



Polystyrene and Styrolux®

General-purpose polystyrene (GPPS)

High-impact polystyrene (HIPS)

Styrene/butadien-block copolymer (S/B/S)



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Polystyrene and Styrolux® – at a glance

Polystyrene is BASF's trade name for its line of general-purpose and high-impact polystyrenes for injection molding, extrusion, thermoforming, blow molding and injection blow molding.

General-purpose Polystyrene is formed by polymerization of styrene. High-impact Polystyrene is produced by polymerization of styrene in the presence of butadiene rubber; the elastomer component is dispersed in the form of spherical particles in the normal polystyrene matrix (Fig. 1).

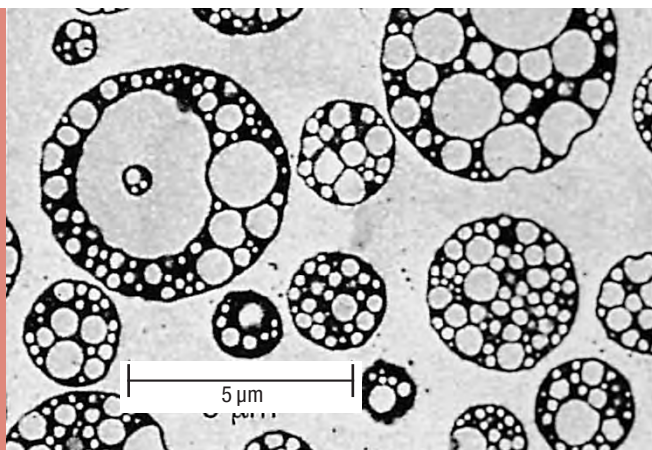
Styrolux® is the trade name for BASF's thermoplastic materials consisting of styrene-butadiene block copolymers. They can be used universally for injection molding, extrusion and thermoforming.

Styrolux is produced by copolymerization of styrene and butadiene in the form of connected blocks. The polystyrene and polybutadiene phases which separately come together form a lamellar structure.

These phases have such vanishingly small dimensions and at the same time are arranged so systematically that light can pass through virtually unhindered without appreciable scattering.

The electron micrograph in Fig. 2 clearly shows the lamellar structural arrangement and the coherent distribution of the rubber phase (dark zones). These features result in the glass-like transparency and the high toughness.

Fig. 1: Electron micrograph of an ultra-thin section of high-impact Polystyrene: the number, size, size distribution and internal structure of the rubber particles determine the property profile of high-impact Polystyrene.



Product line

BASF's Polystyrene range constitutes a highly developed materials line, including both general-purpose and high-impact Polystyrene grades. The basic grades differ primarily in their combination of toughness, rigidity, heat distortion resistance and flow behavior.

Details of the products available are given below:

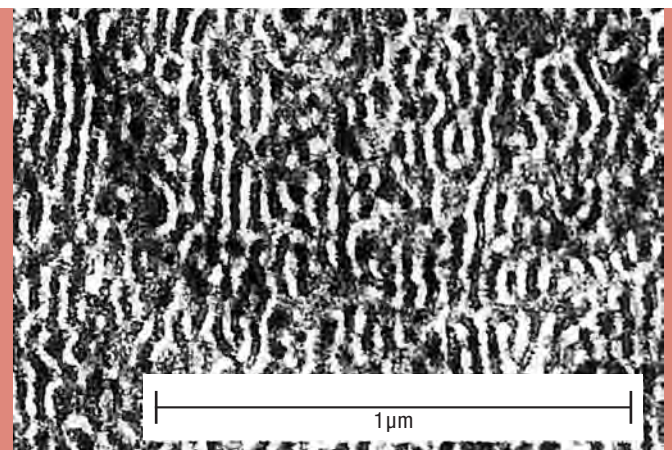
General-purpose Polystyrene

- High molecular weight grades having high strength and graded heat distortion resistance and flow for injection molding and extrusion.
- Product with high heat distortion resistance and intermediate strength and flow for injection molding, extrusion and expanded film production.
- A grade which flows easily and has good strength for general injection molding and extrusion applications.

High-impact Polystyrene

- High-impact to super-high-impact grades with normal flow for extrusion and injection molding.
- Products with increased environmental stress cracking resistance for extrusion and injection molding.
- Polystyrene with high surface gloss.

Fig. 2: Electron micrograph of an ultra-thin section of Styrolux®.





Display

Box

Fruit packaging

Styrolux®

The Styrolux® line encompasses grades which differ in toughness, heat distortion resistance and flow.

- A grade which flows very easily for producing injection-molded, tough-and-rigid parts.
- Tough universal grades for injection molding and extrusion.
- A high-toughness product for extrusion of flat film in admixture with general-purpose Polystyrene for deep-drawn parts.



