	20						20, 25 or 30
Weight of packaged goods	m	kg	10						$m = A \cdot \sigma / 9.81$
Impact factor	G	–	70						see C-diagram
Height of fall	h	cm	90						$h = d \cdot (h/d)$
Cushion thickness	d	cm	?						$d = h/(h/d)$
Cushion area	A	cm^2	?						$A = m \cdot 9.81/\sigma$

– Values from the cushioning diagram with BD = 20 kg/m^3

Impact factor G 70	stat. Surface loading σ: 0.51 $\frac{N}{cm^2}$	h/d: 28

– Calculations

for	$A = 10 \cdot 9.81 / 0.51 = 192$ cm^2
3.1	$d = 90 / 28 = 3.2$ cm
for	
3.2	
for	
3.3	
for	
3.4	
for	
3.5	
for	
3.6	



– Setting the rib geometry

- for each side of the package

Cushioning area	A	cm^2	192	
Ribs				
– thickness ($= 1.1 \cdot d$)	d_R	cm	$1.1 \cdot 3.2 = 3.6$	4,0 selected
– height ($\geq 0.55 \cdot d_R$)	H	cm	$0.55 \cdot 4.0 = 2.2$	2,3 selected
– minimum width ($\geq 0.6 \cdot H$)	b_{min}	cm	$0.6 \cdot 2.3 = 1.4$	

• for each rib element			Base/ Covering	End surfaces
Number of ribs	n	–	4	2
Rib area ($\Delta A = A/n$)	ΔA	cm^2	$192/4 = 48$	$192/2 = 96$
Rib width ($= \Delta A/l$)	b	cm	2.0 selected	3.0 selected
Rib length ($= \Delta A/b$)	l	cm	$48/2.0 = 24$	$96/3.0 = 32$

Sizing of a shock-absorbent expanded foam packaging unit made from Styropor (Example calculation 1, see page 7)

Record No.:			Author:			Date:	

- Packaging producer:
- Manufacturer of goods to be packaged:
- Designation of packaged goods:

1. Requirements/Fixed parameters

Variables	Symbol	Units	Lateral surface						Calculation hints
			All:						
Foam bulk density	BD	kg/m^3							20, 25 or 30
Weight of packaged goods	m	kg							$m = A \cdot \sigma / 9.81$
Impact factor	G	–							see C-diagram
Height of fall	h	cm							$h = d \cdot (h/d)$
Cushion thickness	d	cm							$d = h/(h/d)$
Cushioning area	A	cm^2							$A = m \cdot 9.81/\sigma$

2. Values from the cushioning diagram with BD = __ kg/m^3

Impact factor G:	–						
Start. surface loading σ	N/cm^2						
h/d ratio	–						

3. Calculations

for 3.1

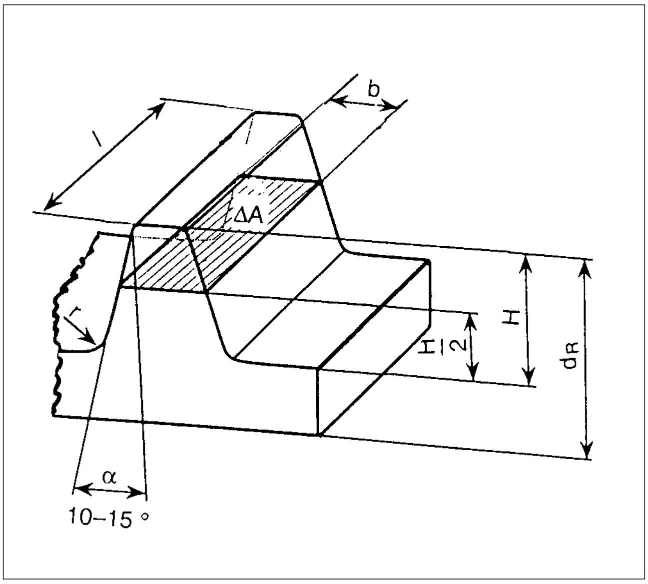
for 3.2

for 3.3

for 3.4

for 3.5

for 3.6



4. Setting the rib geometry

- for each side of the package

Cushioning area	A	cm^2
Ribs		
– thickness (= $1.1 \cdot d$)	d_R	cm
– height ($\geq 0.55 \cdot d_R$)	H	cm
– minimum weight ($\geq 0.6 \cdot H$)	b_{min}	cm

- for each rib element

Number of ribs	n	–
Rib area ($\Delta A = A/n$)	ΔA	cm^2
Rib width (= $\Delta A / l$)	b	cm
Rib length (= $\Delta A / b$)	l	cm

Note

BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

BASF

Technische Information

Styropor®

520

BASF Plastics

44415 Juni 1991 (PW)

7 Packaging

® = Registered trademark

Effects of bulk density on the shock-absorbing properties of expanded materials

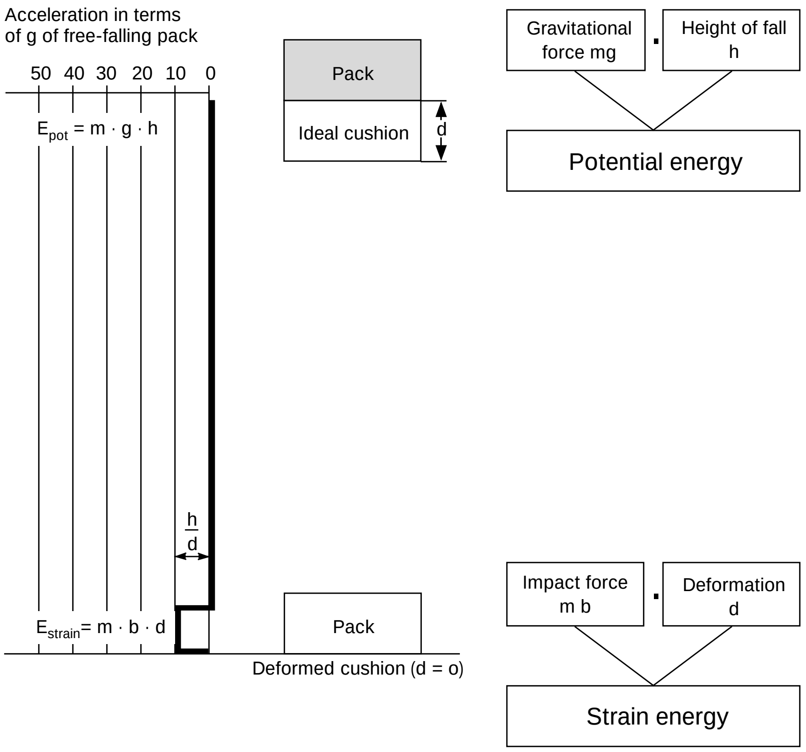
Styropor foam mouldings can be produced in a wide range of densities. Besides density, the material's elasticity may be varied using measures adopted during expansion or subsequent treatment. Thus designers continually ask themselves what density and degree of elasticity are best for their particular packaging problem.

Comprehensive studies in our laboratories have shown that, in the density range from 35 down to 10 kg/m^3 – as well as the elastification measures taken – the cushioning properties worsen. These results contradict the widespread and intuitive assumption that good cushioning materials must be soft.

The reasons for the differences in cushioning characteristics are dealt with in this publication. The mechanism of falling bodies is described, the results of our test are discussed, and recommendations are given for packaging designers.

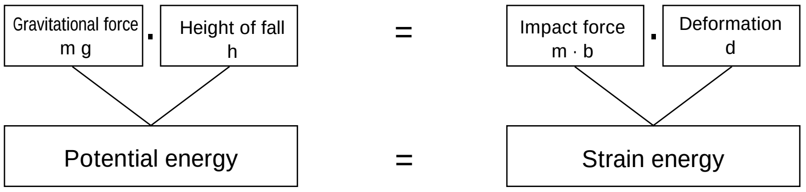
Foams

Free fall and ideal shock absorption



The potential energy of the falling pack is converted, in the ideal case, into harmless strain energy.

Hence



It follows that

dynamic force m b = gravitational force mg x height/deformation ratio h/d

$$\frac{m \cdot b}{m \cdot g} = \frac{b}{g} = h/d$$

The symbol for the $\frac{b}{g}$ ratio is G.

Free fall and ideal shock absorption

The potential energy at impact of a body of mass m that has fallen through a height of h is given by mgh, where g is the acceleration due to gravity. Energy can neither be created or destroyed, merely converted from one form into another. In the ideal case, this energy is converted into strain energy mbd, where b is the constant of deceleration and d is the deformation undergone by the cushioning material. Equating the potential energy to the strain energy and rearranging gives mb = h/d · mg. In other words, the dynamic force mb at the moment of impact is greater than the static force acting on the pack at rest, mg, by an amount h/d. The ratio h/d is equal to b/g; in other words, the numerical value of the deceleration b is a multiple of the acceleration due to gravity. In packaging practice, the b/g ratio is referred to as G. The sensitivity of packed goods to impact loads and the cushioning effect exerted on the packaging are expressed in terms of G.

Properties of cushioning materials

Material **Substance**	**Density** ϱ **kg/m^3**	**Cushioning factor** **C*** **–**	**Specific potential energy** **e*** **cN cm/cm^3**
PE expanded beads	30	3.5	500
PUR soft polyether foams	30	3.1	125
PUR soft polyester foams	30	3.3	200
PUR semi-hard	30	2.8	350
Styropor foam	30	2.2	2400
PS loose-fill material	8	4	400
Foam rubber*	200	4.3	350
Coconut fibres* rubberized	80	3.8	70
Corrugated board* single corrugation	800 g/m^2	2.4	530
Corrugated board* twin-corrugation	1050 g/m^2	2.6	800
Air, 1 bar	1.29	5.11	650

** measured by ILV, Munich*

Comparison of ideal with actual cushions

The term “ideal cushion” embraces the following assumptions.

- The cushion is completely compressed.
- The dynamic force at impact and thus the deceleration of the cushion remain constant during deformation.
- After the cushion has been deformed, the pack is at rest.

Under these ideal conditions, the following relationship applies: $G = h/d$. This theoretical magnitude is adopted to describe the quality of cushioning material. It is related as follows to the actual dynamic multiplier G_{act} by a factor C:

$$\frac{G_{act}}{G} = \frac{G_{act}}{h/d} = C$$

The value C indicates the factor by which the thickness of an ideal cushion must be multiplied to obtain the actual thickness that would give rise to the same value of G in practice.

Actual cushioning materials differ from ideal cushions in that their shock absorption properties alter with the load. Thus any value quoted for C is of no significance unless it is accompanied by the figure for the dynamic load with which G_{act} was determined. A term that is adopted to describe this is the specific potential energy e, i. e. the potential energy per unit volume of cushioning material, or

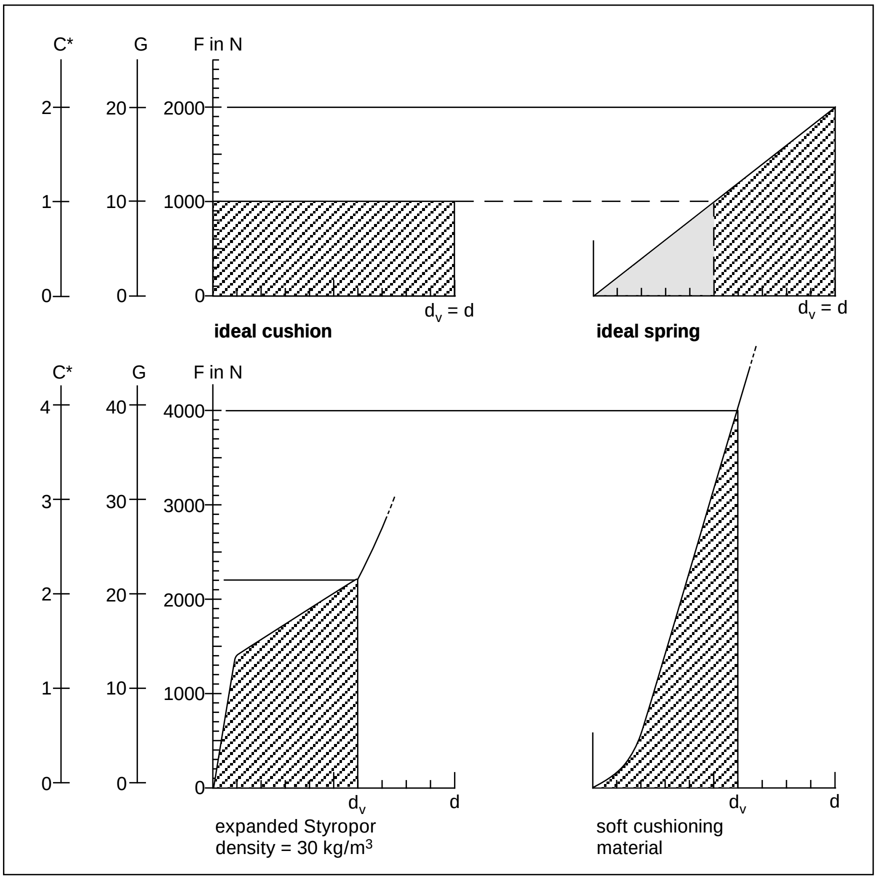
$e = mgh/Ad$

where A = length x width of pack.

The value quoted for e indicates the potential energy of a dynamic load that must be applied to a cushioning material to obtain a given value of C. The pair of values coinciding with the minimum value of C are denoted by an asterisk, i. e. C* and e* Figures for the main cushioning material are listed in the table above. It can be seen from this table that Styropor foam is the best shock absorbing material of all, i. e. it has the lowest value of C*.

Example:
Height of fall h = 100 cm
Thickness of cushion d = 10 cm
Mass of pack contents m = 10 kg
Gravitational force (m · g) ≈ 100 N

Type of cushion	**ideal cushion**	**ideal spring**	**Styropor foam density 30 kg/m^3**	**soft plastic film**
C* from Table	1	2	2.2	4
G = C* (h/d)	10	20	22	40
F = mg G	1000 N	2000 N	2200 N	4000 N



Reasons for differences in C*

The reasons for the differences in shock absorption by the various cushioning materials are apparent from the dynamic force-deformation diagram.

- The acceleration and force remain constant over the entire thickness of ideal cushioning material. The hatched area in the diagrams represent the strain energy, which is equal to the potential energy. Thus C* = 1.
- The force is proportional to the strain over the entire thickness of cushioning representing an ideal spring. Thus, if the strain is 50 %, only one-quarter of the potential energy is converted. As a consequence, greater forces are required to convert the remaining energy. The maximum force is twice as large as that applied in deforming ideal cushioning material. In this case, therefore, C* = 2.
- Styropor foam with a density of 30 kg/m^3 behaves similarly to ideal cushioning material at low values of strain. In the 0 – 5 % range of strain, the force increases rapidly. This part of the curve is followed by a wide range in which the force undergoes little change. At values of strain above 60 %, the force again rises rapidly.

Experiments have shown that shock absorption is highest at 60 % strain, in which case C* = 2.2.

- At low rates of strain, the slope of the force-strain diagram for soft cushioning materials is not very high. Consequently, this range contributes very little to the transformation of energy, i. e. towards deceleration on impact. At higher values of strain, the force increases rapidly and attains a maximum that is substantially higher than that reached with expanded Styropor. In this case, C* = 3 to 4 or more, the actual value depending on the softness.

Effect exerted by density of expanded Styropor on C* and e*

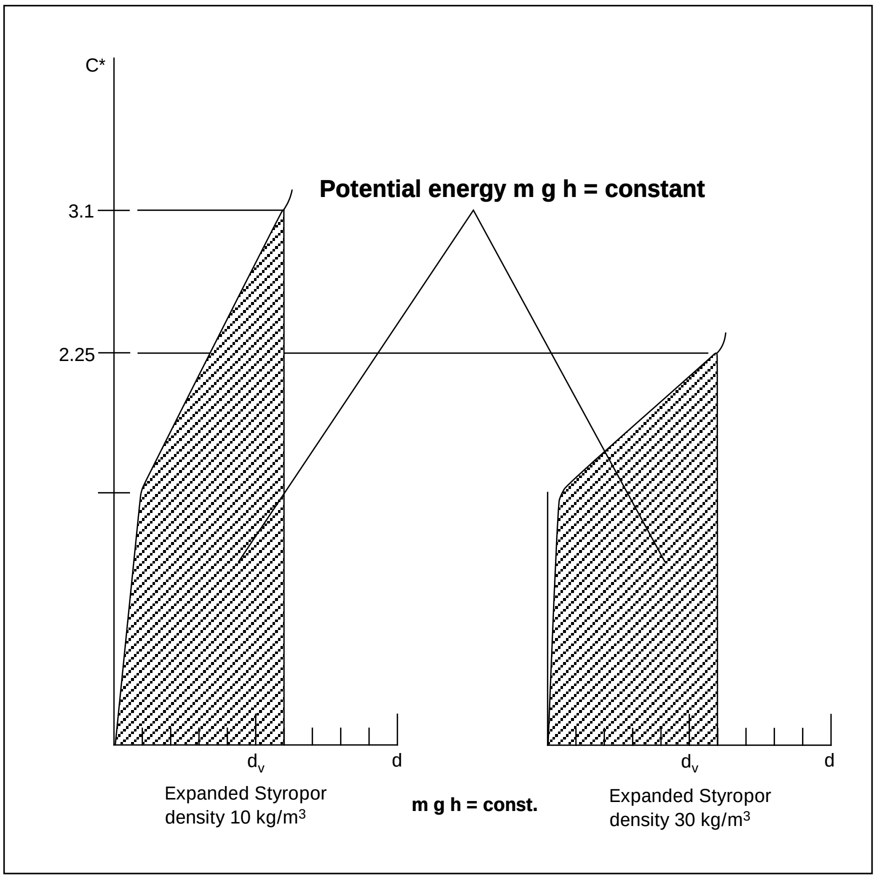
Quality specifications of general validity for cushioning materials can be derived from the force-strain diagram for ideal cushions.

