Packaging with Styropor®

BASF Plastics key to your success

BASF The Chemical Company
### Packaging with Styropor®

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Fig. 1: Packaging line for television sets

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

**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 August 14, 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 polymerization.

**The Styropor® range**

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

**Styropor® P**

Used for making blocks, boards and molded parts.

**Styropor® F**

Flame-retardant materials recommended for making flameresistant blocks and boards in accordance with DIN 4102, as well as molded parts complying with the requirements of Group F 1 according to DIN 53 438, Part 3.

**Neopor®**

Products with flame retardant treatment (see Styropor® F). Expanded foams made from Neopor® are silvery gray in color and have enhanced thermal insulation properties.

**Peripor®**

Products with flame retardant treatment (see Styropor® F). Expanded foams made from Peripor® have particularly low levels of water absorption.

Styropor®, Neopor® and Peripor® are expandable polystyrenes made by BASF. They are 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.

Fig. 2: Size comparison between the raw material and the preexpanded Styropor®

Fig. 3: Increase in volume when Styropor® is preexpanded
From Styropor® to the finished foam

Styropor® is converted into blocks and moulded parts in three stages:
• preexpansion,
• intermediate aging and
• molding.

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 / m³ (39 pcf) to about 10 kg / m³ (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 / m³ (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 equalized 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.

Molding
The cavity of the foaming mold, which is usually in two parts, is now filled pneumatically with the prefoamed material. The mold walls are equipped with holes or slits to connect the mold cavity to the steam chamber. Foam molding 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 mold walls so that they fuse together.

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

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

Fig. 4: Continuous prefoaming unit
Fig. 5: Molding of prefoamed beads
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 economical 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.

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 for that is ready testing is obtained.

Elastification
The elasticity of Styropor® foams can be increased as follows:
- by pressing it inside the mold 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. Molded 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.

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 fiber mats can be incorporated in the coating material to make it impact resistant.

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

Transfers, cold and hot bonding labels can likewise be applied to foam using hand operated, semiautomatic or 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 involves combinations with films (Fig. 19, page 15), sheets or moldings made from solid plastics, as well as with paper and cardboard. These can all be laminated immediately after the completion of foam molding, in a downstream unit or, after the molded part has been allowed to age for a while, in a special coating unit.

Labeling

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

A standard name 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 molded.

20 = density = 20 kg/m³ tolerance: ± 2.5 kg/m³

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

F = fire characteristics (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® packaging under the “single grade, clean and dry” slogan, it is advisable to make sparing use of printing ink and coatings.
The physical properties of the material are influenced by its apparent density and how it has been processed.

**Foam properties of relevance for packaging**

A tabular compilation of the most important properties of Styropor® foams is presented in the appendix to the brochure.

**Compressive stress** according to EN 826

The compressive strength of materials which undergo 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, \( \sigma_{10} \) (see Fig. 10) in order to obtain comparable figures.

The compressive strength 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 center. The application advantage of a smooth, slightly compacted outer skin is therefore not made apparent when testing according to EN 826.

**Tensile strength** according to EN 1608

The tensile strength of Styropor® foams increases with increasing density, as shown in figure 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 EN 12089

The flexural strength, too, increases with increasing apparent density, as shown in figure 9. The material’s deflection at break (toughness) decreases with increasing density and degree of fusion.
**Long-term behavior under load**

The material’s deformation depends not only on the amount of pressure but also on the time for which pressure has been applied (Fig. 11).

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 large increase in strength during the first 24 hours is due mainly to the equalization 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.

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

The mechanical properties of the material depend on temperature. Figure 12 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, page 30), as well as on its moisture content.

The specific heat capacity of Styropor® foams is not influenced by their density. In the bulk density range 20 – 30 kg/m³, the resistance to heat deformation according to EN 826 and EN 1605 is only dependent to a small extent on the bulk density (see Table 5). 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. (e. g. bonding with hot bitumen).

The coefficient of thermal expansion is unaffected by density and is around \(5 \times 10^{-5} \text{K}^{-1}\).