Shrink film printing

Polystyrene and its characteristic properties

Mechanical properties

The typical property values determined on standard test specimens and shown in the overview of the product line give the processor as well as the design engineer the guide values necessary to select the most suitable grade for a specific application. Of course, the mechanical quality of a finished part depends not only on the material: structural design matched to the material and processing and also processing conditions appropriate to the product are also of considerable importance.

Stress-strain characteristics

The behavior of Polystyrene under short-term uniaxial tensile stress at a low deformation rate is depicted in the stress-strain graph shown in Fig. 3 which was obtained in a tensile test in accordance with ISO 527.

General-purpose Polystyrene is typified by a steep, almost linear curve and rupture after very low deformation.

The shape of this curve shows general-purpose Polystyrene to be a rigid and dimensionally stable but relatively non-ductile material having a high tensile strength and low elongation at break.

High-impact Polystyrene displays a less steep initial rise in the curve and, after reaching the yield point, pronounced deformation until rupture. This behavior is characteristic of tough materials.

The toughness of high-impact Polystyrene increases with increasing rubber content.

The stress-strain behavior of Polystyrene is dependent on the temperature and on the deformation rate. As can be seen from Figs. 4 and 5, the elongation at break of high-impact Polystyrene decreases as the temperature drops and as the deformation rate increases while the tensile strength displays the opposite relationship. The temperature effect is significantly greater than the influence of the deformation rate.

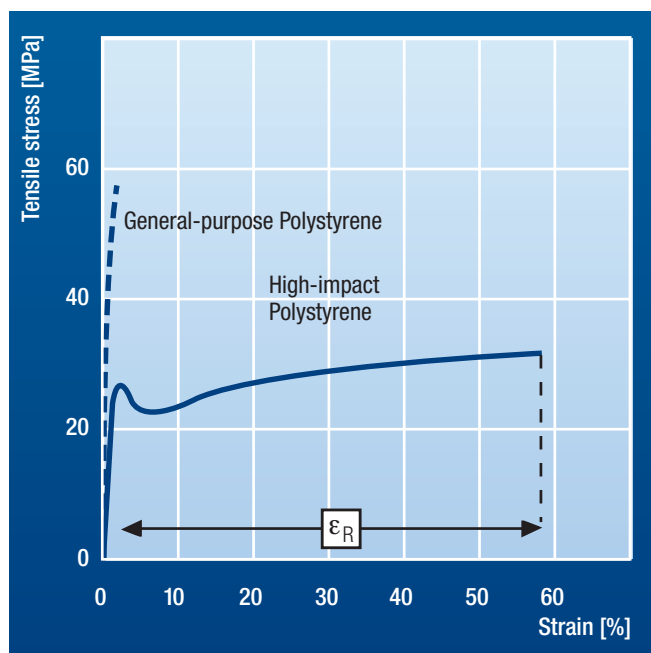


Fig. 3: Stress-strain curves of general-purpose and high-impact Polystyrene in a tensile test in accordance with ISO 527.

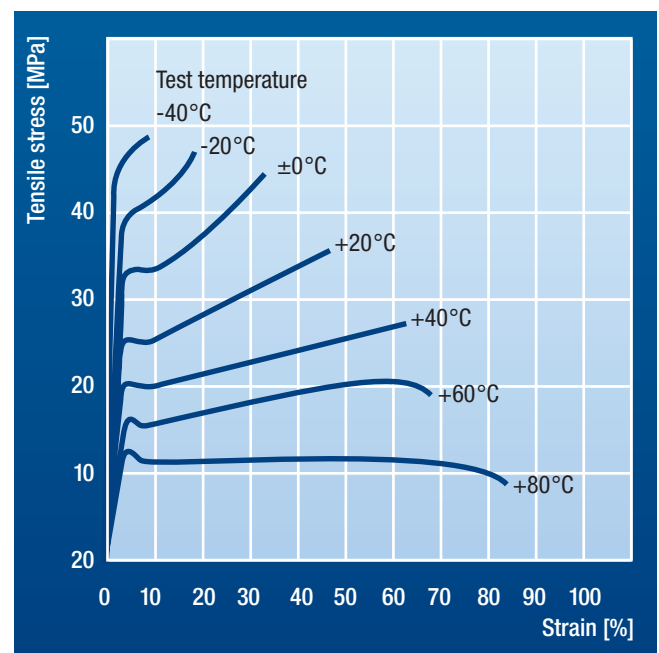


Fig. 4: Stress-strain curves of high-impact Polystyrene at various test temperatures; strain rate = 2 mm/min, determined on injection-molded test specimens.