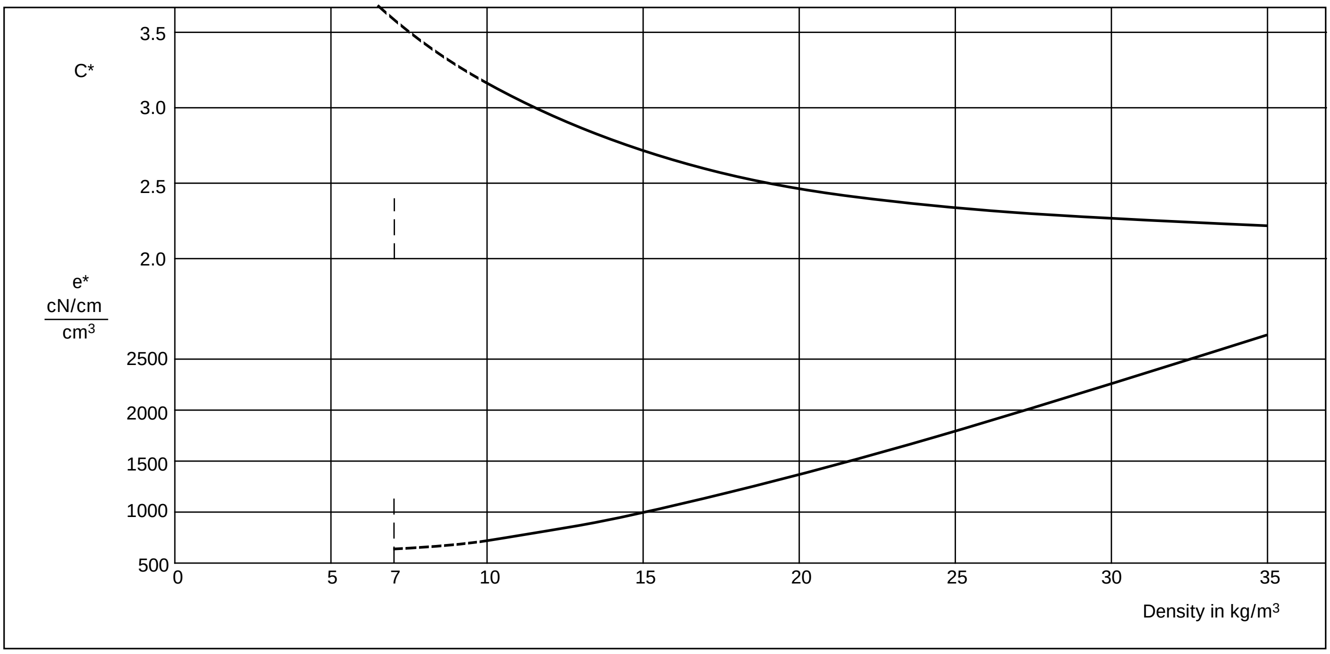
- The force required to raise the strain slightly increases rapidly to a given value.
- The force required should remain as constant as possible over the widest possible range of deformation.

From the stress-strain diagrams, it can be seen that at low values of strain, i.e. of about 5% or less, the corresponding force for Styropor foam with a density of 10 kg/m^3 increases somewhat less than that for a density of 30 kg/m^3; and at higher values, viz. 5% to about 60%, somewhat greater forces are required. As a result of this difference higher values of C* correspond to the lower densities. Plasticizing Styropor foam effects a change in the force-strain characteristic similar to that obtained by reducing the density. Consequently, plasticized expanded plastics are poorer shock absorbers.

In the diagrams below, the values determined for C* and e* in our laboratory have been plotted against density. Differences in the hardness of the expanded plastics can be recognized from the figures for e* (2200 cN cm/cm^3 for a density of 30 kg/m^3 and 700 cN cm/cm^3 for a density of 10 kg/cm^3). The value for e* is an expression for the potential energy mgh that must be applied to a cushioning material to obtain the shock absorption corresponding to a given value of C*.

The effect exerted by the various parameters on the dimensions of the pack are illustrated by the following specimen calculations.

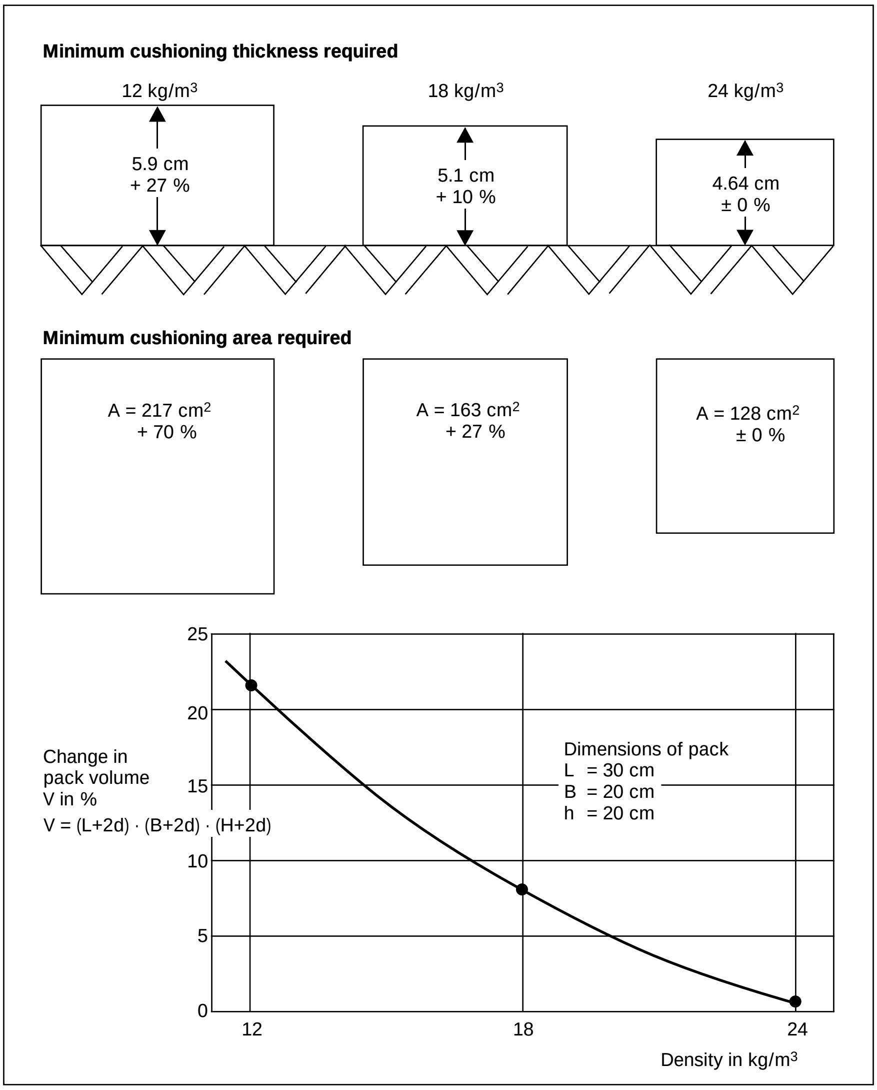




Specimen design calculation
Mass of contents $m = 10$ kg
Weight of contents $mg \approx 100$ N
Height of fall $h = 100$ cm
Maximum permissible value of G (mg) = 50

Cushioning characteristics of Styropor foam of various densities

Density in kg/m^3	12	18	24
C*	2.95	2.55	2.32
e* in cN/cm/cm^3	780	1200	1680



Specimen calculation

A Styropor pack for contents of mass m = 10 kg is to be designed so that the dynamic load does not exceed 50 times the static load, i.e. G = 50, if the pack is dropped through a height of 100 cm.

What should be the thickness of the cushioning material and what area should it present if the density of the pack is 12, 18 and 24 kg/m^3?

The desired values can be obtained from the following equations.

$d = C^* h/G$
$A = mgh/e^* d$

The results are presented in the diagram opposite. If the pack has a density of 12 kg/m^3, its thickness will be 27% greater than that of a 24 kg/m^3 pack; and its area, 70% greater. Although a larger area normally does not entail any disadvantage, greater thickness exerts a very adverse effect on costs. For instance, if the dimensions of the contents were 30 cm x 30 cm x 20 cm, a pack of 12 kg/m^3 density would have to occupy 23% more space than that required by a 24 kg/m^3 pack in order to fulfil the conditions specified above. This extra space would entail higher cost in outer packs, warehousing and transportation. The increase in costs would be particularly great if the packs were too large for the pallets, shelves and vehicles. There are other drawbacks that cannot be expressed so readily in terms of costs, but which affect the protective function of the pack the damage quota, and the presentation of contents.

The main properties are shown as functions of the density in the following diagrams.

Effect of density on the main properties of expanded plastics

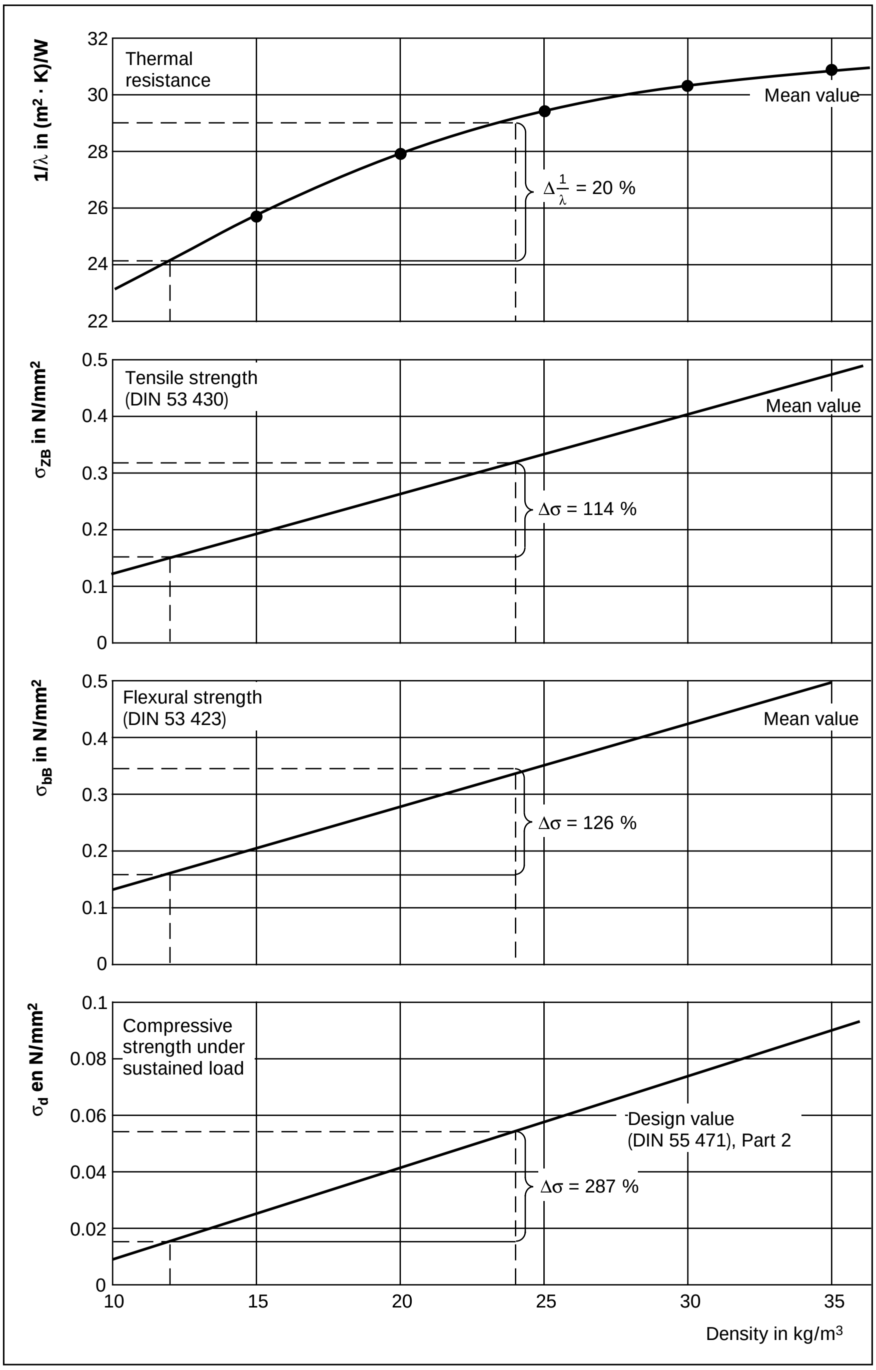
Another function of packs besides cushioning, i. e. absorbing dynamic loads, is to withstand compression. It can be seen from the diagram opposite that the compressive strength of an expanded plastic increases rapidly with its density. Consequently, although material with a low density has a greater cushioning effect, it is less capable of withstanding compressive loads. This fact can be illustrated by figures for the packs designed on the previous pages.

Styropor foam packs are also subjected to flexural and tensile loads during transportation and handling and if they are dropped. In some cases, they must also act as thermal insulation. It can be seen from the diagrams that these properties, too, are adversely effected by a decrease in density.

Thus a pack of density 24 kg/m^3 can withstand a compressive load of 666 N, which is 2.4 times higher than the load that can be withstood by a 12 kg/m^3 pack. Hence the pack with the lower density must be enclosed in an expensive outer pack to withstand the same compressive load.

Hence, any savings in costs that may be effected by purchasing packaging with a lower density must be balanced against the attendant impairment in properties and the higher costs involved in storage, transportation and outer packs.

Density in kg/m^3	**12**	**18**	**24**
Compressive strenght N/mm^2	0,013	0,033	0,052
Cushioning area (see example) in cm^2	217	163	128
Maximum permissible load on pack			
in N	282	538	666
Percentage change	– 58 %	–194	±0 %

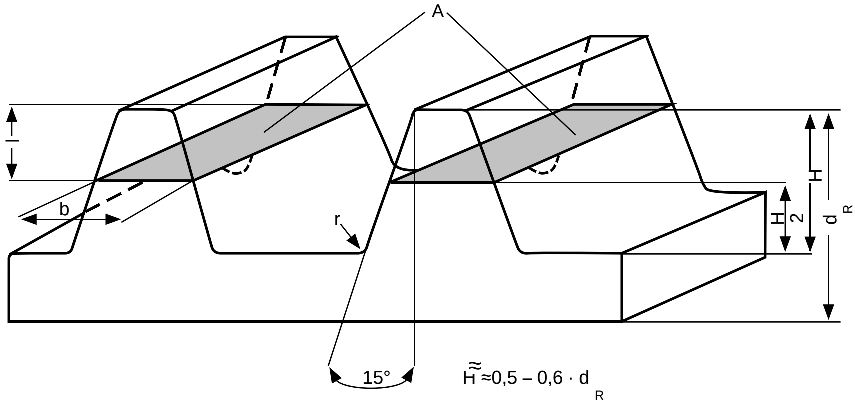


Recommendation on designing packs of the correct density

It has been demonstrated that an increase in density in the 10 – 35 kg/m^3 range is associated with better cushioning effect C* and greater energy absorption e*. Thus well-designed packs of high density are less thick than their low-density counterparts. However, strength considerations impose certain minima on the dimensions and thus upper limits, which depend on the nature of the contents and the dynamic load, on the density. The minimum dimensions that we recommend for various densities are as follows:

- Density 12 kg/m^3
  $H/2.2 \leq b\text{-}H/4$
- Density 18 kg/m^3
  $H/2.6 \leq b\text{-}H/4$
- Density 24 kg/m^3
  $H/3 \leq b\text{-}H/4$

$d_R = 1.1$ d (correction factor for ribbed designs).



For production reasons, efforts are made to restrict differences in density to a minimum. In practice, the following values have been adopted for the two main types of packaging:

- For light and fragile goods density 18 kg/m^3
- Other goods density 24 kg/m^3

An important point in the design of packaging is to ensure that the above demands and the loads read off from the cushioning curves are adhered to. For instance, packaging for goods in the form of panels must be designed with considerably greater densities owing to the high loads on the sides. The same applies to goods that present surfaces that cannot withstand high loads. Hence, neither of the two figures representing the density can be regarded as being of general validity.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

BASF Aktiengesellschaft
67056 Ludwigshafen, Germany

Technical Information

Styropor® **610**

BASF Plastics

38065 January 1997

7 Packaging

Expanded Styropor packaging for withstanding compressive loads

1. Behaviour under compressive loads

Styropor expanded plastics are hard cellular materials, which, according to DIN 7726, constitute the group of expanded plastics with the highest capacity for compressive loads. The compressive stress at 10% strain, as determined by DIN 53421, is laid down as a measure for the capacity to bear compressive loads. The choice of density allows this capacity to be very readily varied. This property of the material, together with the optimized method of production, allows the economic manufacture of self-supporting packaging and load-bearing inserts for combination packs.

The properties are governed by the cellular structure of the polystyrene and the air enclosed in the cells. It can be seen from the compressive stress – strain diagram (Fig. 1) that the strain varies according to the structure of the material.

- At values of 100 kPa for the compressive strength when the density is 20 kg/m^3 or values of 20 kPa when the density is 30 kg/m^3, the values of strain are very low for expanded Styropor. There is almost a linear relationship between stress and strain. This stress range is exploited for the design for packaging that has to bear compressive loads.
- At values of between 100 and 300 kPa for the compressive stress at a density of 20 kg/m^3 or of values between 180 and 500 kPa when the density is 30 kg/m^3, expanded Styropor undergoes considerable deformation. In other words, slight increases in compressive stress effect large increases in strain. This behaviour is exploited in the design of packaging that has to withstand impact loads.
- When the compressive stress is further increased, expanded Styropor undergoes very little further strain. The impact-damping properties, therefore, deteriorate within this range.