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

Water absorption and water vapor permeability

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

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

Electrical properties

Styropor® foam does not conduct electricity. The dielectric constant \(\varepsilon\) 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 \(\delta\) 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 \(10^{14} - 10^{16} \Omega\) (IEC 60093).

Because of the high surface resistance, an electrostatic charge can build up on the surface of some foam components – especially if the atmospheric humidity is low. The surface resistance of moldings can be reduced by adding an antistatic agent during the manufacturing process.

Chemical resistance

(see table 1, page 11)

Styropor®, Neopor® and Peripor® 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 anticorrosive 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 plasticizers, e. g. plasticizer migration in the case of PVC.

If Styropor®, Neopor® or Peripor® have 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 by immersing a piece of Styropor® in the other material and observe what happens. The duration of the experiment can be reduced by raising the temperature of immersion.
Effect of UV light

Styropor® foams, like other plastic 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 effects

Pentane escapes from Styropor® during storage and fabrication. Especially when the foams are being cut with heated wires, measures must be taken to ensure extraction of the resulting vapors, as they contain small amounts of styrene as well as pentane.

The MAK (maximum allowable concentration) for styrene and for pentane should be observed (for details see Technical Information “Expanded Styropor® and the Environment”).

Styropor® foams are not food for animals. Styropor® foams do not rot, are insoluble in water and do not give off any water-soluble substances which could pollute groundwater. 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 time no risk to health has been found.

<table>
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<tr>
<td>Salt solution (seawater)</td>
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<td>Soaps and wetting agent solutions</td>
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<tr>
<td>Bleaching agent solutions, e.g. sodium hypochlorite, chlorine water and hydrogen peroxide</td>
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<tr>
<td>Dilute acids</td>
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<tr>
<td>Hydrochloric acid, 35%; nitric acid up to 50%</td>
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<tr>
<td>Anhydrous acids, e.g. fuming sulfuric acid, 100% formic acid</td>
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<tr>
<td>Caustic soda and caustic potash solutions, ammonia water</td>
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<tr>
<td>Organic solvents, such as acetone, ethyl acetate, benzene, xylene, paint thinners and trichloroethylene</td>
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<tr>
<td>Saturated aliphatic hydrocarbons, surgical spirit, white spirit</td>
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<tr>
<td>Paraffin oil, vaseline</td>
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<tr>
<td>Diesel fuel</td>
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<tr>
<td>Motor fuels (regular and super grade gasoline)</td>
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<tr>
<td>Alcohols, e.g. methanol, ethanol</td>
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<tr>
<td>Silicone oil</td>
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F grades are classified as “flame retardant”. This means that the foam’s flammability and flame spread along the surface have been much reduced. F grades therefore achieve the best possible classification for flammable substances according to various national specifications for building and other materials.

The fire behavior of foam packages made from P grades follows much the same pattern as that of other flammable packaging materials. F grades 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.
Food regulations

BfR, the German Federal Institute for Risk Assessment, publishes recommendations in the German Federal Health Bulletin (Bundesgesundheitsblatt) under the Law on Food and Commodities.

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 monomer used to produce Styropor®, namely styrene, complies with Directive 2002/72/EC and is listed in the new version of the German Ordinance on Materials and Articles of 12/23/1997, including the latest changes of 04/07/2003.

We recommend our Styropor® P moldings and block products for the manufacture of food packaging. The processing and production aids also used in their manufacture are listed in appropriate BfR recommendations for polymers that contain polystyrene.

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 fat-based products such as chocolate, margarine or cream cakes. Here it is best to use some sort of wrapping material like parchment paper, plastic film or aluminum foil.

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 number of industries and for many different types of products. Their main functions can be summarized 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 adaptability 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 vapor, its mechanical properties remain intact
- chemically inert, so that it can be used for food packaging
- easy to mold into almost any shape which helps the packaging designer.