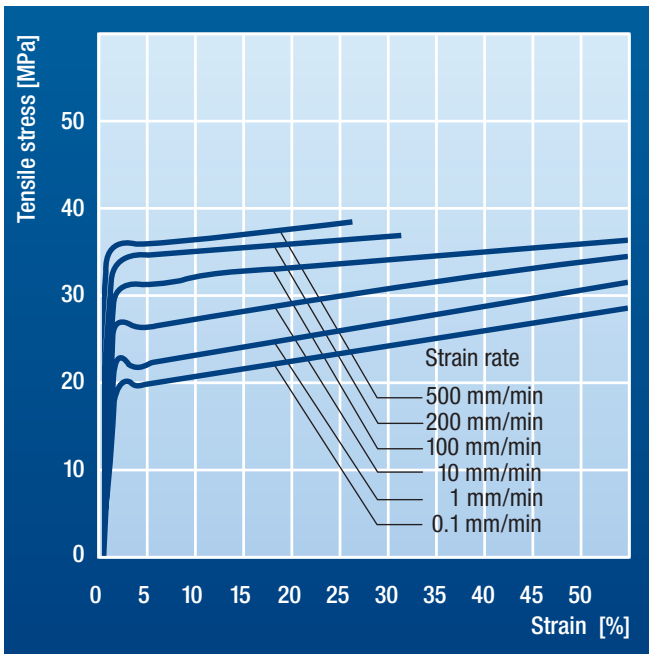


Fig. 5: Stress-strain curves of high-impact Polystyrene at different strain rates. Determined on injection-molded test specimens.

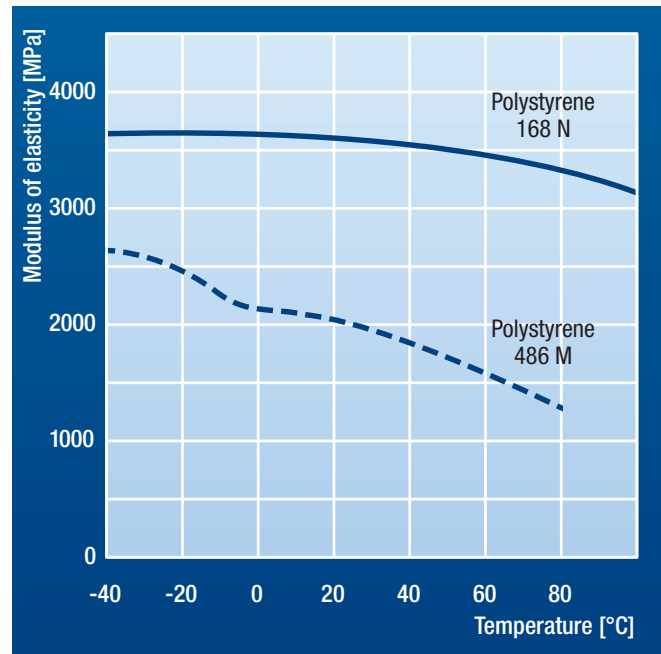


Fig. 6: Modulus of elasticity of Polystyrene in accordance with ISO 527 as a function of the temperature. Determined on injection-molded test specimens.

Modulus of elasticity (Young's modulus)

An important parameter for describing the rigidity is the modulus of elasticity determined in a tensile test; this is likewise dependent on the temperature (Fig. 6).

Shear modulus and logarithmic decrement of the mechanical damping

In place of the modulus of elasticity, the shear modulus determined in the ISO 6721-2 torsional pendulum test is often employed as a measure of rigidity. Fig. 7 shows the temperature dependence of the shear modulus. The shear modulus of general-purpose Polystyrene is virtually constant over a wide temperature range. Only in the softening range of Polystyrene does it drop sharply by several powers of ten. The logarithmic decrement of the mechanical damping displays a maximum at this juncture.

High-impact Polystyrene displays an additional slight drop in the shear modulus or a secondary damping maximum at about -80°C . This is explained by the glass transition temperature of the rubber component which lies in this region.

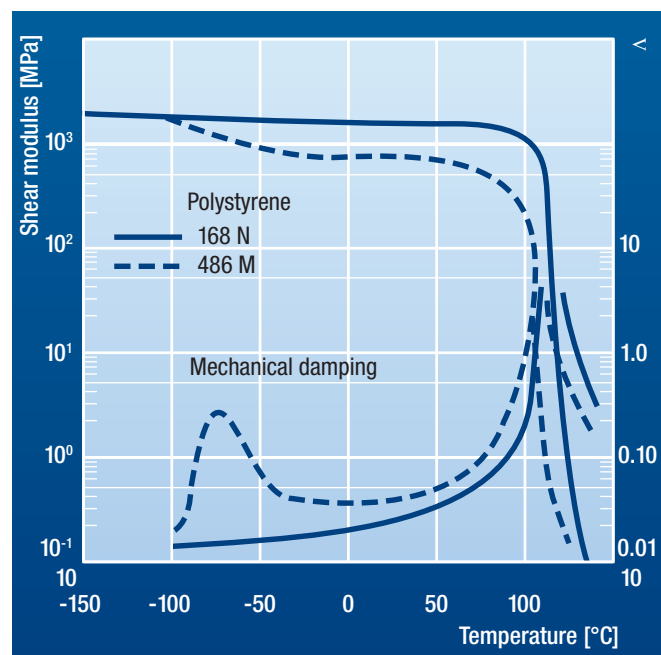


Fig. 7: Shear modulus and mechanical damping of Polystyrene as a function of temperature.