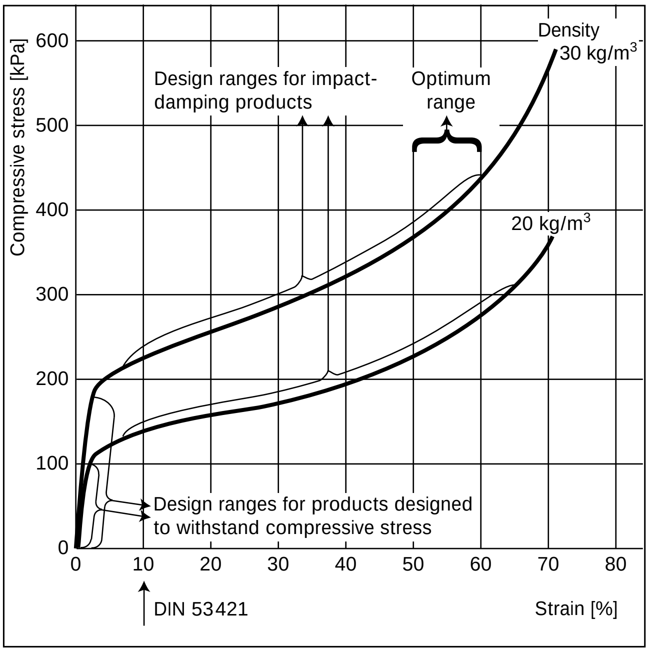


Fig. 1 Compressive stress-strain relationship for expanded Styropor.

It must be noted that packing's ability to withstand compressive stress is not determined from the stress – strain values obtained in the DIN 53421 test or from values obtained from any stress-strain diagram (Fig. 1). For this purpose, values that take account of practical conditions are essential.

2. Factors that affect the permissible compressive loads bearing capacity of Styropor packaging (values of compressive strain)

Packaging that has to withstand compressive loads must retain its shaper during long loading periods and under the usual dynamic loads that occur during transportation. In order to ensure this, the following factors must be taken into account in determining the maximum permissible compressive strength that the packaging will have to display.

- The age of the cellular material
- The behaviour on long-term loading
- The behaviour on changes in temperature
- The behaviour towards dynamic loads
- Geometric form

2.1 Age of the cellular material

The factors introduced by the age of the cellular material are the absorption of air and the release of blowing agent. After the material has been expanded, the pressure of the gas in the cells is initially reduced. The extent of the reduction depends on the increase in cell volume and the air displacement. In this stadium, the only load-bearing capacity available is that exerted by the cellular structure. After about 24 hours, the gas pressure in the cells will have roughly approached atmospheric pressure as a result of air diffusion. As a consequence, the gas pressure can give support to the cellular structure. This effect brings about a 25% increase in compressive strength. However, a certain amount of residual blowing agent still remains in the expanded material that composes the substance of the cellular framework and acts as a plasticizer. Within about 4–8 weeks, the bulk of this will have diffused from the material, with the result that the compressive strength will have increased by a further ca. 15%. The ultimate strength is thus largely achieved.

- The values mentioned in Table 1 are based on a minimum age of 14 days.

2.2 Duration of loading

In the DIN 53421 tests, the specimens are loaded for about one minute (10% strain for d = 50 mm and v = 5 mm/min). In practice, packaging must withstand compressive loads for much longer periods. Fig. 2 shows the behaviour of expanded Styropor with densities of 20 and 30 kg/m^3 on long-term loading. The abscissae are loading periods of up to 500 days, and the ordinates

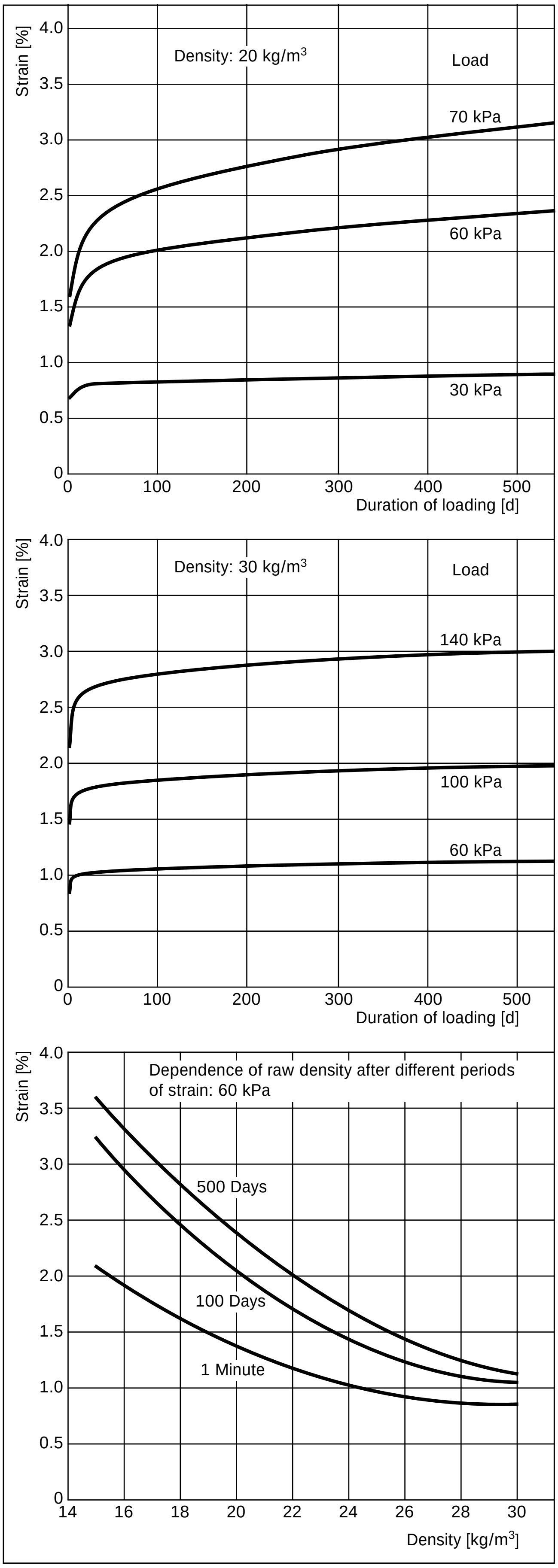


Fig. 2 Relationship to density after various durations of loading

represent the percentage change (strain) in the thickness of the expanded material. For example, it can be derived from these graphs that specimens with a density of 20 kg/m^3 exposed to a load of 70 kPa undergo comparatively strong deformation. However, only that package that has a stable shape is suitable in practice. If the density is 20 kg/m^3, the demand would be satisfied by loads of approximately 40 kPa. However, this applies only to static loads at room temperature.

- The values listed in Table 1 are based on loading periods of approx. 1 year.

2.3 Effect of temperature

Expanded Styropor is a thermoplastic with a softening range of 90 to 100 °C. However, the mechanical properties already change under the normal fluctuations in ambient temperature. The load-bearing capacity under compressive loads (see Fig. 3) increases at temperatures below 20 °C and decreases at temperatures above 20 °C.

- The values listed in Table 1 are based on exposure to temperatures up to a maximum of 30 °C.

2.4 Dynamic loads

The behaviour under dynamic loads is governed by the type of loading and the arrangement of the packaging during transport.

- The values listed in Table 1 make allowance for loads that are stacked in road vehicles on Central European roads.

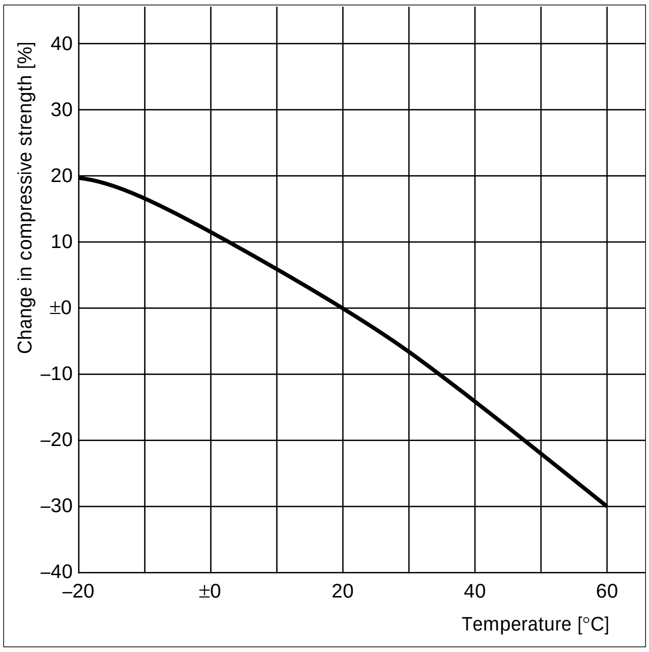


Fig. 3 Effect of temperature on the compressive strength

2.5 Geometrical form

Values of compressive strength for the packaging loads listed in Table 1 are permissible only when the loaded sections have adequate flexural strength. Particular attention should be devoted to this in the design of boxes with high walls.

- Experience has shown that packaging elements have adequate flexural strength if the ratio of their thickness (d) to their height (h) ≧ 0.1.

3. Calculation of packaging to withstand compressive loads

The following relationships have been adopted for the calculation:

$F_{max} \leqq \sigma_{d,\,max} \cdot A$
$d/h \geqq 0.1$
where
F_{max} = maximum load exerted by stack
$\sigma_{d,\,max}$ = maximum permissible compressive stress
A = supporting area (area of load-bearing expanded plastic)
d/h = stiffness factor

Values for the maximum permissible compressive strength applicable to designing expanded Styropor packs that withstand compressive stresses

Density of-cellular material in kg/m^3	17.5	20.0*	22.5	25.0*	27.5	30.0*	32.5	35.0*	37.5	40.0	42.5	45.0*
Maximum permissible compressive strength $\sigma_{d,\,max}$ in N/mm^2	0.031	0.039	0.047	0.055	0.063	0.071	0.079	0.087	0.096	0.103	0.111	0.119

**Values taken from DIN 55471, Part 2.*
1 MPa ≙ 1,000 kPa ≙ 1 N/mm^2.

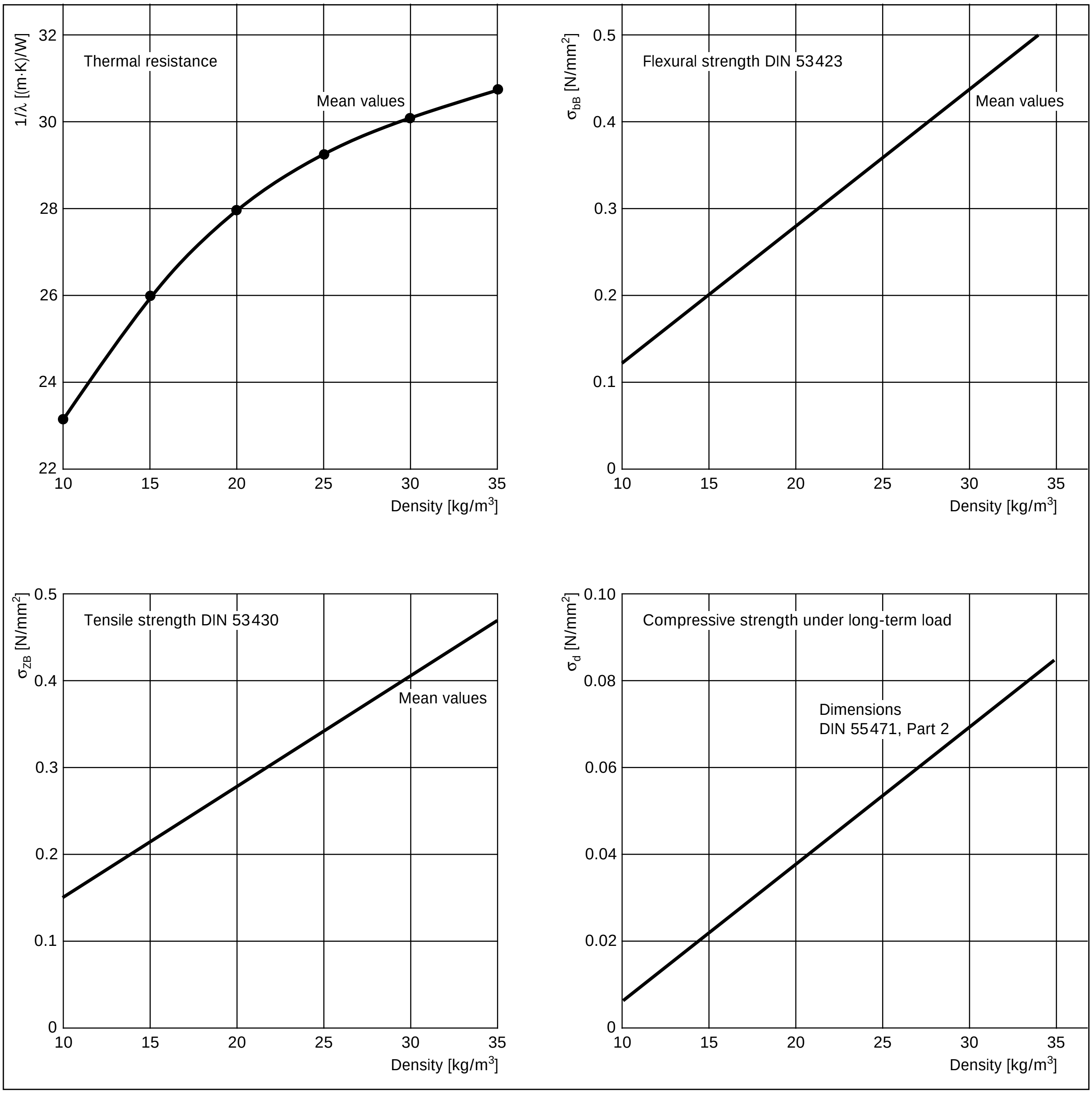


Fig. 4 Effect of density on important properties of the expanded plastic

It must be noted that the values quoted in Table 1 are those for the maximum permissible compressive stress. If exceptionally severe conditions exist in practice (see Item 2), correspondingly lower values must be laid down.

- Specimen calculation 1

A load of F_{max} = 2,000 N is to be applied to a Styropor packaging.

What bearing surfaces are necessary if the density is 20, 25 and 30 kg/m^3?

Solution: $d/h \geq 0.1$ applies for plastics elements:

$$A \geqq \frac{F_{max}}{\sigma_d}$$

σ_d = f (density) from Table 1

$A \geqq \frac{2000\ \text{N}}{0{,}039\ \text{N/mm}^2}$ for a density of 20 kg/m^3

= 51,282 mm^2 ≈ 513 cm^2

$A \geqq \frac{2000\ \text{N}}{0{,}055\ \text{N/mm}^2}$ for a density of 25 kg/m^3

= 36,364 mm^2 ≈ 364 cm^2

$A \geqq \frac{2000\ \text{N}}{0{,}071\ \text{N/mm}^2}$ for a density of 30 kg/m^3

= 28,169 mm^2 ≈ 282 cm^2

- Specimen calculation 2

The wall of a packaging has a length (l) of 250 mm, a height (h) of 180 mm, and a density of 22.5 kg/m^3. The force exerted by the stack (F_{max}) is 120 N.

What wall thickness is required?

Solution:

$$A \geqq \frac{F_{max}}{\sigma_d}$$

$$\geqq \frac{120}{0.047}$$

$$\geqq 2.553\ \text{mm}^2$$

$d = A/l$
$= 2.553/250$
$= 10.2$ mm

$d/h \geqq 0.1$
$d \geqq 0.1 \cdot 180$
$d \geqq$ **18 mm**

Owing to the demand for adequate flexural strength, is a thickness of ≧ 18 mm required for the wall of the packaging.

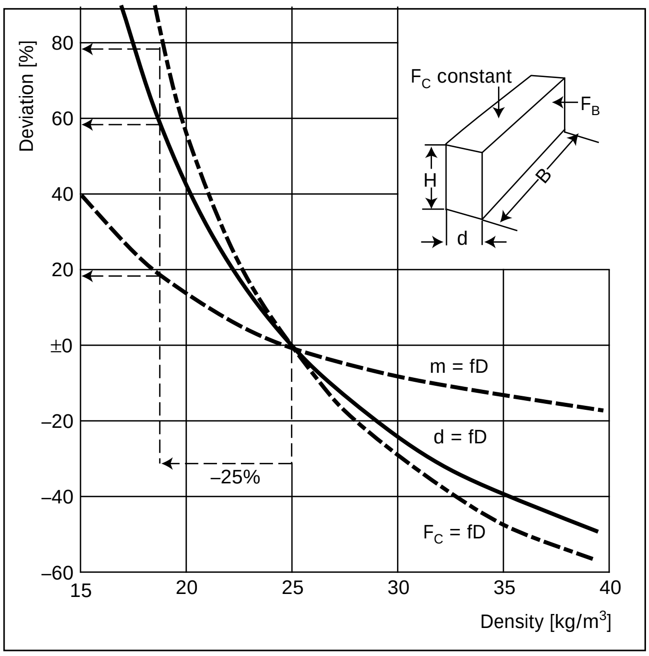


Fig. 5a Effect of density D on the wall thickness d, the raw material input m and the permissible bending force F_B of an expanded plastic sheet, permissible compressive force F_C = constant

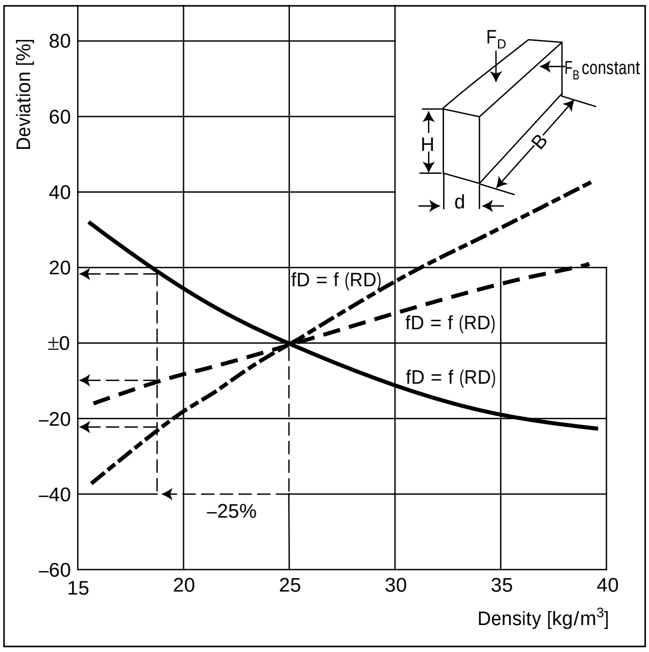


Fig. 5b Effect of density D on the wall thickness d, the raw material input m and the compressive force F_C of an expanded plastics panel, permissible bending force F_B = constant

4. Effects of density

It is evident from Table 1 that the maximum permissible compressive strength increases with the density. In the given range of densities, the following relationship exists.