Ease of molding

Foam components can be made in almost any shape for a wide range of packaging applications using the simplest and most economical 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 or exposed to vibration
- impact and stress distributors which evenly distribute mechanical forces across the whole loadbearing surface
- inserts and supports which prevent movement of the goods inside the pack (made of pieces of foam, molded 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 molded.
Many types of packaging

The main uses of Styropor® packages are described below.

- **Packaging inserts**
  These are molded 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 in-house transport containers.

- **Box-type packs**
  With customized inside space: individual portion packs, partitioned packs and packs which protect the contents against heat.

- **Composite moldings**
  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, and for gift and display packs.

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

- **Transport and display pallets**

Fig. 15: Tray for transporting food – compression resistant and reusable

Fig. 16: Thermally Insulating packs for fresh fish
**Packages and closures**

Proven and simple – self-adhesive 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 palletized 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 figure 19. This compressed part becomes elastic and functions as a hinge for a limited period.

![Figure 18: Shrink-wrapped pallet pack](image)

![Figure 17: Multiple component packs protect the contents and are attractive in appearance](image)

![Figure 19: Package with integrated hinges](image)
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 plastic straps which go around the pack, straps with jointed studs or with wooden carrying handles which can be slid into the pack (Fig. 23).

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Fig. 20: Packaging for hydrants with interlocking mechanism

Fig. 21: Packaging for fire hydrants. Second use: installation in the ground as protection against frost and to promote drainage
Packaging and sales promotion

Styropor® foam is also used for publicity and sales promotion packaging, since it can be molded 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-to-measure pack. The only condition is that the inside is designed in such a way that all the products of a particular range can be accommodated.

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 sales for an attractive 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. 10, 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 figure 10 show that Styropor® foams show very little deformation at compressive stresses up to about 100 – 200 kPa (14 psi – 29 psi). This stress range is exploited for compression-resistant packages.

If the foam is subjected to larger 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 molded 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 all round?)
- stackability of the packs (... how high will the stacks be, how great the stacking pressure and do 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 ambient temperatures 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
Structural reinforcements

The strength of Styropor® moldings 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 semicircular so as to minimize the risk of mechanical damage.

The example of packaging for an engine block illustrates the interplay of these factors (Fig. 26).

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Fig. 26: All-round pack for car engines

Fig. 27: Packs with side cushions to protect the contents against impact
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 \( E = (m \cdot g) \cdot h \). 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.
Figure 29 a shows that the maximum force acting on an ideally cushioned body, i.e. in the theoretically most favorable 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 deformation.

but rather at Styropor® foams satisfy these conditions particularly well compared with other cushioning materials. As the force-deformation diagram (Fig. 29 b) shows, the 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.

Real cushions behave less favorably than ideal cushions. The reason for this is the change in deformation force as the cushion deforms, especially at high deformations. Accordingly the best shock-absorbing properties are obtained not at complete, deformations of 50 to 60%.

The requirements for a good cushioning material can be derived from figure 29 b:

- increase in deformation resistance to a specific value for a short deformation distance
- as constant a deformation resistance as possible over the greatest possible deformation distance.
Design of cushioning

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 behavior is illustrated in figure 32, 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 head-first dive, the force acting on the body will initially be at a minimum. Water here acts as a cushioning material and brakes the body but 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 favorable behavior 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 (greater load acting on the body) in order to convert the diving energy within the available diving distance.
maximum load acting on body during diving

\[ h_2 = 5 \text{m} \]
\[ d = 2 \text{m} \]
\[ h_1 = 3 \text{m} \]
\[ d = 2 \text{m} \]

Fig. 31: Recesses enable this pack to be used for several automobile window panes

Fig. 32: Cushion model: — “Diving from a spring-board”
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”.

\[
\frac{h}{d} = \frac{\text{drop height in cm}}{\text{cushion thickness in cm}}
\]

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

---

**Fig. 33:** Cushion diagram for foams made of EPS 20

**Fig. 34:** Calculation example with the aid of the cushioning diagram for 20 kg/m³ (1.25 pcf) foam

---

### Example 1

#### (load for optimum cushioning)

**known:**
- \( RD = 20 \text{ kg/m}^3 \)
- \( m = 10 \text{ kg} \)
- \( m \cdot g = 98.1 \text{ N} \)
- \( h = 90 \text{ cm} \)
- \( G = 70 \)