Polystyrene and its characteristic properties

Impact toughness

In contrast to the relatively low deformation rate in the tensile test and the creep test, the high deformation rate in the impact test leads to a significantly higher dynamic load on the test specimens.

Most high-impact Polystyrenes fail in the ISO 179 flexural impact test only if the test specimens have been notched beforehand.

The ISO 179/1eA test of the notched impact toughness is carried out on specimens provided with a V-notch.

In the flexural impact test, the stress direction in injection-molded specimens is the same as the preferred orientation direction. This increases the measured impact toughness and the flexural impact test therefore serves primarily for comparing the toughness of different products.

In practice, however, multiaxial stress without a preferred direction has to be expected. This is addressed by the instrumented puncture test of ISO 6603-2, in which a blow is struck centrally on a flat surface (e.g. a circular disk).

Thermal properties

Heat distortion resistance

The heat distortion resistance of finished Polystyrene parts is dependent on their shape, the production conditions, the type of heat source and the duration of heating and also on the Polystyrene grade in question. Parts produced without application of an external load and having low internal stresses can be heated for a short time to about 15°C below the Vicat softening temperature without undergoing distortion.

Linear thermal expansion; specific heat

The temperature dependence of the linear thermal expansion and the specific heat of Polystyrene can be seen in Figs. 9 and 10.

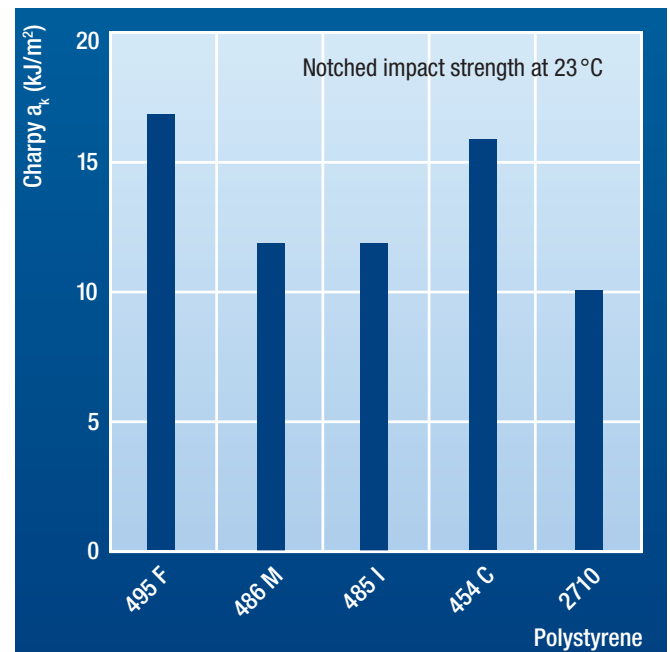


Fig. 8

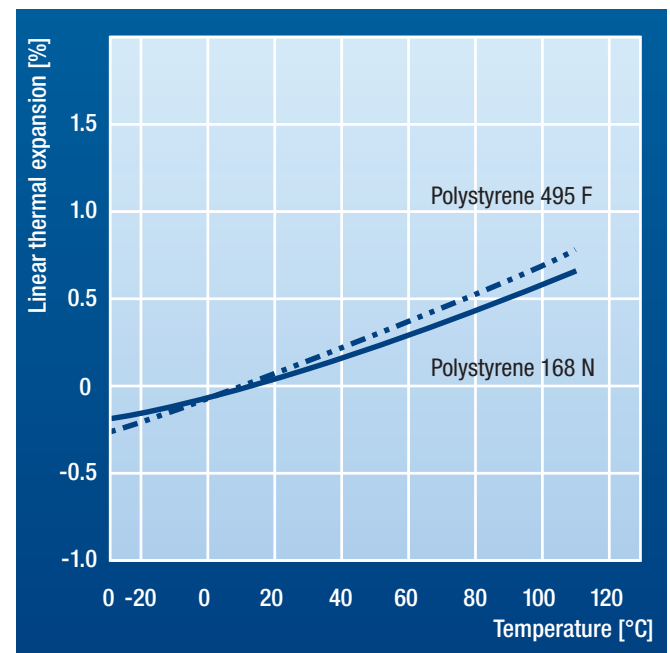


Fig. 9: Linear thermal expansion of Polystyrene as a function of temperature.