$\sigma_{\text{max perm}} = 0.0032 \text{ x } D - 0.025$

[where D_m is the density in kg/m^3 and σ is the maximum permissible compressive stress in N/mm^2]

This relationship allows accurate values of permissible tensile stress to be calculated for all densities ranging from 17.5 to 45 kg/m^3.

As was explained in Chapter 3 (Specimen calculation 1), packaging with the same load-bearing compressive strength can be designed from material with different densities. In this case, however, it must be noted that each change in density involves a change in packaging properties and specific material characteristics. Fig. 4 shows the effect of density on important specific material characteristics; and Figs. 5a + b demonstrate the effect on the packaging properties, viz. the permissible flexural force and the permissible force exerted when the packaging is stacked.

Both the mechanical properties and the heat insulation improve with an increase in density in the range in question. If the retention of certain properties entail a reduction in density, greater wall thicknesses are always required (see Figs. 5a + b). The following examples demonstrate that a change in design can alter the raw materials input after a reduction in density to a greater or lesser extent.

Example 1

Demands
- The density of the raw materials to be reduced by 25% from its original value of 25 kg/m^3
- The permissible force exerted by the stack to remain the same

Results from Fig. 5a
- Wall thickness required to be 57% more
- This would involve an 18% increase in the raw materials input
- The permissible flexural force increases by 78%

Example 2

Demands
- The density to be decreased by 25% from its original value of 25 kg/m^3
- The permissible flexural force to remain the same

Results from Fig. 5b
- The wall thickness required to be 18% greater
- The raw materials input is decreased by 12%
- The permissible compressive force is decreased by 25%

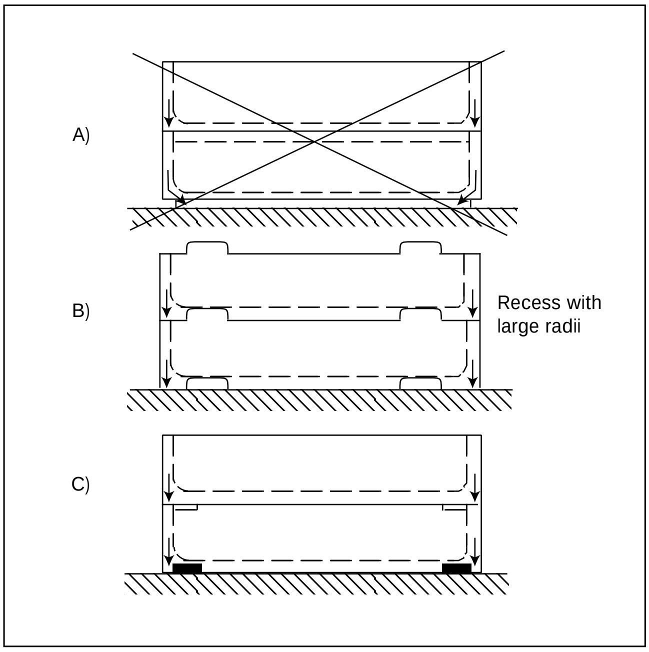


*Fig. 6
Stacking aids
A Risk of failure as a result of excessive notch stresses
B + C Lines of force directed vertically, and thus no risk of dangerous notch stresses*

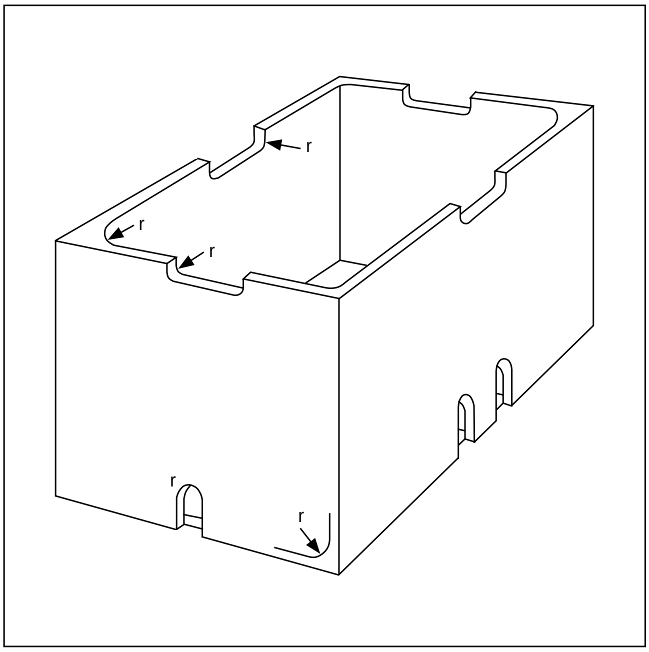


Fig. 7 Design recommendations for interior corners and edges (r = ≧ 10 mm).

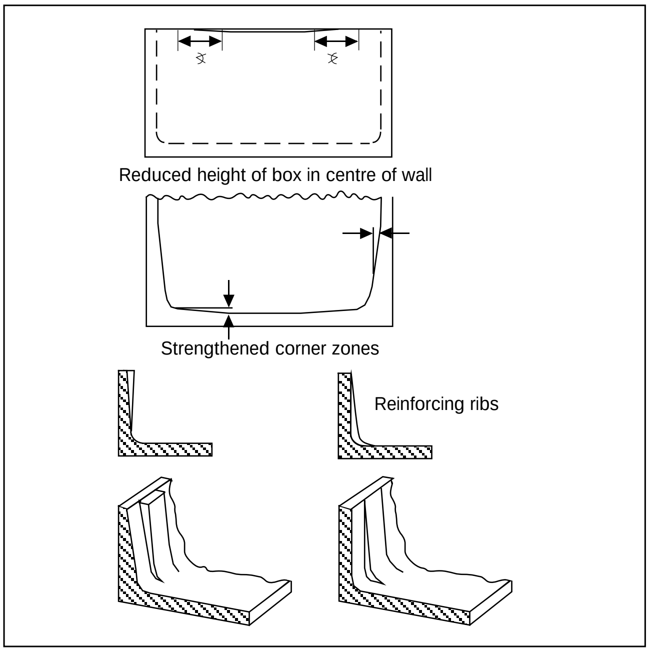


Fig. 9 Design recommendations for box walls with improved resistance to buckling

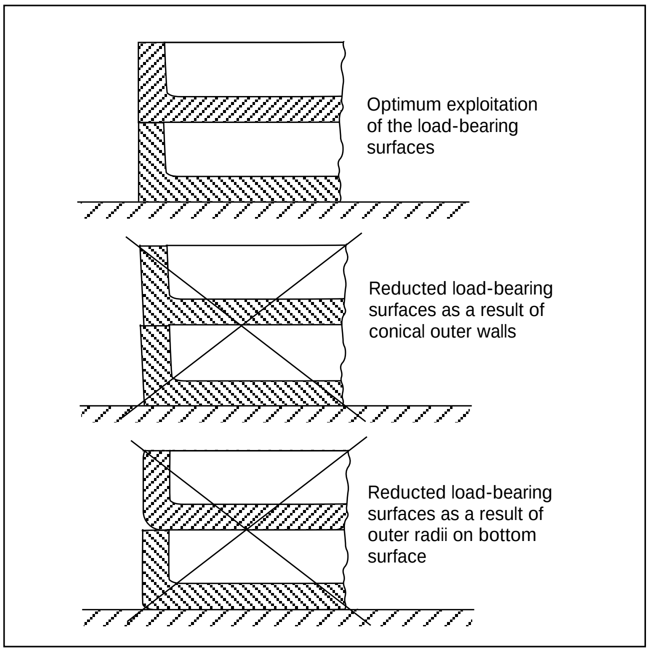


Fig. 8 Design recommendations for external structures

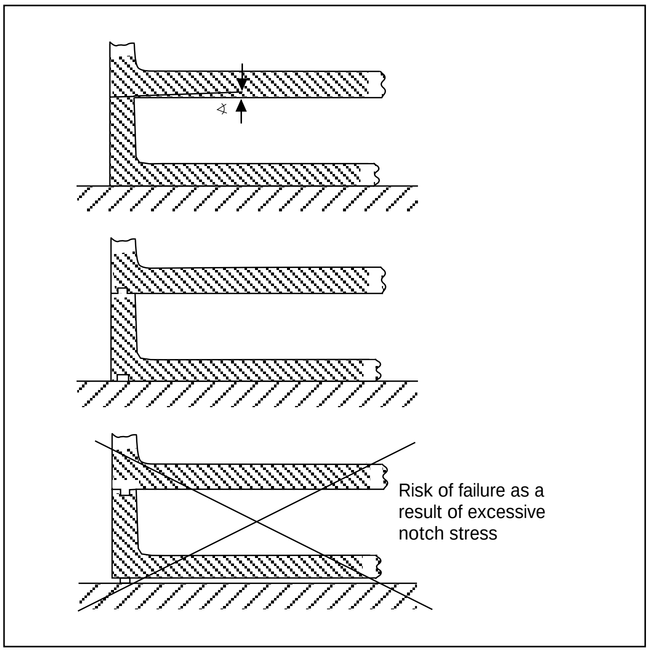


Fig. 10 Design recommendations for improved connections between the bottom and the wall

Remarks
The basis upon which the curves in Figs. 5 a/b have been calculated is as follows:

σ_{Cperm} = 0.0032 D – 0.025 in N/mm^2
where D is the density in kg/m^3
$\sigma_C = F_C/A = F_C/Bd$
σ_{Bperm} = 0.016 D – 0.04 in N/mm^2
$\sigma_B = FBH/Bd^2/6$

5. Design recommendations

The following additional points must be observed in the design of Styropor packaging.

- The permissible compressive strength must be adhered to.

- The load-bearing walls of the Styropor packaging must guide the forces of compression in a straight line vertical to the bottom. This point must be particularly observed in the design of stacking aids (see Fig. 6).

- All corners and edges in the interior of the packing must be designed with as large radii as possible (≧ 10 mm; see Fig. 7). The same applies to recesses in the walls and bottom.

- In order to obtain the maximum possible bearing surfaces, preference should be given to rectangular outer edges and outer walls that run exactly vertical to the surface of the bottom (see Fig. 8). Allowance can be made for the conicity required for demoulding during production on the vertical surfaces inside the box.

- The load-bearing surfaces should be designed, if possible, in the stable zone of the corners, in order to counteract the risk of buckling when the packaging walls are high. Loads can be relieved on the centre of the packaging walls by recesses (ventilation holes and handle recesses) or by reducing the height of the wall by 1–2 mm. The same effects can be achieved by vertical ribs (see Fig. 9).

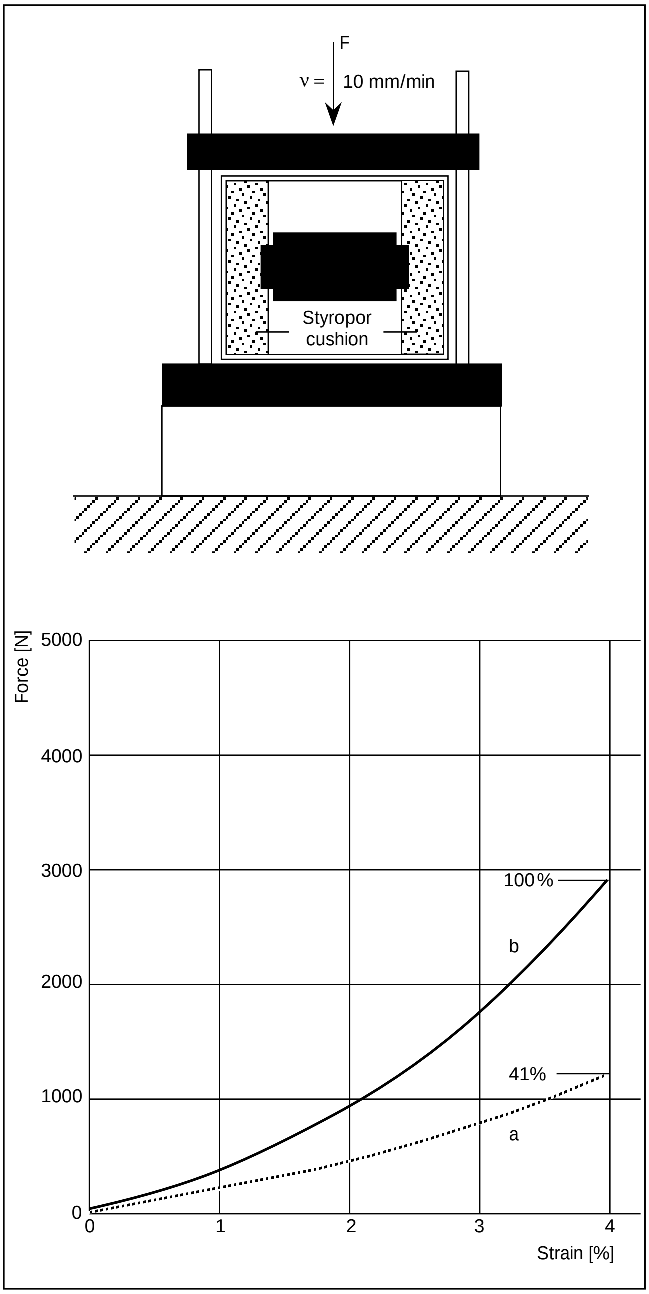


Fig. 11 Force – deformation diagram Specimens (a) Corrugated cardboard folding box (2.70) L x B x H = 32 x 29 x 28 cm. (b) Corrugated cardboard folding box (2.70) with two expanded Styropor side shells density = 20 kg/m^3, d = 9 cm, L x B x H = 32 x 29 x 28 cm.

- The loose connection of the bottom and wall supports can be improved by appropriately moulding the bearing surfaces (see Fig. 10). This applies particularly to high walls.

6. Combination packs

The behaviour of expanded Styropor, as described, and the design recommendations are valid for combination packs as well as for self-supporting packages. In this respect, too, the high capacity to withstand compressive loads offers considerable advantages. In Fig. 11, this is illustrated by the example of a lateral leaf combination pack produced from corrugated cardboard and Styropor. A pack without side leaves can withstand about 60% less load than those produced with Styropor. Even greater differences can be expected if moisture has an effect, for example during normal climatic change. This is because the strength of expanded Styropor, in contrast to that of corrugated board, is fully retained even on direct contact with washer. This shows that Styropor mouldings ensure a secure stack in all stages of transportation, even under severe practical conditions.

Note

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7 Packaging

Thermally insulating packaging

Thermally insulated packaging is needed whenever

- the temperature of the packaged goods must be kept above ambient temperatures, e. g. hot take-away foods,
- the temperature of the packaged goods must be kept below ambient temperatures, e. g. fresh fish, ice cream, or
- the temperature of the packaged goods must not reach extremes of ambient temperatures during transportation and storage, e. g. pharmaceuticals or aquarium fishes.

A condition for the fulfillment of such requirements is a packaging material having a low thermal conductivity. The value of this specifies how great the heat flow is in a temperature gradient under standard conditions (DIN 52 612). As Fig. 1 shows, the mean thermal conductivity of expanded Styropor foams is very low by comparison with conventional packaging materials and even dense plastics. Expanded Styropor foams are therefore also the ideal material for thermally insulating packaging.

Calculations for thermally insulating expanded Styropor foam packaging can be carried out using its thermal conductivity when transportation and storage conditions are known.

Depending on the variation of the temperature of the packaged goods a distinction is made between two theoretically different thermal conditions, the calculation of which is based on different mathematical relationships.

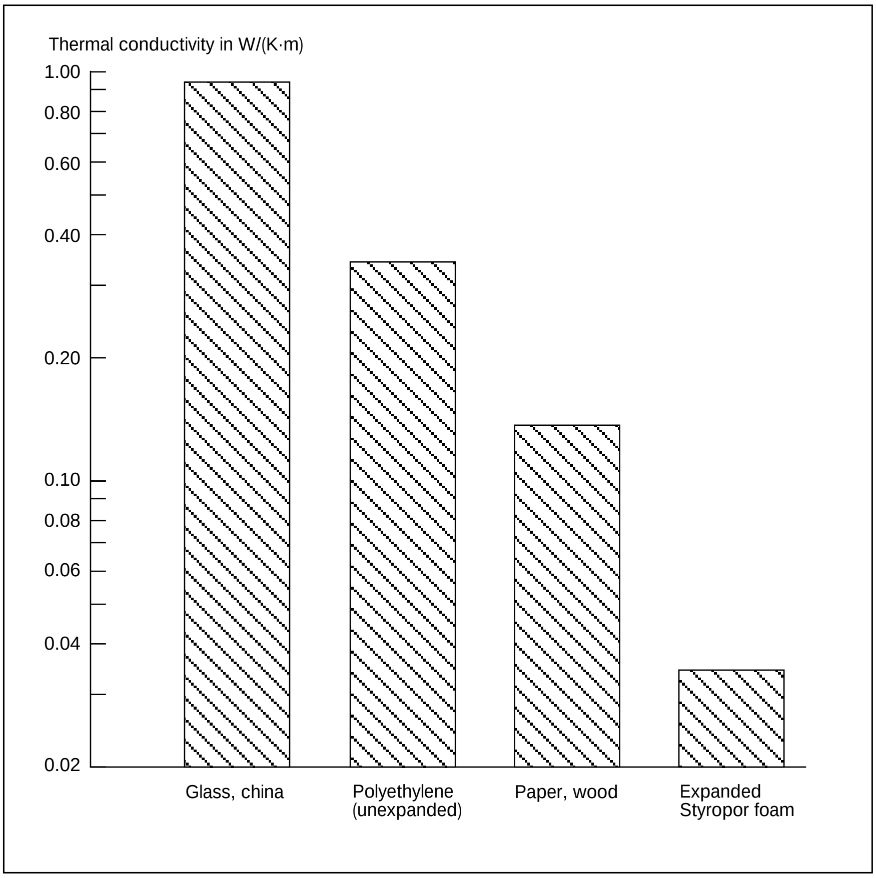

Fig. 1 Thermal conductivity of some packaging materials

- The temperature difference between the packaged goods and surroundings remains approximately constant during a certain period of time. This is the case, e. g., when ice at the freezing point is enclosed with the packaged goods (see Fig. 2 b and Example calculation 2 in Table 1).
- The temperature difference between the packaged goods and ambient temperature falls as storage time increases. This is the case for packaged goods without addition of ice at the freezing point (see Fig. 2 a and Example calculation 1 in Table 1).