**required:** \( A \) und \( d \) from cushion diagram:
- \( h/d = 28 \)
- \( \sigma = 0.51 \text{ N/cm}^2 \)

**Calculations:**
- \( d = \frac{h}{(h/d)} = \frac{90}{28} = 3.2 \text{ cm} \)
- \( A = \frac{m \cdot g}{\sigma \cdot \sigma} = \frac{98.1}{0.51} = 192 \text{ cm}^2 \)

### Example 2

#### (load for optimum cushioning)

**known:**
- \( RD = 20 \text{ kg/m}^3 \)
- \( m = 10 \text{ kg} \cdot (m \cdot g = 98.1 \text{ N}) \)
- \( d = 4.2 \text{ cm} \)
- \( h = 100 \text{ cm} \)
- \( h/d = 24 \)

**required:** \( A \) und \( G \) from cushion diagram:
- \( G = 60 \)
- \( \sigma = 0.62 \text{ N/cm}^2 \)

**Calculations:**
- \( A = \frac{m \cdot g}{\sigma \cdot \sigma} = \frac{98.1}{0.62} = 158 \text{ cm}^2 \)

---

\[m \cdot g = 1 \text{ kg} \cdot \frac{9.81 \text{ m}}{\text{s}^2} = 9.81 \text{ N}\]
Apart from cushioning diagrams there is a simple to use “BASF dimension calculator” for determining optimum cushion thickness and surface area. The basis for dimensioning cushioning elements is formed by the minima of the cushioning curves (Fig. 33). 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. 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 10 to 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 figure 36. The special features of these packs are as follows.

- 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 shells. 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. 35: Guidelines for correct rib design

Fig. 36: Different designs for shock-absorbent packs
Styropor® foams are classified as rigid foams in accordance with DIN 7726. They therefore combine maximum compressive stress with low deformation. It is very easy to influence the compressive stress values by means of density. Molded packaging units – including self-supporting packs as well as inserts – can therefore be economically produced.

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-molded cushioning inserts.

Figure 39 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. 37: Compression resistant packaging for refrigerators
Design of packs for load-bearing applications

The compressive stress deformation curves shown in figure 10, page 9, were obtained in tests with a constant rate of deformation in accordance with EN 826. 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. These enable the designer to calculate the permitted loads to which Styropor® foam packs can be subjected, using the following equation:

\[ \sigma_d = \frac{F_{\text{max}}}{A} \]

- \( \sigma_d \) = permissible compressive stress in N/mm²
- \( F_{\text{max}} \) = maximum stress in N
- \( A \) = surface area under stress in mm²

The important point to note is that the figures given in the standard referred to above 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. 12).

Fig. 38: Stacking aids

Fig. 39: Force-deformation diagram

Fig. 40: Correctly designed stacking aids

A: risk of breakage due to excessively high notch stresses
B+C vertical forces, therefore no dangerous notch stresses
Recesses with large radii
Deformable stacking aids

Force-deformation diagram: Test pieces
- a. collapsible, corrugated cardboard 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, corrugated cardboard box (2.7)
  L x W x H = 32 x 29 x 28 cm
  (12.6 x 11.4 x 11.0 in) d = 9 cm (3.5 in)
  with two Styropor® foam side shells of density 20 kg/m³.
**Calculation**

A Styropor® pack is to be subjected to a maximum load \( F_{\text{max}} \) of 2000 N. What would the supporting surface area have to be for foams with densities of 20, 25 and 30 kg/m\(^3\) (1.25, 1.56, and 1.87 pcf).