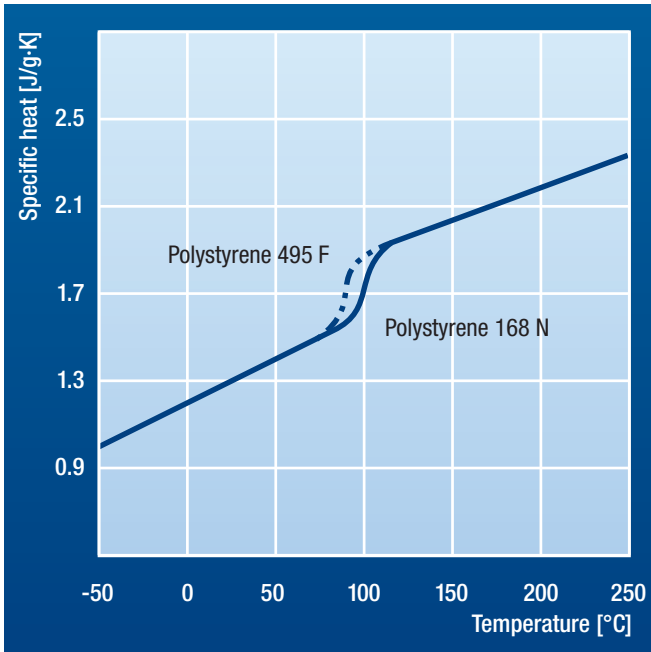


Fig. 10: Specific heat of Polystyrene as a function of temperature.

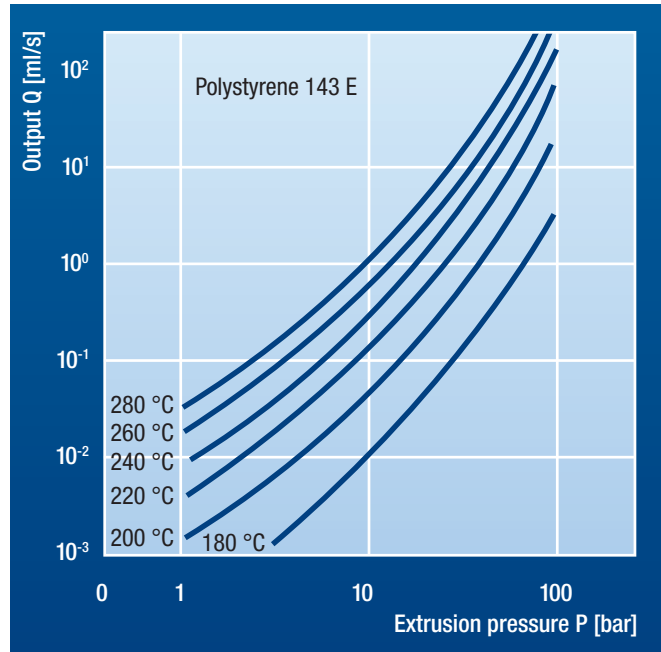


Fig. 11: Melt output of Polystyrene 143 E as a function of the extrusion pressure (flow curves), measured at from 180 to 280 °C.

Rheological properties

Like all thermoplastics, Polystyrene is a non-Newtonian fluid. This means that the viscosity depends not only on the temperature but also on the shear rate. As a result, the melt output increases overproportionally with increasing pressure. In Fig. 11, the temperature is also shown as a parameter.

The shear rate D in a circular nozzle is proportional to the throughput Q and inversely proportional to the cube of the radius r as given by the formula

$$D = \frac{4Q}{\pi \cdot r^3}$$

Fig. 12 shows the relationship between viscosity and shear rate for three different Polystyrene grades.

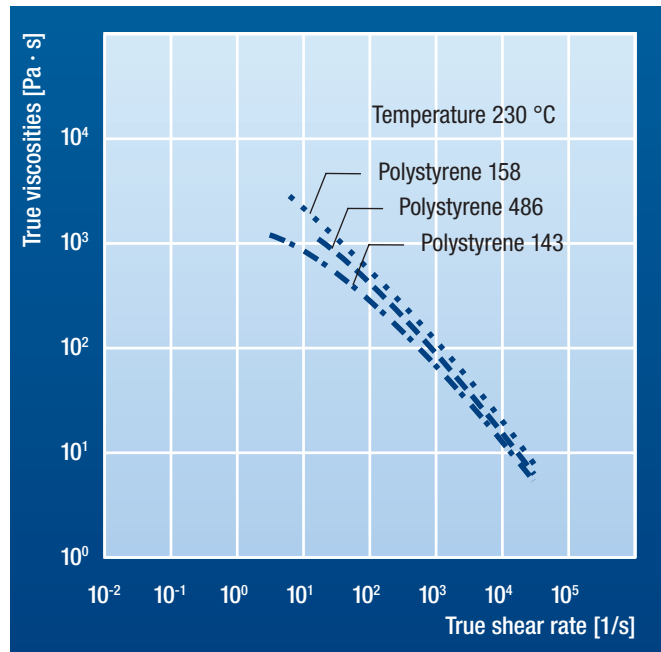


Fig. 12: Viscosity of Polystyrene as a function of the shear rate (measured in accordance with ISO 11443).

Polystyrene and its characteristic properties

Electrical properties

Polystyrene is a very good electrical insulator.