The formulae for calculation under both sets of conditions are presented in Fig. 2. It may be seen from the formulae that the thermal insulation time rises with

increasing	**decreasing**
• mass of the packaged goods or ice	• temperature difference between packaged goods and surroundings
• specific heat of the packaged goods or heat of fusion of the ice	• internal surface area of the packaging
• temperature difference between the filling temperature and permitted final temperature	• thermal conductivity (dependent on the bulk density of the expanded foam)
• wall thickness	
• heat transmission resistance values $1/\alpha$	

Example 1

The permissible thermal insulation time for a package of cheese is to be calculated. The following values are known:

Weight of the cheese	$m = 8.0$ kg
Thickness of the packaging	$d = 0.04$ m
Bulk density of the expanded foam	$BD = 20.0$ kg/m^3
Initial temperature of the cheese	$\vartheta_a = + 0$ °C
Permissible final temperature of the cheese	$\vartheta_e = + 10$ (C
Ambient temperature	$\vartheta_u = + 20$ (C
Heat capacity of the cheese	$c = 2.85$ kJ/(kg · K) from Table 5
Internal surface area of the packaging	$A = 0.3480$ m^2

Calculation according to Formula 1

$$t = m_v \cdot c_v \cdot \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \ln \frac{\vartheta_u - \vartheta_a}{\vartheta_u - \vartheta_e}$$

$$1/\alpha = 0.5 \ \frac{m^2 \cdot K}{W} \text{ from Tab. 2}$$

$$\lambda = 0.035 \ \frac{W}{m \cdot K} \text{ from Tab. 3}$$

$$= 8 \cdot 2.85 \cdot \frac{0.5 + \frac{0,04}{0.035}}{0.3480 \cdot 3.6} \cdot \ln \frac{20-0}{20-10} \left[kg \cdot \frac{kJ}{kg \cdot K} \ \frac{\frac{m^2 \cdot K}{W} + \frac{m \cdot m \cdot K}{W}}{m^2} \cdot \frac{1 \ W \cdot h}{3.6 \ kJ} \cdot \frac{K}{K} \right]$$

t = 21 h

Example 2

The permissible thermal insulation time for a shipping package with enclosed cooling pack is to be calculated. The following values are known:

Weight of the cooling pack	$m_k = 2$ kg
Cooling pack medium	ice water at –1 °C
Thickness of the packaging	$d = 0.05$ m
Bulk density of the expanded foam	$BD = 25$ kg/m^3
Internal temp. of the packaged goods	$\vartheta_i = + 4$ °C from Table 4
Ambient temperature	$\vartheta_u = + 25$ °C
Internal surface area of the packaging	$A_i = 0.5$ m^2

Calculation according to Formula 2

$$t = m_k \cdot s \ \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \frac{1}{\vartheta_u - \vartheta_i}$$

$s = 335$ kJ/kg from Table 5
$\lambda = 0.034$ W/(m · K) from Table 3
$1/\alpha = 0.5$ m^2 · K/W from Table 2

$$= 2 \cdot 335 \cdot \frac{0.5 + \frac{0.05}{0.034}}{0.5 \cdot 3.6} \cdot \frac{1}{25-4} \left[kg \cdot \frac{kJ}{kg} \ \frac{\frac{m^2 \cdot K}{W} + \frac{m \cdot m \cdot K}{W}}{m^2} \cdot \frac{1 \ W \cdot h}{3.6 \ kJ} \cdot \frac{1}{K} \right]$$

t = 35 h

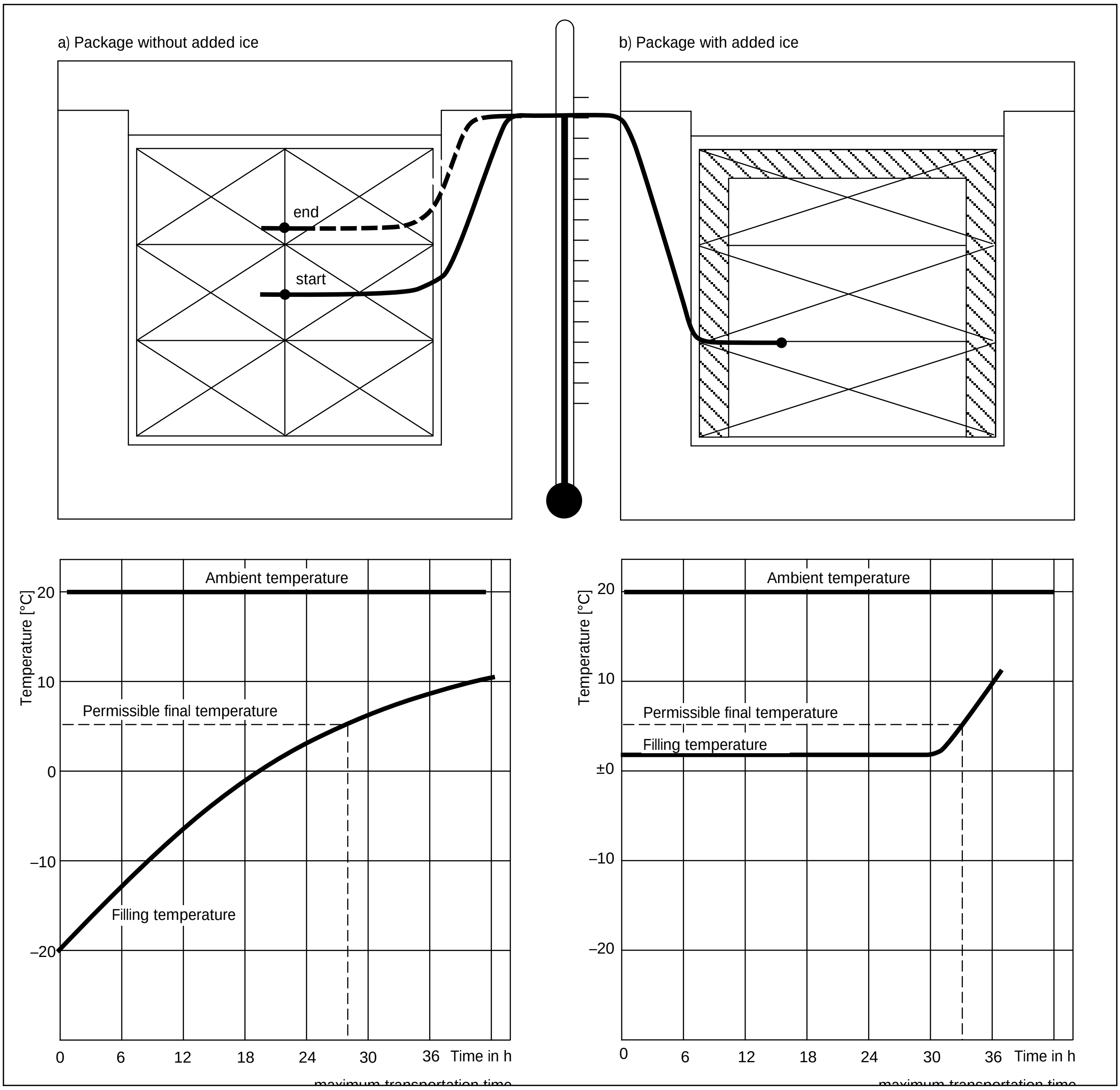

Fig. 2 Method of calculation for thermally insulating packaging made from expanded Styropor foam

Formula 1 $$t = m_v \cdot c_v \cdot \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \ln \frac{\vartheta_u - \vartheta_a}{\vartheta_u - \vartheta_e}$$

Formula 2 $$t = m_k \cdot s \, \frac{1/\alpha + d/\lambda}{A \cdot 3.6} \cdot \frac{1}{\vartheta_u - \vartheta_i}$$

		Units	**Notes**
A	Heat transmission area	m^2	internal surface area of pack
ϑ_a	Temp. of goods at start of insulation time	°C	temperature when packed
ϑe	Temp. of goods at end of insulation time	°C	
ϑ_i	Temperature in the package	°C	see Table 4
ϑ_u	Mean ambient temperature	°C	–
c_v	Specific heat of the shipped goods	$kJ/(kg \cdot K)$	see Table 5
d	Wall thickness of packaging	m	–
m_k	Mass of thermal ballast	kg	–
m_v	Mass of shipped goods	kg	–
s	Specific latent heat of the ballast	kJ/kg	see Table 5
t	Thermal insulation time	h	–
$1/\alpha$	Surface heat transmission resistance on both sides of the packaging	$m^2 \cdot K/W$	see Table 2
λ	Thermal conductivity of expanded foam	$W/(m \cdot K)$	see Table 3

The extent to which these parameters affect the thermal insulation times differs. This is illustrated in Fig. 3 with reference to an example in which the most important independent variables have each been improved by 20 %. This allows the following statements of general validity for the design of thermally insulating packaging units to be derived.

- By adding ice to cool packages the maximum insulation time can be increased by a significant multiple. Thus the use of cooling packs in packages to be kept cold should always be checked (see Fig. 3).
- A reduction in the internal surface area of the packaging brings about a disproportionately large increase in the maximum thermal insulation time. The internal surface areas of the packaging should therefore be as small as possible. This is achieved by fitting the packaging closely to the packaged goods as well as by means of a shape for the packaging which is as near cubic as possible. Moreover, in doing so the amount of Styropor needed is minimized (see Fig. 4).
- If the weight or heat capacity of the packaged goods is increased without changing the geometry of the packaging, the maximum thermal insulation time increases by the same ratio (see Fig. 3).
- Any increase in the thickness of the packaging wall results in an increase in the maximum thermal insulation time. The degree of improvement is also affected by the surface coefficient of heat transfer and therefore has to be determined in each specific case (see Fig. 3).
- Any increase in bulk density in the range of 0 to 40 kg/m^3 has the consequence of extending the maximum thermal insulation time. The degree of improvement is also affected in this case by the surface coefficient of heat transfer and therefore has to be determined in each specific case (see Fig. 3).
- If the mass and volume of a cubic package are increased by the factor x the maximum thermal insulation time increases by a factor of $\sqrt[3]{x}$. Therefore, as large a packaging unit as possible should always be chosen.

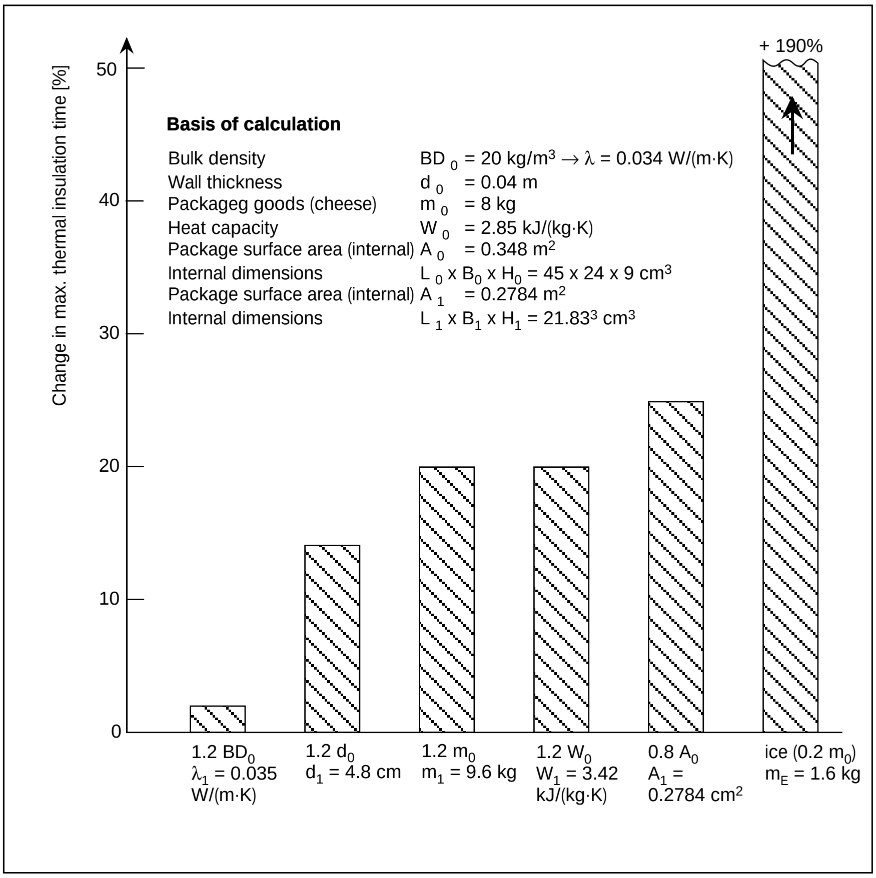

Fig. 3 Relative increases, $\Delta t_E/t_E$, in the effective insulation period brought about by changes in the values of selected parameters

Packaging calculations

Two example calculations are presented in Table 1. The required values for surface heat transmission resistance, thermal conductivity, internal temperature of the packaging, specific heat capacity and heat of fusion were taken from Tables 2 to 5.

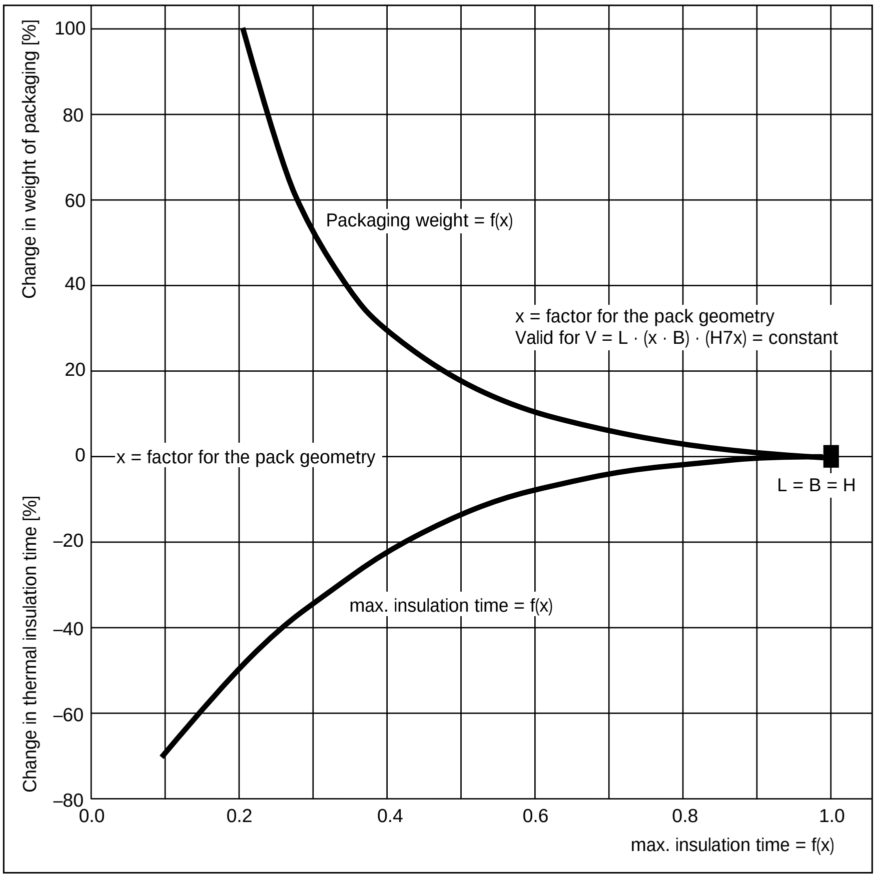

Fig. 4 Effects of the geometric shape on thermal insulation time and package weight

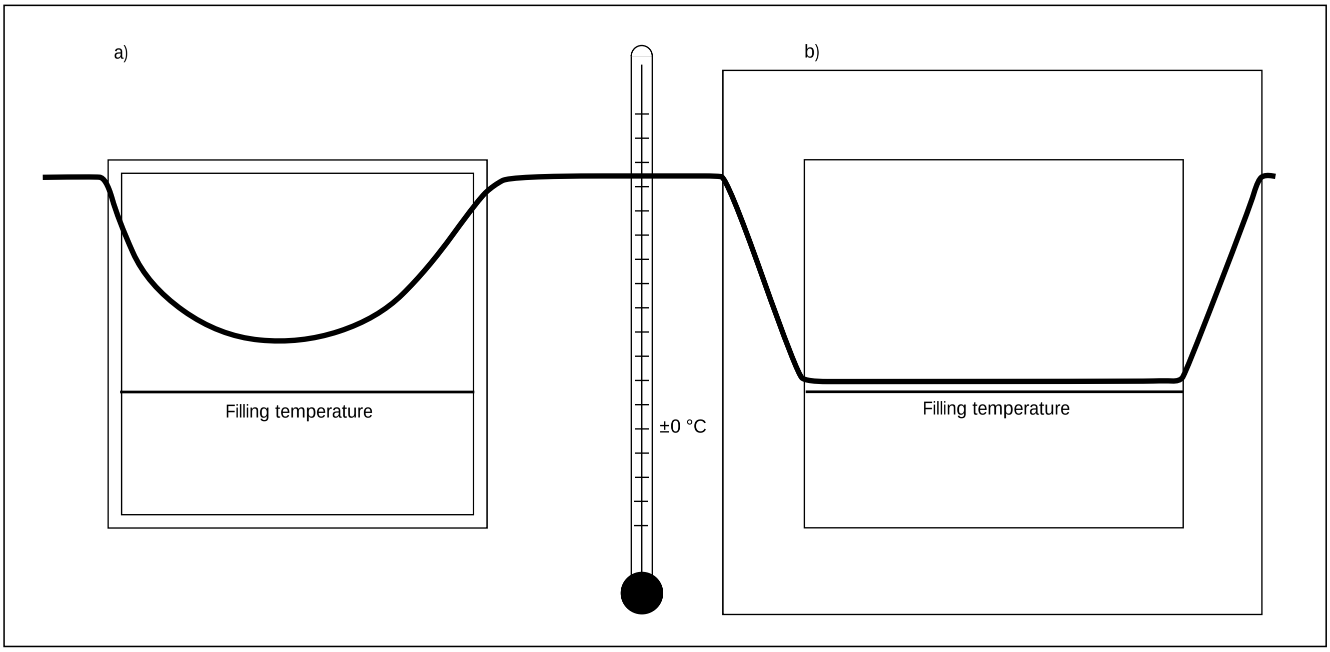

Fig. 5 Variation of the temperature of the packaged goods in packages having (a) poor and (b) good thermal insulating efficiency

Design notes

In carrying out calculations for thermally insulating packaging the assumption is made that no temperature differences arise inside the packaged goods. In order to approach this assumption as closely as possible in practice the following guiding principles should be observed in the course of design.