This is calculated using the following equation:

\[
\frac{F_{\text{max}}}{d_{\text{max}}} \cdot A = \frac{F_{\text{max}}}{d_{\text{max}}} \cdot A
\]

\( F_{\text{max}} \) = maximum stacking load

\( d_{\text{max}} \) = maximum permissible compressive strength (see table 2)

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

\[
\begin{align*}
\text{for density 20 we have:} & \\
A & \approx \frac{2000 \text{ N}}{0.039 \text{ N/mm}^2} = 51282 \text{ mm}^2 \approx 513 \text{ cm}^2
\end{align*}
\]

\[
\begin{align*}
\text{for density 25 we have:} & \\
A & \approx \frac{2000 \text{ N}}{0.055 \text{ N/mm}^2} = 36364 \text{ mm}^2 \approx 364 \text{ cm}^2
\end{align*}
\]

\[
\begin{align*}
\text{for density 30 we have:} & \\
A & \approx \frac{2000 \text{ N}}{0.071 \text{ N/mm}^2} = 28169 \text{ mm}^2 \approx 282 \text{ cm}^2
\end{align*}
\]

**Design recommendations**

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

- The load-bearing walls of the foam packs must transmit the stacking forces down to the floor vertically and in a straight line. This is particularly important when designing stacking aids (Fig. 38/40).

- 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 base (Fig. 41).

- On the basis of experience, packaging elements are sufficiently rigid if the ratio of their thickness \( d \) to height \( h \) is >0.1 (Fig. 42).

<table>
<thead>
<tr>
<th>Table 2: Permitted compressive stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Permitted compressive stress ( \sigma_{d,\text{max}} ) N/mm(^2) at nominal density according to DIN 55471, Part 1</td>
</tr>
</tbody>
</table>

* 1 N/mm\(^2\) = 1000 kPa
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.

A key property of thermally insulating materials is their 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.

**Design of thermally insulating packaging**

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 (Figs. 43 and 47 b).
- 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 (Figs. 44 and 47 a).

The formulae for these calculations are given in figure 47, page 31 and in DIN 55471, Part 2.

---

**Fig. 43**: Safe transport of highly perishable goods in thermally insulating boxes made of Styropor® foam

**Fig. 44**: Heat-Insulating pack for pharmaceutical preparations
BASF has developed programs for 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 (Fig. 46) were each altered by 20% and the effect on the maximum thermal insulation period determined.

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 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 a cubic pack are increased by the factor x the maximum thermal insulation period will increase by a factor $\frac{1}{x^3}$. One should therefore always use the largest possible packaging unit.

### Table 3: Thermal conductivity $\lambda$ in W/(m · K)*

<table>
<thead>
<tr>
<th>Foam grade</th>
<th>mean foam temperature in °C</th>
<th>+50</th>
<th>+10</th>
<th>±0</th>
<th>−50</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPS 15</td>
<td></td>
<td>0.042</td>
<td>0.037</td>
<td>0.036</td>
<td>0.029</td>
</tr>
<tr>
<td>EPS 20</td>
<td></td>
<td>0.040</td>
<td>0.035</td>
<td>0.033</td>
<td>0.028</td>
</tr>
<tr>
<td>EPS 25</td>
<td></td>
<td>0.038</td>
<td>0.034</td>
<td>0.031</td>
<td>0.027</td>
</tr>
<tr>
<td>EPS 30</td>
<td></td>
<td>0.037</td>
<td>0.033</td>
<td>0.031</td>
<td>0.027</td>
</tr>
<tr>
<td>EPS 35</td>
<td></td>
<td>0.037</td>
<td>0.033</td>
<td>0.031</td>
<td>0.027</td>
</tr>
<tr>
<td>EPS 40</td>
<td></td>
<td>0.037</td>
<td>0.033</td>
<td>0.031</td>
<td>0.027</td>
</tr>
</tbody>
</table>

*The thermal conductivity increases with moisture content.*
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 pack is uncertain, the ice should at least be distributed along the four walls.
- Ribs should be incorporated inside the pack to minimized temperature differences.