The dependence of the dielectric constant and dissipation factor on the frequency can be seen from Fig. 13.

Optical properties

The crystal-clear general-purpose Polystyrene grades have a light transmission of about 90% in the visible region (400-800 nm). The absorption increases sharply in the UV region (Fig. 14).

Further optical property data for general-purpose Polystyrene are shown in Table 1.

The high-impact Polystyrenes are more or less opaque depending on rubber content.

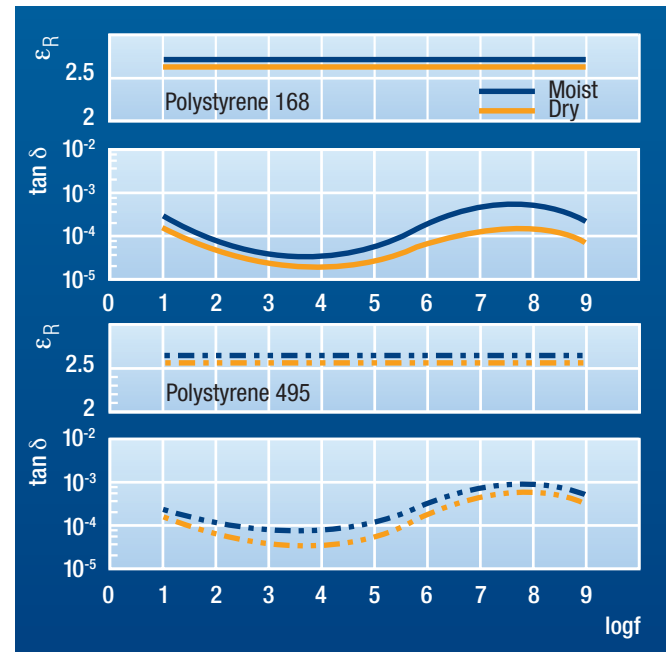


Fig. 13: Dielectric constant ϵ_R and dissipation factor $\tan \delta$ of Polystyrene as a function of frequency (measured at 23 °C on both dry specimens and on specimens conditioned to equilibrium moisture content in a standard 23/50 atmosphere—ISO 291).

Tabelle 1: Brechzahl und Abbesche Zahl von Standard-Polystyrol

Index of refraction	Abbe number
n_D^*	$v = \frac{n_D - 1}{n_F - n_C}$
1.59	31

*) Index of refraction and Abbe number measured in accordance with ISO 489 at 20 °C

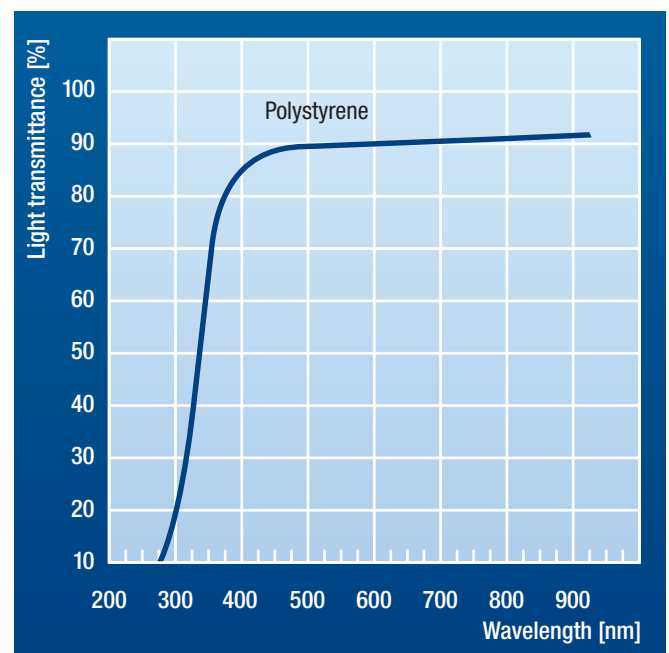


Fig. 14: Light transmittance of Polystyrene (thickness = 2 mm).



Snap-open packaging for yogurt

Permeability to gas and water vapor

Like all plastics, polystyrene has a certain permeability to gases and vapors which increases with rising temperature. Typical values for Polystyrene are shown in Table 2.

The gas permeability of Polystyrene is a particularly important factor in designing packaging for goods which have a pronounced taste or odor since it is possible for aromas to escape and also for gases and vapors to permeate in from the outside. The outward diffusion of aromas leads to a change in taste especially when the individual taste components diffuse at different rates.

The risk of changes caused by gases permeating in is particularly great in the case of atmospheric oxygen which can lead to oxidative degradation of constituents or give rise to microbiological processes.

Water absorption

Owing to its nonpolar character, Polystyrene displays only a slight tendency to absorb water.