- Airtight connections between the upper and lower parts of the packaging, e. g. by means of well-fitting tongue-and-groove joints.
- Compact, as far as possible cubic, arrangement of the packaged goods in order to obtain a low ratio of surface area to volume.
- Placing a coolant (ice) at the uppermost position in the package provided a specific position of the packaging unit can be guaranteed. When the position of the packaging unit is unpredictable the coolant should be distributed over at least four side areas.

Uniform temperatures within the packaged goods are also obtained by providing internal ribs which allow better air circulation in the package and by means of thicker packaging walls. In Fig. 5 a poorly insulated package with walls of inadequate thickness and made of an unsuitable packaging material (thermal conductivity is too high) is contrasted with a correctly dimensioned package made from Styropor. While in the expanded foam package the temperature level can be kept approximately constant over the entire contents, in the poorly insulated package the packaged goods at the walls of the package are nearly at ambient temperature.

Table 2 Surface heat transmission resistances in $\frac{m^2 \cdot K}{W}$

Packaging in direct contact with	$\frac{1}{\alpha_i}$	$\frac{1}{\alpha_a}$	$\frac{1}{\alpha_i} + \frac{1}{\alpha_a}$
a) liquid goods	0	0.1	0.1
b) solid goods	0.2	0.1	0.3
c) an air gap	0.4 – 0.6	0.1	0.5 – 0.7

Table 3 Thermal conductivity λ in $\frac{W}{m \cdot K}$

Bulk density of the expanded foam BD kg/m^3	Mean expanded foam temperature in °C			
	+ 50	+ 10	± 0	– 50
15	0.042	0.037	0.036	0.029
20	0.040	0.035	0.033	0.028
25	0.038	0.034	0.031	0.027
30	0.037	0.033	0.031	0.027
35	0.037	0.033	0.031	0.027
40	0.037	0.033	0.031	0.027

When there is direct contact with liquid the thermal conductivity is approximately 0.001 higher

Table 4 Typical values for the internal air temperature in some types of package

a) Bottle package with cooling packs (ice waters)	4 to 10 °C
b) Bottle package with ice bag Ice bag separated from the bottles by a Styropor from panel	> 10 °C
c) Fish package with added ice	3 °C
d) Goods with separate dry ice	– 30 to – 50 °C

Table 5 Specific heat capacity and heat of fusion of different packaged goods

Packaged goods		Density in kg/dm^3	Specific heat in $kJ/(kg \cdot K)$	
			before solidification	after solidification
Beer		1.02 – 1.04	3.77	–
Butter		0.95	2.51 – 2.68	1.26
Eggs		1.09	3.18	1.67
Ice		0.88 – 0.92	–	2.09
Ice cream		–	3.26	1.88
Fish,	fresh	1.00	3.43	1.80
	smoked	–	3.18	–
	dried	–	2.26	1.42
	oily	–	2.85	1.59
	frozen	0.90	–	–
	quick frozen	1.00	–	–
Meat,	beef, fatty	0.92	2.54	1.49
	beef, lean	1.00	3.25	1.76
	veal	1.00	2.95	1.67
	mutton, fatty	0.92	2.51	1.46
	mutton, lean	1.00	3.05	1.72
	pork, fatty	0.92	2.13	1.34
Poultry		–	2.93 – 3.18	1.67
Vegetables		0.3 – 0.8	3.35 – 3.89	1.76 – 2.05
Cheese,	low-fat	–	2.85	1.67
	full-fat	–	1.88 – 2.51	1.26
Potatoes		–	3.55	1.76
Margarine		–	2.72 – 2.93	1.46
Milk		1.03	3.93	2.51
Fruit		0.8	3.64 – 3.89	1.72 – 2.09
Oil		–	1.67	1.46
Cream		1.02	3.56	1.51
Lard		0.9 – 0.97	2.51	1.67
Chocolate		–	3.18	–
Water		1.00	4.18	–
Wine		1.00	3.77	–
Sugar		1.58 – 1.61	–	1.26

		Freezing point in °C	Density in kg/dm^3	Specific heat at 0 °C in $kJ/(kg \cdot K)$	Heat of fusion in kJ/kg
Ice		± 0	1.0	2.09 (ice)	335
Aqueous common salt solution					
Wt.% of salt	7.0	– 4.6	1.05	3.824 (liquid)	312
	13.6	–10.4	1.10	3.586 (liquid)	289
	22.4	– 21.2	1.17	3.339 (liquid)	260
	26.4	± 0	1.20	3.247 (liquid)	247
Dry ice					
commercial		– 78.5	1.5 – 1.55	–	573
“snow”		– 78.5	1.53	–	573

Note

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Technical Information

Styropor®

810

BASF Plastics

28689 May 1994

8 Recycling/Disposal

Recycling and disposal methods for used expanded Styropor

The special characteristics that distinguish cellular material made from Styropor (expanded Styropor) have secured for it two main fields of application:

- in building, as thermal insulation and ultralight material;
- in packaging, as a versatile material fulfilling several functions.

Building

Building is becoming ever more subject to the needs of energy saving, noise prevention, and environmental protection, all finding their embodiment in legislation – e.g. in the German Thermal Insulation Order. Expanded Styropor offers ways to meet these new or revised requirements.

Builders will also have to observe more stringent rules about waste management in future. German legislators are particularly active, introducing a Building Waste Order, Communal Waste Technical Regulations, and a Recycling Economy Act. In practice, this means *demolition* will be replaced by *dismantling:* the trade will have to take back and reuse salvaged materials.

Little scrap expanded Styropor is produced in new building work, but the material has now been in use for forty years, and a certain amount of scrap will result from rebuilding and demolition. All this scrap Styropor can be put to good use.

Packaging

Styropor packaging is used to protect goods of all kinds in transit, a function for which it is well qualified. Like all other packaging materials, expanded Styropor that has served its initial purpose may be subject to legal rules – e.g. the Packaging Order in Germany (as well as the Communal Waste Technical Regulations and the Recycling Economy Act mentioned above).

In the case of expanded Styropor scrap, both recovery of useful material and ultimate disposal can be accomplished in ways that are both ecologically and economically satisfactory. The methods employed are of proven value. The most important of those in use today are described below.

1 Reworking during manufacture of expanded Styropor

Scrap material arising during the manufacture of expanded Styropor block and mouldings can often be reworked, subject to the need to avoid alteration of the properties of the finished product.

The scrap must be clean, and it has to be ground to the appropriate particle size before use.

Grade	Uses	Size range	Sieve size
I	Soil improver	4 – 8 mm	12 mm
II	Composting aid	6 – 12 mm	30 mm
III	Field drainage	8 – 25 mm	40 mm

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2 Styromull®

2.1 Manufacture

Styromull consists of graded fragments obtained by size reduction of scrap expanded Styropor – e.g. discarded packaging. Depending on the type of rotary cutter employed, the particle size may be anything between 1 mm and 30 mm.

Properly made, Styromull is a valuable product. The principal requirements are:

- a range of particle sizes found through experience to suit the intended application;
- the mass fraction of oversize and undersize particles should not exceed about 40%.

The particles are graded by screening with sets of sieves selected in accordance with the table on page 1. The sieves can easily be changed.

2.2 Soil improvement

Using Styromull to improve soil exemplifies the way in which scrap can serve a new purpose consistent with protection of our environment. In Germany, Styromull is a recognized soil improver under the terms of the Fertilizers Act of 1977.

This tried and tested application of Styromull has existed for decades. It encompasses use

- in soil for potting and growing plants,
- as a soil improver,
- for drainage,
- as a composting aid.

Styromull is odourless, chemically neutral, and compatible with all plants. It helps make horticultural soil stand watering better, lightens heavy soils, and helps drain waterlogged soils.

Styromull is currently being used:

- in industrially produced propagating composts and soil improvers;
- as a component of mixtures used for propagation and growing in nurseries, produce gardens, and garden centres;
- in orchards and vineyards, and for landscape gardening, sports fields, and riding centres;
- where planting conditions are extreme, as in roof gardens and urban roadside flower beds;
- as a filter material for pipe drains;
- as a filler for slit drainage;

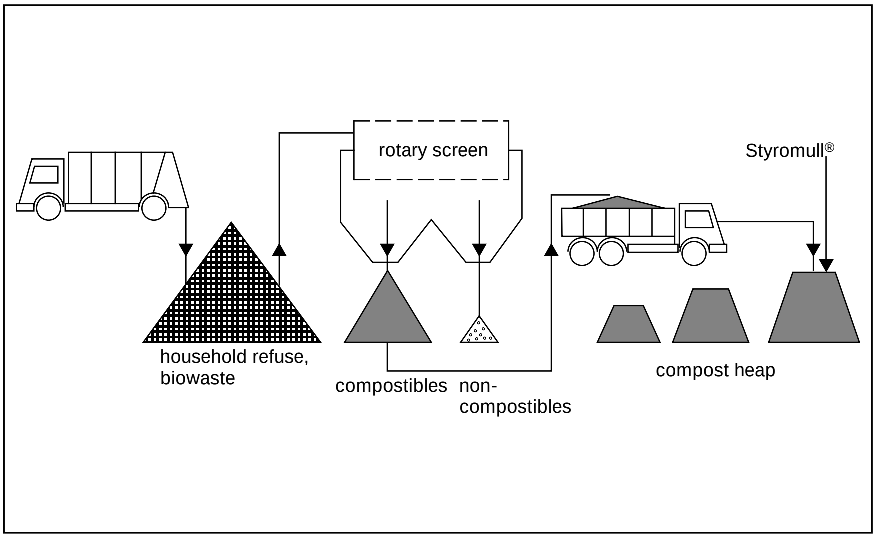


Fig. 1 Large-scale composting

- as an aid to composting household refuse, biowaste, and difficult organic material such as cuttings from grassy road verges.

Composting involves the partial decomposition of organic waste – which may include matter of animal origin – by aerobic microorganisms, leaving humus that may be used as a soil conditioner. The process can be accelerated by the incorporation of Styromull (3–5 parts by volume to 20 parts by volume of waste).

The Styromull is a bulking agent, increasing microbial activity through improved aeration. The temperature range in which breakdown is rapid is attained sooner, and the temperatures reached are also high enough for sanitization of the compost. Stacks containing Styromull need turning less often, which reduces expense and also cuts down the release of odours.

Cellular polystyrene does not rot, even in a compost heap. The most that can happen to the Styromull is some mechanical size reduction, to which microorganisms may contribute.

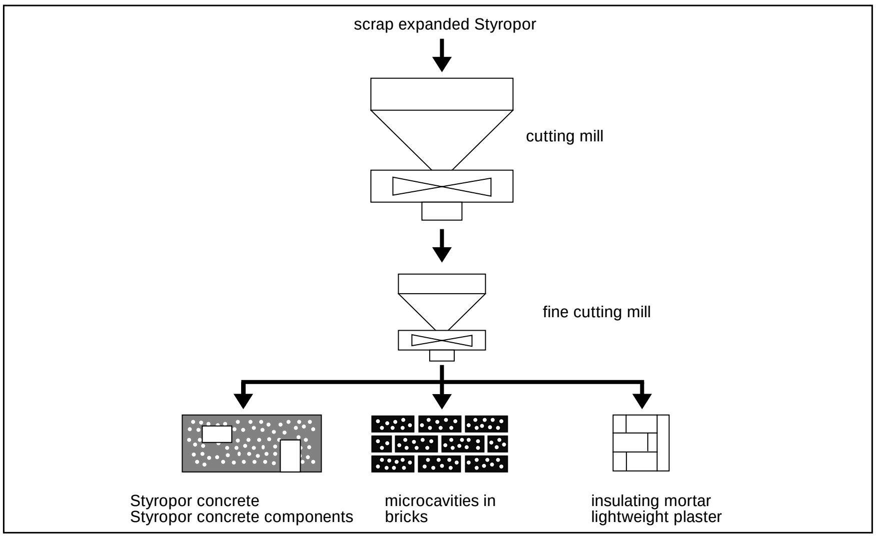


Fig. 2 Reuse in building

3 Reuse in building

In the building industry, scrap expanded Styropor has a number of interesting uses as ultra-light-weight aggregate or cavity former (cf. Fig 2).

In all these applications, particles of the cellular polystyrene are embedded in a matrix – usually loadbearing – of mineral material. To ensure that the building material has the required properties, the quantity, particle-size range, and particle shape of the comminuted cellular polystyrene must be carefully controlled.

A variety of rotary cutters and screens can be used to produce Styromull. It is essential that the dust and fines produced during grinding be removed from the aggregate.

(a) Forming microcavities in clay firebrick

In the Poroton® process, brick clay is mixed with particles of scrap expanded Styropor (size 1 – 4 mm) before being extruded, cut by wires, and fired. The quantity of ground scrap corresponds to about a third of the volume of the brick. The air-filled voids left behind when the brick is fired increase its thermal resistance considerably and reduce its weight.

(b) Styropor concrete

'Expanded polystyrene particle aggregate' is a well-known term that did not exist until Styropor concrete was introduced. In the current process now, the ground expanded Styropor scrap (size 1 – 4 mm) is incorporated in the concrete mix and remains in the hardened concrete matrix. By varying the density of the concrete between 300 kg/m^3 and 1000 kg/m^3, a range of building materials offering varying degrees of thermal resistance, strength, noise attenuation, and fire resistance may be produced (cf. Fig. 3). Styropor concrete is classed as incombustible (Class A 2) in accordance with DIN 4102 Part 1.

(c) EPS insulating mortar for rendering

EPS insulating mortar for rendering is defined in DIN 18550 Part 3 as a mixture of expanded polystyrene beads (size 1 – 3 mm), mineral binder (cement, lime), and admixtures. It has been found that replacing – at least partially – expanded beads by ground scrap from Styropor foam of the appropriate particle size has no deleterious effects. The mortar is applied as an undercoat 30 – 60 mm thick, usually by spraying (cf. Fig. 4). A conventional finishing coat is applied about a week later, giving the undercoat time to harden.

Fig. 3 Styropor concrete

Fig. 4 Rendering with EPS insulating mortar

(d) Lightweight plaster

Lightweight plaster containing fine expanded Styropor beads, usually supplied as a dry mix, has a greatly reduced modulus of elasticity when hardened. It can be used externally as a base coat or internally, and its main advantage is that it is much less subject to cracking than conventional external render or internal plaster. It is also easy to work and covers well. The expanded Styropor beads can be replaced in part or wholly by finely ground Styropor foam scrap.

4 Recovery of polystyrene

Since expanded Styropor foam consists of practically nothing other than polystyrene – a thermoplastic polymer – and air, the polystyrene can be recovered from scrap simply by compacting, melting, and degassing. Purpose-designed single-screw and twin-screw extruders and rotary compacting and sintering machines are available for this.

The quality of the recovered polystyrene depends on both the type of equipment used and the presorting procedure, which involves

- presorting to remove foreign materials and dirt, and
- detection and removal of metal.

The recovered polystyrene has the greatest number of uses if:

- the melt is not kept hot for too long, does not become too hot, and suffers minimum shear (this depends largely on the screw geometry);
- the melt is degassed thoroughly;
- the melt is automatically filtered;
- the pellets are cut cleanly, free-flowing, and free from dust.

The recovered polystyrene pellets can be made into new products, so the way is open for repeated reuse.

5 Energy recovery

Burning expanded Styropor in the open produces copious black smoke and is not permissible, even for the most soiled scrap. But in modern municipal incinerators, which afford a good supply of air and temperatures of about 1000 °C (cf. Fig. 5), combustion is complete and leaves neither ash nor soot.

The products of combustion are carbon dioxide and water vapour, except in the case of building insulation – which has been made flame-retardant by the inclusion of minor amounts of halogen compounds. In this case, trade amounts of halogen halides can be detected, but they have no significant effect on the composition of the exhaust gases.

If scrap expanded Styropor is broken up roughly and mixed with other waste, it reduces the quantity of fuel needed to sustain combustion: 1 kg of Styropor is thermally equivalent to 1.2 – 1.4 litres of fuel oil, depending on the density and calorific value of the oil.

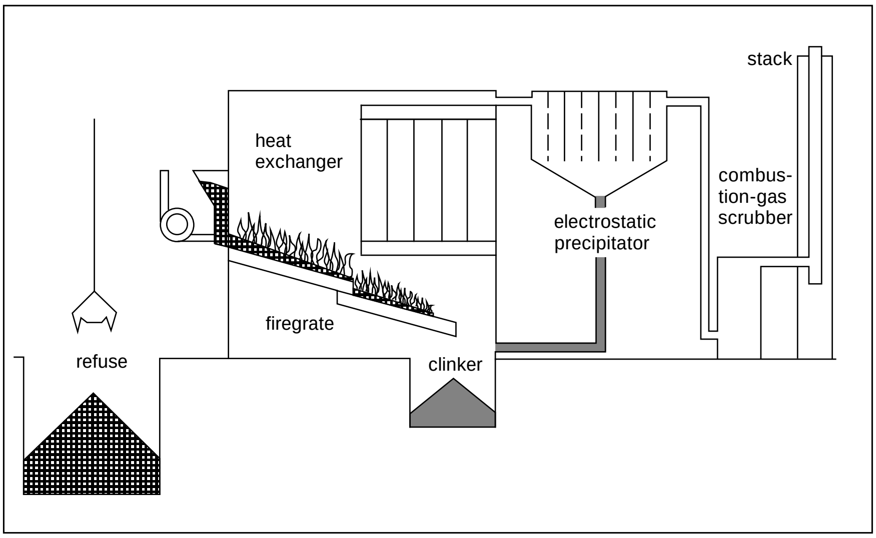


Fig. 5 Modern municipal incinerator

Some large Styropor convertors use ground rejected material, offcuts, etc. to fire their steam generators. For this purpose, the boiler must be fitted with a special firing box and the appropriate control devices. The operators of such boilers must also take special care that the composition of the exhaust gases does not contravene local regulations.