<table>
<thead>
<tr>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Heat transfer area</td>
</tr>
<tr>
<td>$\theta_a$</td>
<td>Temperature of contents at start of thermal insulation period</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>Temperature of contents at end of thermal insulation period</td>
</tr>
<tr>
<td>$\theta_0$</td>
<td>Temperature inside the pack</td>
</tr>
<tr>
<td>$\theta_u$</td>
<td>Mean ambient temperature</td>
</tr>
<tr>
<td>$c_v$</td>
<td>Specific heat of packaged goods</td>
</tr>
<tr>
<td>$d$</td>
<td>Wall thickness of pack</td>
</tr>
<tr>
<td>$m_k$</td>
<td>Weight of thermal ballast</td>
</tr>
<tr>
<td>$m_v$</td>
<td>Weight of packaged goods</td>
</tr>
<tr>
<td>$s$</td>
<td>Latent heat of transformation of ballast</td>
</tr>
<tr>
<td>$t$</td>
<td>Thermal insulation period</td>
</tr>
<tr>
<td>$1/\alpha$</td>
<td>Heat transfer resistance on either side of the pack’s walls</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Thermal conductivity of the foam</td>
</tr>
</tbody>
</table>

Conversion factor: 1 Wh = 3.6 kJ

![Methods of calculating thermal insulation of Styropor® foam packs](image-url)
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 liter 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.

- Molded 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 Clostridium butolinum cannot decompose the proteins in the food, so that no foul smell of decay is produced as is the case with gasimpermeable 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 metabolic processes are 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 CO₂ concentration will automatically be produced in sealed foam boxes. This will depend upon the temperature, i.e. on the metabolic rate.
Among the indirect effects is also the influence exerted by water which is present in small quantities in freshly foamed molded parts.

Molded 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, page 11), there is little likelihood of packaged goods affecting the foam pack. The only substances requiring care are fats, plasticizers and organic solvents. If Styropor® foam packaging is allowed to come into contact with plastics containing plasticizer or painted surfaces, they can stick together at the points of contact. A white coating can also be formed due to migration of plasticizer into the foam surface which then softens and becomes sticky. Most of the plasticizers contained in flexible PVC products will attack Styropor® foam, apart from certain specialty plasticizers such as the Palamoll® range made by BASF. The people responsible for doing the packaging do not always have any influence on the choice of plasticizer and the best way of overcoming the problem of plasticizer 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).
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 programs for packages are given in DIN EN 24180-1/2, available from

Deutsches Institut für Normung e.V.
Vertrieb über:
Beuth Verlag GmbH
Burggartenstraße 6
10787 Berlin
Germany
Phone: (0 30) 26 01–0
Fax: (0 30) 26 01–12 60
Email: postmaster@beuth.de

Deutsche Post NL P Express
Deutschland
Verpackungsprüfstelle
Hilbertstraße 31
64295 Darmstadt
Germany
Phone: (0 6151) 9 08 – 0
Fax: (0 6151) 9 08 – 44 14
Email: verpackungsprüfstelle@deutschepost.de