Table 2: Typical values for the permeability to water vapor and gases of Polystyrene, Styroblend WS and Syrolux at 23°C (measured on 100 µm thick films)

Brechzahl	Water vapor ¹⁾ $\text{g} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$	Oxygen	Nitrogen $\text{cm}^3 \cdot \text{m}^{-2} \cdot \text{d}^{-1} \cdot \text{bar}^{-1}$	Carbon dioxide
General-purpose Polystyrene	12	1000	250	5200
Impact-resistant Polystyrene	13	1600	400	10,000
Styrolux*	14	2600	700	15,000

1) DIN 53122; moisture gradient from 85% to 0% relative atmospheric humidity. * More about water vapor permeability of various plastics also see page 23.

Polystyrene and its characteristic properties

Resistance to chemicals

Polystyrene is resistant to water, alkalis and dilute mineral acids, as well as to aqueous solutions of most salts.

However, it is swollen by some organic solvents and dissolved by others. This is true of aromatic and chlorinated hydrocarbons, ethers, esters and ketones. Polystyrene is also attacked by concentrated sulfuric acid and strong oxidizing agents, e.g. nitric acid, chlorine water, bromine water and sodium hypochlorite solution.

Detailed information on the resistance to chemicals is given in the Technical Information Bulletin "Polystyrene – resistance to chemicals".

Environmental stress cracking behavior

Certain media may initiate cracking in Polystyrene moldings subjected to external or internal mechanical stresses. Cracking may be induced even by the agents that normally do not attack or hardly attack unstressed moldings.

For example, aliphatic hydrocarbons such as heptane have a very

strong effect in triggering environmental stress cracking in both general-purpose Polystyrene and the high-impact grades.

A medium is said to initiate environmental stress cracking if its presence reduces the time-dependent loadability compared to the behavior in a neutral environment.

The tensile creep test is an example of a method which can be employed for such an evaluation.

Fig. 15 shows the behavior of high-impact Polystyrene specimens produced under identical process conditions but exposed to different media during the test.

The converse can be seen in Fig. 16, where the medium is the same in all cases and the differences in the environmental stress cracking behavior result from the different process conditions.

The environmental stress cracking resistance depends not only on the type of product in question but also on its condition after processing. If damage by environmental stress cracking is to be avoided, it is therefore not sufficient to know the product properties but it is just as important to monitor the quality of the moldings rigorously.

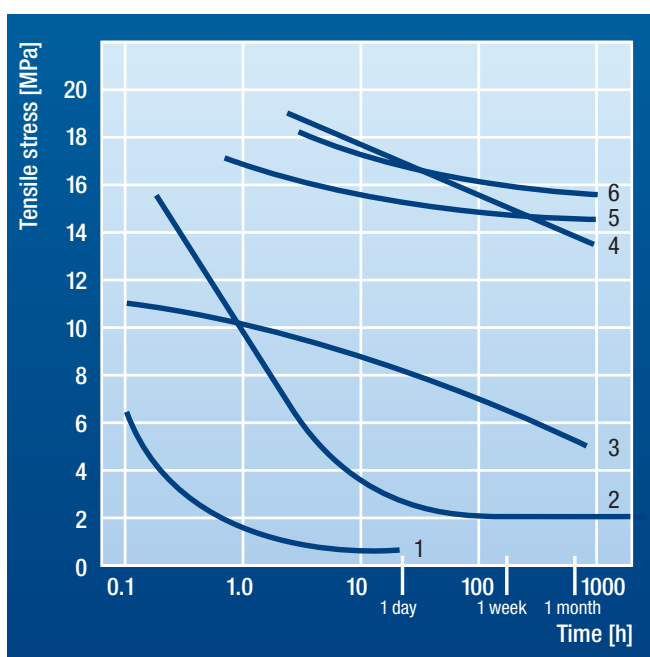


Fig. 15: Stress cracking test on high-impact Polystyrene at 20 °C in various media. Creep rupture curves for
 1. n-heptane
 2. Olive oil/oleic acid, 1:1
 3. Methanol
 4. Battery acid
 5. Distilled water
 6. Air

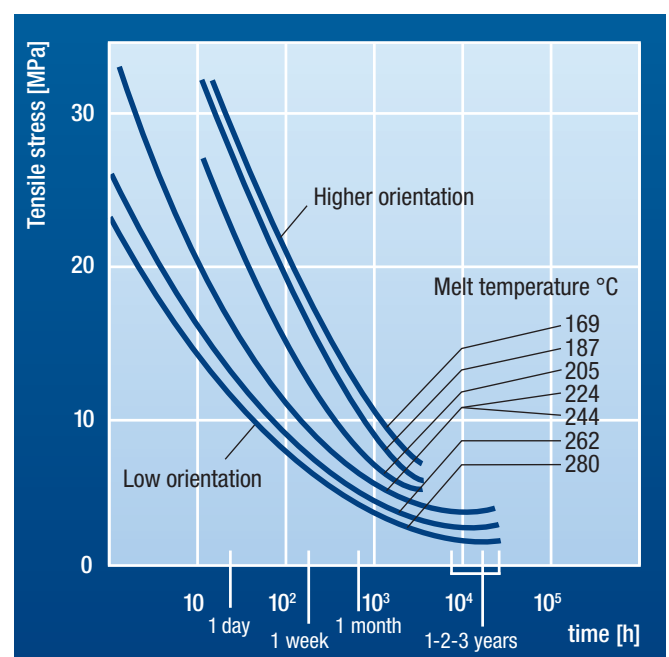


Fig. 16: Creep rupture curves of high-impact Polystyrene in olive oil/oleic acid, 1:1. Determined on test specimens with different de-grees of orientation. The higher the melt temperature, the lower the degree of orientation.