6 Controlled tipping (landfill)

Quantities of discarded scrap expanded Styropor are not always sufficient to justify separate collection and utilization. The scrap can then be tipped with communal refuse, preferably broken up to make compaction easier.

When included in sanitary landfill (cf. Fig. 6), scrap expanded Styropor assists aeration and dewatering of organic refuse and accelerates its decomposition. In doing so it reduces both the risk of overheating and smouldering and the formation of malodorous products. It does not itself give off any harmful substances and therefore does not pollute the air, the ground, or ground water.

7 Summary

Scrap expanded Styropor is not a burden on our environment, as this survey of the principal ways in which it is being handled shows. It serves as a fuel, either in municipal incinerators or for firing industrial boilers, which results in the economic use of its high heat content. Its polystyrene content is also being recovered, for use in many ways. In finely divided form it is being used as a soil improver and composting aid (Styromull) or as ultra-lightweight aggregate in concrete and mortar.

8 Relevant legislation in Germany

Recycling Economy Act
Communal Waste Technical Regulations
Solid Waste Charges Act
Packaging Order
Building Waste Order

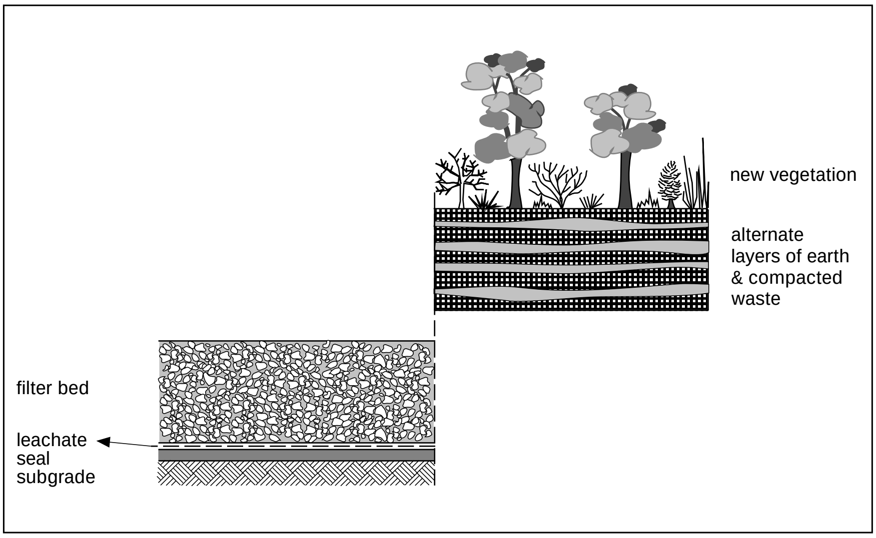


Fig. 6 Controlled tipping (landfill)

9 Further reading

Further information on plastics scrap and waste is contained in various publications that can be obtained on request from the following organizations:

BELGIUM

Association of Plastics
Manufacturers in Europe
Avenue Louise 250
1050 Brussels

GERMANY

Verband Kunststofferzeugender
Industrie e.V. (VKE)
Karlstrasse 21
60329 Frankfurt

Verband der Chemischen
Industrie (VCI)
Karlstrasse 21
60329 Frankfurt

Gesamtverband Kunststoffverarbeitende Industrie e.V. (GKV)
Am Hauptbahnhof 12
60329 Frankfurt

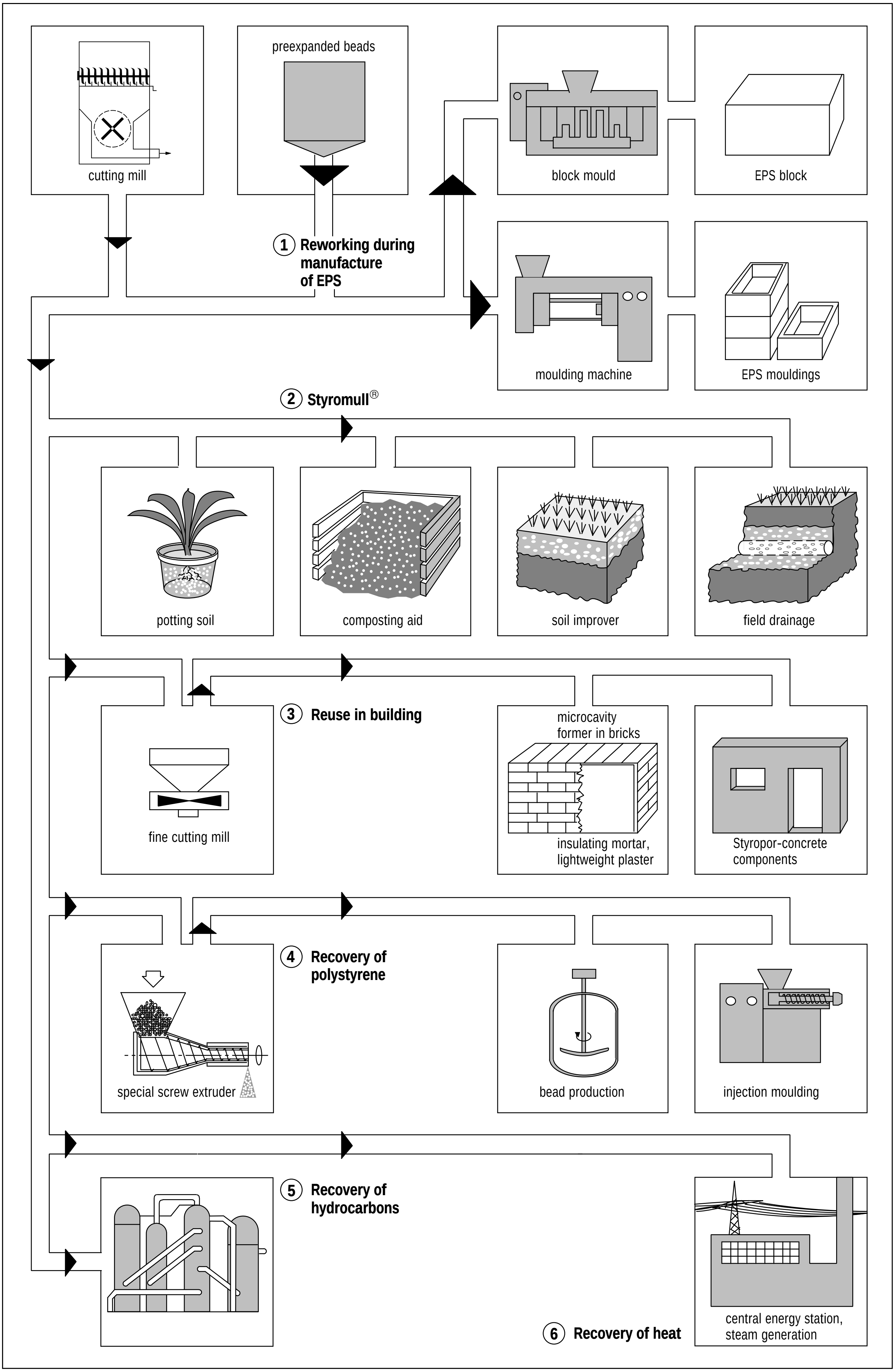
Industrieverband Verpackung und
Folien aus Kunststoff e.V. (IK)
Kaiser-Friedrich-Promenade 87
61348 Bad Homburg

Industrie-Verband Hartschaum e.V.
(IVH)
Kurpfalzring 100 a
69123 Heidelberg

Note

The statements in this publication are based on our present knowledge and experience. They do not relieve processors of the responsibility of carrying out their own tests, because many factors that could influence the results may arise during processing and application. Neither do they imply any legally binding assurance of certain properties or of suitability for a particular purpose. The recipient of our products should respect any proprietary rights and observe existing legislation.

Utilization of scrap expanded Styropor



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Styropor®

8 Recycling/Disposal

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Production and properties of Styromull®

Styromull is a mixture of flakes obtained by shredding expanded Styropor waste or used packaging. In conformance with a German law on fertilizers passed on 15 November, 1977, Styromull is an odourless, chemically neutral soil improver that is compatible with plants. It allows the consolidation of horticultural soils, loosens heavy soils, and allows soggy soils to be more effectively drained.

Its applications are

- pipe and mole drainage
- lawns and playing fields
- soil improvement and landscaping
- compost activator for household, biological, and garden refuse.

Styromull acts as a filter material and improves the permeability and aeration of the soil.

Other applications for Styromull include the following.

- The industrial-scale production of horticultural composts and soil improvers.
- Growing vegetables under glass, cultivation of ornamental plants, and tree nurseries.
- Light reflectors in greenhouses.
- Planting on critical sites, e.g. roof gardens, underground car parks, and municipal arbours.

Production

A number of manufacturers offer machinery for the comminution of expanded Styropor. The size of the flakes obtained from these machines lies between 1 mm and 30 mm.

Styromull produced for a given purpose must satisfy certain quality specifications.

- The size of the flakes must conform to the standard for the given application.
- About 60% of the flakes must lie within the specified grain size distribution.

Sets of screens of various sizes are required to attain the desired particle size distribution at given speeds and should be readily interchangeable.

Quality	Flake size (mm)	Size of perforations in screen (mm)
I – for substrate and soil improvement	4–8	12
II – for composting	6–12	30
III – for drainage	8–25	40

Properties

The size of the flakes is restricted to the 4 – 25 mm range. The apparent density of loosely packed flakes is 12 – 20 kg/m^3. The chemical properties are identical to those of polystyrene. In other words, Styromull is absolutely compatible with plants and does not rot. It does not react in anyway whatever with the soil, plant roots, or the groundwater.

Styromull is compressible. A compressive load of 2 x 10^{-2} N/mm^2 – corresponding to that exerted by soil of one metre depth – reduces the volume of an initially loose layer of Styromull to about 50 % of its original value. If it is only lightly compressed, it partly recovers when the load is removed.

The permeability of Styromull conforms to Darcy's law:

$Q = khA/d$

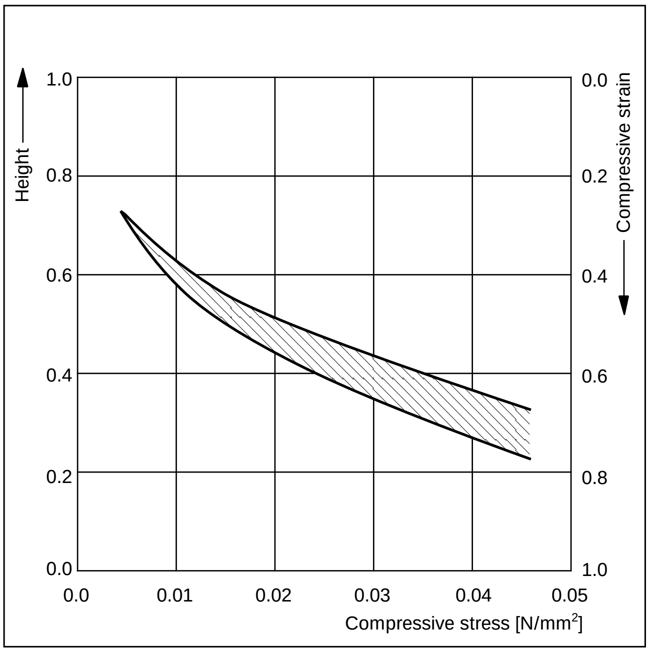
where

k = permeability [cm/s]
Q = volume flow rate [cm^3/s]
A = cross-sectional area of the Styromull bed [cm^2]
d = thickness of the Styromull bed [cm]
h = pressure head of water above the Styromull bed [cm]

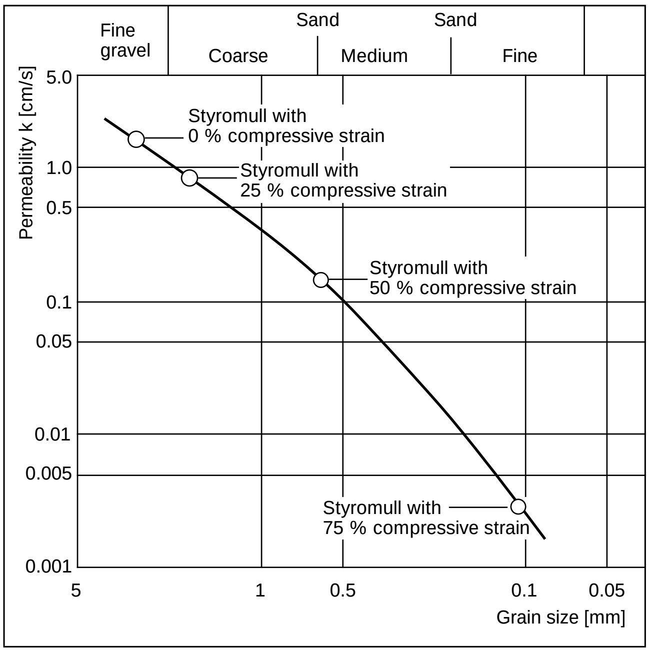
At room temperature, *k* is 1.8 cm/s for uncompressed Styromull and 0.1 cm/s for Styromull compressed to 50 % of its original volume. These figures correspond to the permeability of mineral soils with particles of 3 mm to 0.6 mm size, i. e. fine gravel to coarse sand.

Styromull improves the permeability of any earth with which it is mixed. If the soil has to be significantly loosened, the proportion of Styromull should be at least 10 % by volume.

Note



Reduction in volume on the application of compressive load



Permeability

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Drainage with Styromull®

1. Mole drains

The main application for clean, uncontaminated Styromull in agriculture is the melioration of soggy soils. In waterlogged soils, impermeable layers underly the loam and impede the passage of the water and air required for plant growth. Topsoil that is separated from the subsoil by impermeable layers rapidly becomes sodden or even flooded after rainfall, but dries out during periods of drought. Consequently, the plants suffer the effects of both extremes. The impermeable layer can be broken up by means of a mole plough to permit drainage, but the channels thus formed tend to close again. This can be prevented by filling the channels with Styromull and thus effecting mole drainage.

If the gradient permits, water can flow through these drains filled with Styromull. The only difference between them and perforated drainpipes is that they offer greater resistance to flow; but the area of contact with the soil is also greater, and the water enters the channel more easily.

Circular or rectangular cross-sections ?

Rectangular cross-sections are preferable to circular, because they offer the following three decisive advantages.

1. The area of contact with the soil is greater, i. e. 30% for a rectangle with a height : width ratio of 3 : 1.
2. The channel can extend vertically through any impermeable layer.
3. Local deviations in the gradient of the channel are unimportant.

Thus channels filled with Styromull can allow excess water to be drained from waterlogged soils through any impermeable layers into the subsoil. If the gradient is adequate and the channels are not too long, the water may also run off horizontally. Styromull mole drains can be regarded as a characteristic element in land drainage and can be used in conjunction with branches, collector pipes, interceptors, drainage boards, and outfall ditches. They represent a very easy means of permitting the free passage of air and water through heavy soils, preventing excessive surface run-off on slopes, and for ensuring the drainage required for vineyards, orchards, and lawns.

Channels of 50 – 80 cm depth can be formed by drawing a mole plough through the soil with a tractor. They can be simultaneously filled by running Styromull through a hopper into a vertical shaft fitted behind the plough blade. The Styromull thus falls down the shaft into the channel.

The heavy, often compacted soils in many orchards and vineyards cannot always be channelled by this means, because there is seldom sufficient space between the rows of vines or fruit bushes to apply the high tractive force required (except by cables). Under these circumstances, the channels can be cut by a tilting blade plough drawn and powered by a small vineyard tractor. In this case, too, the channels, e. g. of 10 cm width, can be filled with Styromull in the same operation.

The channels cut into the subsoils for large lawns are usually very closely spaced, i. e. at intervals of 60 to 120 cm.

Styromull mole drains with the appropriate gradient cannot simply run direct into an outfall ditch, because the Styromull would be washed out. The connection between the end of the channel and the outfall is made by a perforated flexible drainpipe. A ca. 5 m length of the pipe is laid at the foot of the channel and is completely embedded in Styromull over a distance of about one metre from the outfall. Thus, in effect, the mole channel terminates in a bed of Styromull, and the water runs through the perforations into the drainpipe, which then conveys it to the outfall. The upper end of the pipe must be plugged.

About 6 m^3 of Styromull are required for each 100 m of channel 10 cm width and 60 cm height.

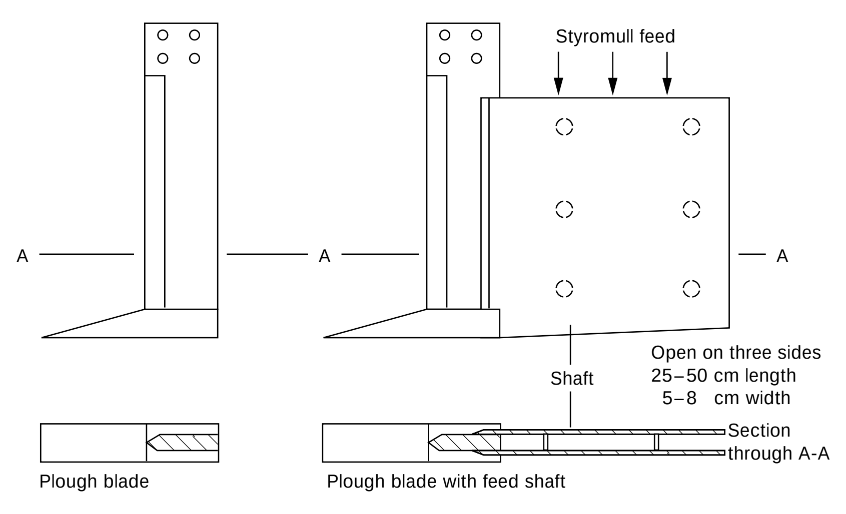
2. Pipe drainage

Pipe drains are effective only if the topsoil above them is sufficiently permeable to allow the passage of water. If it is not or if impermeable layers intervene, drainage will be unsatisfactory. In water-logged zones mole drainage is combined with pipe drainage in impermeable soils. Alternatively, drainage boards can be stood on end in the soil alongside the drainpipes.