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 and marking, including packaging checks
- in-plant transport costs
- shipment 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/she expects from a brand name and this is what he/she 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 comparison of profitability.
<table>
<thead>
<tr>
<th>Properties</th>
<th>Applicational advantages and possibilities</th>
<th>Examples/further advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-cell characteristics</td>
<td>Buoyancy of the air enables maximum use to be made of the PS cell structure. High strength and rigidity despite light weight</td>
<td>Low raw material requirements</td>
</tr>
<tr>
<td></td>
<td>Presence of air inside the cells imparts cushioning and thermal insulation properties to the foam</td>
<td>Shock-absorbent packaging thermally insulating</td>
</tr>
<tr>
<td></td>
<td>No absorption of moisture</td>
<td>Waterproof molded parts</td>
</tr>
<tr>
<td>Light weight, density normally between 20 and 30 kg/m³</td>
<td>Low transport costs</td>
<td>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</td>
</tr>
<tr>
<td>Strength depends on density but shows little variation</td>
<td>Packs can be designed to provide the required protection and strength. This means: optimization of the amount of material needed, protection of the packaged goods, low breakage rate and few claims</td>
<td>Stackable fruit and vegetable trays fish boxes Packs for heavy items such as automobile engines and gear units, machine parts, heavy household appliances</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>Compression-resistant packs with good buckling resistance and stackability</td>
<td>Stackable fruit and vegetable trays fish boxes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Packs for heavy items such as automobile engines and gear units, machine parts, heavy household appliances</td>
</tr>
<tr>
<td>Definable shock-absorbing capacity</td>
<td>Cushioning effect can be calculated, thereby ensuring reliable cushioning effect</td>
<td>Packs for electronic instruments, stereo equipment, television sets and measuring instruments, glass and porcelain articles and the like</td>
</tr>
<tr>
<td>Low specific cushioning factor</td>
<td>Cushioning elements can be thin, so that cushioned items need little space</td>
<td></td>
</tr>
<tr>
<td>Specific energy absorption capacity increases with density</td>
<td>Cushioning elements require little material, excellent protection in case of edge and corner impact</td>
<td></td>
</tr>
<tr>
<td>Wet strength</td>
<td>Strength is not affected by wet or damp conditions as is the case with cellulose-based packaging materials</td>
<td>Pallets for transporting plants, fruit and vegetable trays, fish boxes</td>
</tr>
<tr>
<td></td>
<td>Empty and full packs can be stored in the open, provided contents are not affected by damp</td>
<td>Savings in storage space</td>
</tr>
<tr>
<td>Low-temperature resistance</td>
<td>No embrittlement at low temperatures</td>
<td>Packs for deep-frozen goods</td>
</tr>
<tr>
<td>Thermal insulation ( \lambda = 0.03 \text{ W/(m \cdot K)} )</td>
<td>Cold and heat insulation effect can be calculated. Protection against rapid temperature changes ensures that packaged contents are subjected to minimum temperature differences</td>
<td>Packs for highly perishable foods and other substances sensitive to high temperatures such as fish, seafood, dairy products, ice cream, deep-frozen foods, hot ready meals, pharmaceutical and biological preparations</td>
</tr>
<tr>
<td>Heat resistance at 80°C under compressive stress up to 2 N/cm²</td>
<td>Combination with shrink-wrapping film, transport of hot contents</td>
<td>Shrink-wrapped items, transport of hot meals</td>
</tr>
<tr>
<td>Resistant to chemical with few exceptions, dust-free, hygienic, permitted for food packaging</td>
<td>Prepackaging is often unnecessary</td>
<td>Food packs, outer packaging for chemicals, pharmaceutical preparations and cosmetics environment-friendly disposal</td>
</tr>
<tr>
<td>Attractive appearance</td>
<td>Attractive presentation of goods, underlining product quality</td>
<td>Attractive food and display packs</td>
</tr>
<tr>
<td>Environment-friendly</td>
<td>Ground-down packaging waste can be recycled</td>
<td>Soil conditioning, drainage, composting, reuse in the production of block foam and molded parts. Can be reconverted into polystyrene by sintering and melting</td>
</tr>
<tr>
<td></td>
<td>Normal methods of disposal can be used</td>
<td>Energy recovery by incineration</td>
</tr>
</tbody>
</table>
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 industrial, commercial and communal collecting centers. 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 (see also fig. 51).

**Recycling in foam production**

Ground, clean foam waste can, within certain limits and for certain types of products, be reused in the foam molding 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.

**Recycling in PS processing**

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. The resultant recycled material may be used for making extruded and injection-molded parts.

**Energy recovering**

Styropor® foam can be incinerated in municipal and communal refuse incinerators at the usual temperatures of about 1000°C and with an adequate supply of air. The foam should be chopped up coarsely and mixed with other refuse. This allows trouble-free disposal without any residues. The high energy content of foams enables the amount of extra heating to be reduced – 1 kg of Styropor® saves 1.2 – 1.4 liters of fuel oil.

**Raw materials recycling**

In raw materials recycling expanded foam waste and mixed plastics waste are converted back to fresh chemical raw materials which are not subject to any restrictions regarding applications.

The waste material can also be used in the production of cement and pig iron.

**Landfill**

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.

Plastic waste is a raw material – it is a shame to send it to landfill. As stated above, there are numerous processes available for making use of it. In many companies, reutilization of Styropor® foams is state of the art. Landfill disposal will also be permissible under German legislation until the middle of 2005. In order to save space, prevent the formation of air pockets in the dump and make compaction easier, the waste should be granulated.

Energy recovering

![Soil improvement with Styromull®](image)
Recycling of Styropor® foams

**Mechanical recycling**
- Recycling in foam production

**Recycling in Construction industry**
- Production of Porous Bricks
- Insulating Plaster/ Lightweight Plaster
- Styropor® Concrete Gap-Filling Material
- Styropor® Concrete Building Components

**Recycling in Polystyrene Processing**
- Extrusion Granulation Plant
- Board Extrusion
- Automatic Injection Molding Machine

**Recycling as Styromull®**
- Drainage
- Plant Substrate
- Soil Conditioning
- Composting

**Raw Material**
- Agglomeration Plant
- Oil/Gas

**Energy Recovery**
- Power Plant Electricity/Steam

**Other Plastic Wastes**

Fig. 51: Recycling of Styropor® foams
Table 5: **Physical properties of Styropor® foams for packaging**

<table>
<thead>
<tr>
<th>Properties 1)</th>
<th>Test standard</th>
<th>Unit</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>DIN EN ISO 845</td>
<td>kg/m³</td>
<td>20 – 30</td>
</tr>
<tr>
<td>Thermal conductivity at 10 °C compression</td>
<td>DIN 52612</td>
<td>mW/(m · K)</td>
<td>33 – 36</td>
</tr>
<tr>
<td>Compressive stress at 10 % compression</td>
<td>DIN EN 826</td>
<td>kPa</td>
<td>110 – 140</td>
</tr>
<tr>
<td>Modulus of elasticity (pressure test)</td>
<td>DIN EN 826</td>
<td>Mpa</td>
<td>3.5 – 4.5</td>
</tr>
<tr>
<td>Long-term compressive stress &lt;1% after 50 years</td>
<td>DIN EN 1606</td>
<td>kPa</td>
<td>25 – 40</td>
</tr>
</tbody>
</table>

| Permitted compressive stress for packaging calculations | DIN 55471, Part 2 2) | kPa | 39 | 71 |
| Specific cushioning factor, C* | DIN 55471, Part 2 2) | 1 | 2.5 | 2.5 |
| Specific impact resistance capacity e* | DIN 55471, Part 2 2) | kJ/m² | 150 | 250 |
| Flexural strength | DIN EN 12089 | kPa | 250 – 310 | 430 – 490 |
| Shear strength | EN 12090 | kPa | 124 – 154 | 214 – 244 |
| Tensile strength | DIN EN 1608 | kPa | 230 – 330 | 380 – 480 |
| Short-term resistance to heat deformation | DIN 53424 | °C | 100 | 100 |
| Long-term resistance to heat deformation DLT(1)5: compression at 20 kPa/80°C/48 h) | DIN EN 1605 | % | <5 | <5 |
| Coefficient of linear expansion | 1/K | 5 – 7 · 10⁻⁵ | 5 – 7 · 10⁻⁵ |
| Specific heat capacity | DIN 53765 | J/(kg · K) | 1210 | 1210 |
| Water vapor diffusion flow density²) | DIN EN 12086 | 1 | 75 | 85 |

1) = Corresponding to test standard  
2) = DIN 55471, Part 2  
3) = Value according to DIN 4108, Part 4

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**Note**

The data contained in this publication are based on our current knowledge and experience. In view of the many factors that may affect processing and application of our product, these data do not relieve processors from carrying out their own investigations and tests; neither do these data imply any guarantee of certain properties, nor the suitability of the product for a specific purpose. Any descriptions, drawings, photographs, data, proportions, weights etc. given herein may change without prior information and do not constitute the agreed contractual quality of the product. It is the responsibility of the recipient of our products to ensure that any proprietary rights and existing laws and legislation are observed. (May 2006)