Hold-ups also occur in soils whose permeability just suffices for the passage of water. This applies particularly to zones in which the water converges, i. e. in the immediate vicinity of the drainpipe perforations. The permeability in these zones must be very high, and this can be achieved by embedding the pipes in Styromull.

The amount of Styromull required for this purpose is 1 – 3 m^3 for each 100-m length of flexible drainpipe with rated diameters of 50 and 65 mm. It depends on the method adopted for laying. Styromull can be metered most accurately if a mole plough is used to lay the pipe. If the pipe is laid in an open trench, the amount of Styromull required for each 100 m is about 2 – 3 m^3.

Note



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Laying out lawns and construction of sport grounds using Styromull®

Lawns are often laid on heavy soils. The severe punishment that they often have to withstand leads to dense compaction that hinders or completely suppresses aeration of the soil and run-off of water. The turf becomes patchy, is no longer hard-wearing, and thus cannot fulfil its functions.

The soil must be sufficiently resilient to avoid the dense compaction brought about by repeated pounding. It has been demonstrated in practice that this aim can be realized by adding Styromull to the topsoil. The following addition rates are resorted to in standard practice.

Heavy soils (clay and heavy loam)

Owing to the lack of permeability, the restricted aeration, and the pronounced tendency to compaction of these soils, the admixture of 20 – 40 litres/m^2 of Styromull is recommended.

Medium soils (light to sandy loam)

In view of the low permeability and the tendency to compaction of these soils, the admixture of 20 – 25 %, in terms of volume, of Styromull is recommended.

Light soils (sandy loam to sand)

These soils have adequate permeability. Additional loosening would further reduce the ability to store water and lead to damage of the turf during long periods of no rainfall. For this reason, Styromull should be mixed into the soil only in those spots on the playing field that are subject to heavy wear and thus compaction. The proportion recommended in this case is 10 –15 %, expressed in terms of volume.

Subsoil

If the subsoil is by nature not very permeable, steps must be taken to ensure that excess water can run off, i. e. Styromull mole drains should be laid at intervals that depend on the consistency of the subsoil. If, in addition, the mean annual rainfall is very high, it is recommended that flexible Vinoflex® drainpipes be laid at right angles to the mole drainage system.

Practical hints

After the site has been levelled, the Styromull mole drains are ploughed in to the depth of the drainpipes. The drainpipes themselves are installed and covered copiously with Styromull.

If the upper topsoil down to a depth of 20 cm has to be meliorated, the amount of Styromull required in keeping with the soil consistency is spread over the surface and worked uniformly in, preferably with a low-speed rotary cultivator.

A layer of Styromull of 1 cm depth spread over an area of 100 m^2 corresponds to a volume of 1 m^3. Hence if the Styromull is to be mixed with the topsoil in proportions of 25 %, the thickness of the layer of Styromull to be applied is 5 cm. If the cultivators cannot work in this layer to the requisite depth, half the amount of Styromull is applied and worked in with the cultivator. Afterwards, soil is ploughed to a depth of 20 cm. The second half of the Styromull is then spread over the soil and worked in. Steps must be taken to ensure that the meliorated topsoil tallies with the subsoil.

Turf of exceedingly high quality can be obtained by removing the topsoil and by working 30 %, expressed in terms of volume, of Styromull into the upper 5 –10 cm of the subsoil in order to impart greater resilience.

In view of the extremely great differences in the quality of soils, it is impossible to present a typical figure for the Styromull requirements. The following numerical example has been taken completely at random.

Let us suppose a difficult case in which an area of 8000 m^2 has to be turfed. The topsoil is heavy and has to be mixed with 25 %, expressed in terms of volume, of Styromull to a depth of 15 cm. Suppose also that the subsoil is not very permeable and has to be drained (before the topsoil is applied) by a Styromull mole system with channels spaced at intervals of 80 cm. The requirements in this case are as follows.

(a) For mole drainage with Styromull channels of 10 000 m length, 0.30 m height, and 0.08 m width = 240 m^3 Styromull

(b) For the topsoil
80 x 4 m^3 = 320 m^3 Styromull

Thus a total of 560 m^3 of Styromull would be required to cover an area of 8000 m^2.

In a less critical case in which the subsoil is sufficiently permeable, the mole drainage with Styromull can be dispensed with and the requirement would be of the order of 320 m^3 for the 8000 m^2 of turf.

A resilient layer between the subsoil and the topsoil would entail an additional 120 – 240 m^3 of Styromull.

Improvement of existing turf

The aim in this case is to alter the topsoil and the subsoil so that the permeability and resilience meet requirements without unnecessarily destroying the surface and so that the turf can be made available again at short notice.

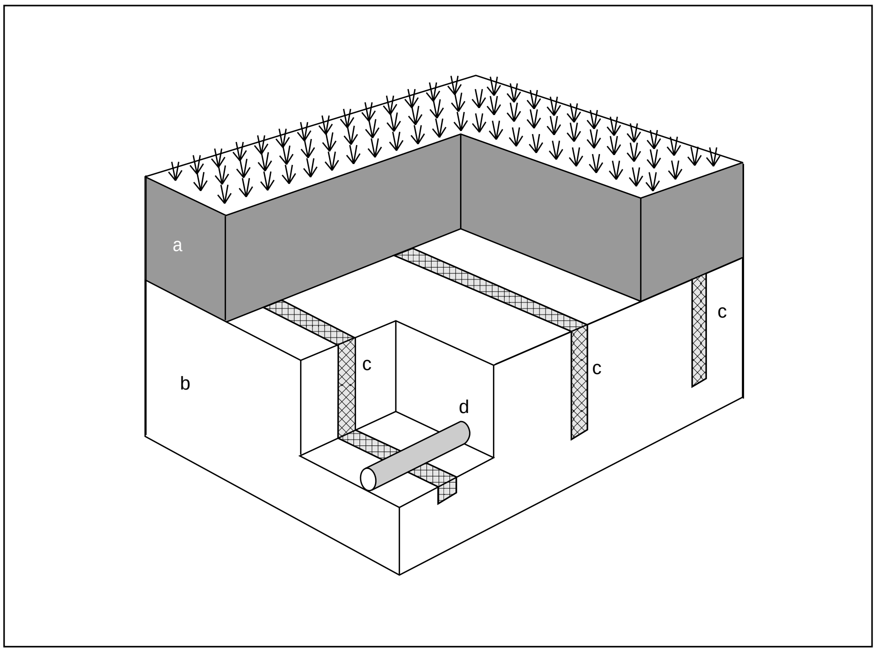
If waterlogging is still in the initial stages and the grass still grows, strips can be ploughed to a depth of about 50 cm and simultaneously filled with Styromull. About 5 m^3 of Styromull would thus be required for a strip of 100 m length. Immediately after they have been filled, the strips can be reclosed by running the tractor wheel along them.

If the turf has worn bare and has been compacted, the topsoil must be reworked. It would be advisable to take advantage of the circumstance by laying mole drainage with Styromull in the subsoil by means of a mole that extends sufficiently below the reworked topsoil. Subsequently, Styromull should be spread over the surface as previously described and worked into the topsoil.

Frequently, badly worn lawns are returfed. Under these circumstances, it must be ensured that the new turf is not laid on a compacted soil. In this case, too, the subsoil should be channelled and drained with Styromull.

A difficulty that mostly exists in the subsequent mole drainage of existing turf is that there are no means for running off the water in the drains. If this is the case, a flexible drainpipe could be laid underneath the mole drains so that any excess water can be run off to the sides of the lawn or playing field. Alternatively, holes can be drilled into deeper, more permeable layers of subsoil and filled with Styropor drainage rods.

Note



Schematic diagram of a turf drainage system

a Topsoil
b Subsoil
c Mole drainage with Styromull
d Flexible drainpipe

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Soil improvement and landscaping with Styromull®

Styromull can be mixed with peat for propagating composts, horticultural earths, and nutrient peat. The mixture that is used for propagation contains 50 %, expressed in terms of volume, of Styromull and 50 % of peat and is enriched with lime and 1 kg/m^3 compound fertilizer, e.g. Nitrophoska® Blue Extra. In propagating composts, Styromull promotes vigorous and rapid root growth by raising the soil temperature, improving aeration, and reducing waterlogging. Rooted cuttings of plants that require high soil temperatures and good aeration should be allowed to grow further in mixtures of Styromull and earth or peat.

Experience has shown that the following proportions of Styromull, in terms of volume, can be recommended.

- Up to 25 %
  for Aphelandra, Asparagus plumosus, Azalea, Cineraria, cyamen, Erica gracilis, Euphorbia pulcherrima, ficus, fuchsia, gloxinia, Primula obconica, monstera, and saintpaulia;
- Up to 50 %
  for adiantum, Anthurium scherzerianum, epiphytic bromeliaceae (e.g. vriesias), and cypripedium;
- Up to 75 %
  for epiphytic orchidaceae.

The Styromull is simply mixed with the earth or peat compost (or, for orchids, the sphagnum moss). Large Styromull flakes are particularly suitable for cultures that prefer a coarse substrate, e.g. anthuriaceae, epiphytic bromeliaceae, and orchidaceae. Styromull can be mixed quicker and better with peat than with earth, and small flakes give more intimate mixtures than large ones.

Since Styromull neither contains nor takes up plant nutrients, the amount of fertilizers added to mixtures containing it must be determined on the basis of the total volume of the mixture. Good results have been obtained by mixing Triabon® and Basacote® into the substrate.

It is an advantage to mix Styromull with peat. The flakes reduce the risk of premature waterlogging, particularly if the soil is mechanically irrigated. The useful life of the peat can be more than doubled in this way. Good thermal insulation provided by Styromull benefits the plants, particularly in winter. The evaporation rate is also reduced, and measurements have demonstrated that Styromull in the soil significantly reduces nocturnal cooling.

Styromull is worked into heavy soils at a rate of 10 – 20 litres/m^2. It is unnecessary for sandy, permeable soils.

Since the material is very light, it should be spread out uniformly when there is no wind. Immediately afterwards, it should be worked into the soil with a plough, disk harrow, rotary cultivator, or other suitable equipment. In windy or stormy weather, the Styromull should be laid in the plough furrows and ploughed in immediately. Alternatively, it should be wetted, e.g. with a 10% solution of Nitrophoska Blue Extra, so that it lies on the ground like damp peat.

In some cases, the soil must be loosened to some depth, e.g. in replanting vineyards and orchards. Under these circumstances, it would be worthwhile to work correspondingly larger amounts of Styromull into the soil down to the depth reached by the plough.

The most favourable times for applying Styromull over large areas are autumn and winter. If increased quantities are required for thoroughgoing improvement, the Styromull should be divided up and worked into the soil in two or three lots in order to ensure better mixing. For simplicity's sake, the Styromull can be incorporated together with enriched manure. Although the amounts thus incorporated in the one application are small, they will mount up if the manure is applied regularly, because Styromull does not rot. Hence, over the years, even the heaviest soils become permanently loosened.

Styromull attracts particular interest if the soil presents difficulties that detract from the economics of viticulture, pomiculture, and landscape gardening. The soil in vineyards and orchards is often compacted, soggy, and inadequately aerated. If Styromull is applied in the corresponding amounts, even the heaviest and wettest of soils are loosened and become friable. Permanent improvements can thus be expected.

In fruit-growing, Styromull is primarily indicated if the structure of the soil does not permit satisfactory early growth and the trees show signs of chlorosis.

Styromull is also suitable for loosening soil that has been compacted by earthmoving machines.

Other applications with a high potential for Styromull arise in landscape gardening. The soil on a former building or construction site that has to be landscaped has more often than not been badly mauled and compacted by excavators, tractors, and heavy vehicles. Considerable efforts are required to bring these soils into condition for cultivation. Styromull allows the soil to be loosened more easily and rapidly than by conventional methods. The improvement is also more lasting.

Styromull's efficiency in promoting mellowness can be turned to good account if bulbs (e.g. irises and lilies), bushes and conifers, which require a light, well-drained soil, have to be planted in a heavy soil. If Styromull is introduced into the hole that has been dug to receive them, the plants take full root much more quickly.

Great benefits can be derived from Styromull when trees have to be planted to cast shade on roadways, playgrounds, parks, or paved recreation grounds. In these cases, the tree is usually planted in a “tub”, and air access to the roots is often restricted by a stone or asphalt cover. The situation can be remedied and the soil can be permanently aerated by adding Styromull in proportions of 20 to 30% by volume.

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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Styromull® as a composting aid

Composting involves the degradation of waste organic matter into humus. This substance, valued as a soil conditioner equalling peat, is formed through the activity of the microorganisms living in and on the soil, including filamentous bacteria (actinomycetes) and various other bacteria and fungi. This activity may be promoted by a number of creatures, particularly woodlice, various mites and collembolan insects, and earthworms, which live on digestible components of the waste and either discard or excrete the rest in finely divided form. The final degradation of the complex organic matter is however brought about by the microbial enzyme complexes.

The aerobic microorganisms involved in the formation of humus need an adequate supply of oxygen. If it is not available, anaerobic microorganisms may take over, leading to putrefaction – a form of breakdown in which a principal product is a gas, methane, which may carry with it evil-smelling byproducts.

Other requirements are an adequate proportion of water, low acidity, and a high enough ratio of nitrogen to carbon, but these can do no good if insufficient air enters.

A good, well aerated compost heap can easily be built up by hand – sodden material between dry layers, fine between coarse, nitrogen-deficient between nitrogen-rich, and so on – but the labour involved is considerable. If big enough, such a heap will soon begin to function through the exponential growth of the colonies of microorganisms. As microbial activity increases, so does the temperature, which rises dramatically, first to the level preferred by the mesophilic organisms and then possibly to 60 – 70 °C, where activity drops off, owing to the lower numbers and lesser diversity of the thermophilic organisms (only some like it hot).

A considerable but limited rise in temperature is held to be desirable, since it inactivates both pathogenic organisms and seeds through coagulation of protoplasm. The compost is thereby sanitized.

As the organic matter decomposes, the compost heap tends to sink in, cutting off air that would otherwise replenish the diminished supply of oxygen. This reduces the activity of aerobic organisms and may lead to conditions under which anaerobic bacteria can start the formation of smellier products. To counter this, the heap may be turned frequently, admitting fresh air. A simpler and less labour-intensive procedure is to incorporate an inert, nonabsorbent bulking agent at the start, so helping to create air pockets and open channels.

Styromull: an ideal bulking agent

Styromull, consisting of small pieces of expanded polystyrene, seems an obvious candidate for the task of keeping compost heaps open, and in fact it has proved to be a particularly useful composting aid, largely because it does not itself decompose.

Styromull is made from scrap expanded Styropor, particularly Styropor packaging, which is passed through rotary knives. For addition to waste to be composted, about 60 % of it should pass a 12 mm screen but be retained by a 6 mm screen.

The proportion of Styromull mixed with the organic waste should be from 15% to 25% by volume, depending on the moisture content of the waste. Mixing should be as even as possible. Aeration of the material is then considerably improved, and the heap does not need to be turned, or at least not so frequently. Incorporation of Styromull accelerates the activity of aerobic microorganisms, bringing about quicker and more complete conversion of waste to useful humus. As a secondary effect, there is a reduction in leachate, which might otherwise affect underlying soil adversely.

Formation of virtually odourless, sanitized soil conditioner is measurably quicker if Styromull is mixed with the compostable organic waste.

Fig. 1
Turning a compost heap that includes 15–25% Styromull by volume

Summary

Biowaste, grass cuttings, and other green garden waste can be composted in a short time if mixed with about a fifth of their volume of Styromull. The product is a valuable humus-rich soil conditioner. Decomposition is accompanied by neither nasty smells nor pollution by leachate.

The Styromull can be obtained from any scrap expanded Styropor (including used fish boxes), even if it is soiled with organic matter. Private households can mix kitchen and garden refuse with old Styropor packaging broken up by hand or with a machine used for chopping up stalks and twigs.

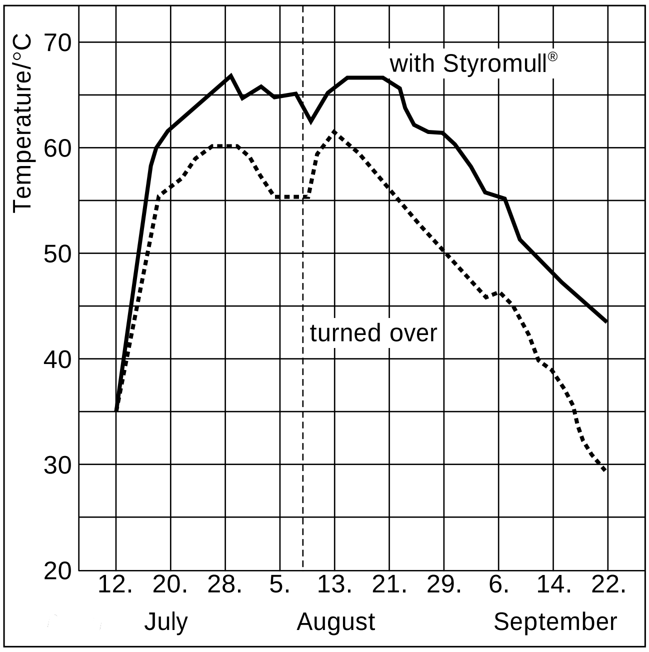

Fig. 2
Temperatures in compost heaps

Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors of the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

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