Aging behavior

Polystyrene is stabilized against the aging which can be brought about by exposure to atmospheric oxygen at elevated temperatures. Indoors under normal light and temperature conditions, parts made of Polystyrene retain their appearance and their functionality for years.

Outdoors, the UV rays in direct sunlight are primarily responsible for damage. This aging shows up both as a gradual change in appearance, i. e. yellowing and loss of surface gloss, and also as a decrease in the mechanical strength. Dark colors have better resistance than a pale or transparent product.

For the above reasons, Polystyrene is not recommended for articles which are used outdoors for a prolonged period.

Resistance to high-energy radiation

The effect of high-energy radiation (fast electrons, protons, α particles, neutrons, X- and γ -rays) on polystyrene depends on the radiation dose, the dose rate, the irradiation temperature, the geometry of the irradiated specimen and the surrounding medium.

When atmospheric oxygen is excluded, general-purpose Polystyrene is one of the most radiation-resistant plastics known. On irradiation in air, the radiation dose which causes damage is substantially lower.

The radiation resistance of high-impact Polystyrene is significantly below that of general-purpose Polystyrene.

The good radiation resistance of Polystyrene compared to other thermoplastics is demonstrated in Fig. 17.

Resistance to microorganisms

Polystyrene is immune to termites and is not a nutrient for microorganisms. For this reason, any signs of attack can be attributed to foreign substances which have collected on the surface.

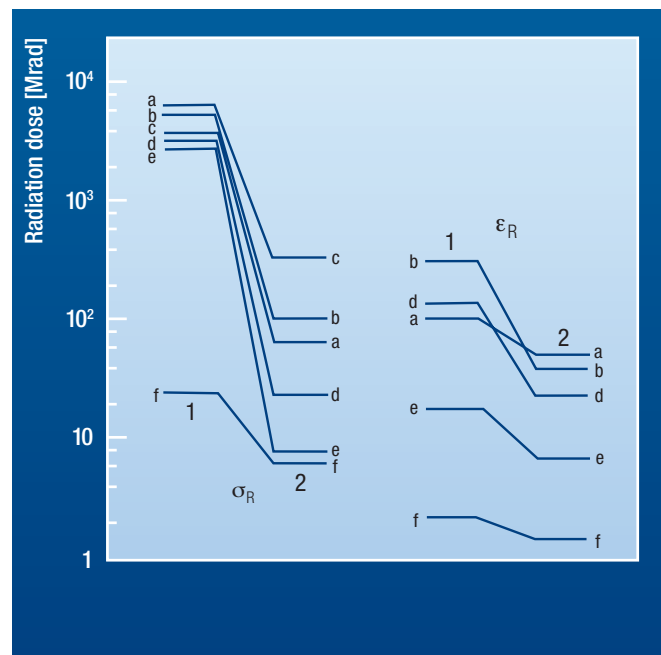


Fig. 17: Radiation dose at which the tensile strength σ_R or the elongation at break ϵ_R of polymers is reduced by 25% under the radiation conditions indicated. (method of H. Fischer, K.-H. Hellwege and W. Langbein)

- a) Styrene-acrylonitrile copolymer
 - b) General-purpose Polystyrene
 - c) Rigid PVC
 - d) Plasticized PVC
 - e) Branched polyethylene
 - f) Polypropylene
- 1) = Irradiation in vacuo at 500 Mrad/h
2) = Irradiation in air at 1 Mrad/h.

Special Polystyrene grades and their particular properties

High-gloss Polystyrene

Polystyrene 454 C

PS 454 C is a high-impact Polystyrene with a good combination of impact resistance, high flowability, heat resistance and high gloss.

Processing:

In injection molding, PS 454 C can be processed at melt temperatures of up to 260 °C. When appropriately processed, parts made of PS 454 C display a high level of gloss. In this context, it is advantageous to employ molds with a high-gloss polish. PS 454 C is suitable for the internal gas pressure method. The melt temperature during extrusion should not exceed 240 °C.

Areas of application:

- refrigerator interiors
- toilet water tanks
- TV front frames and back panels
- front covers for electronic entertainment
- office and household articles
- air conditioning units
- toys



Mirror cabinet and toilet water tank

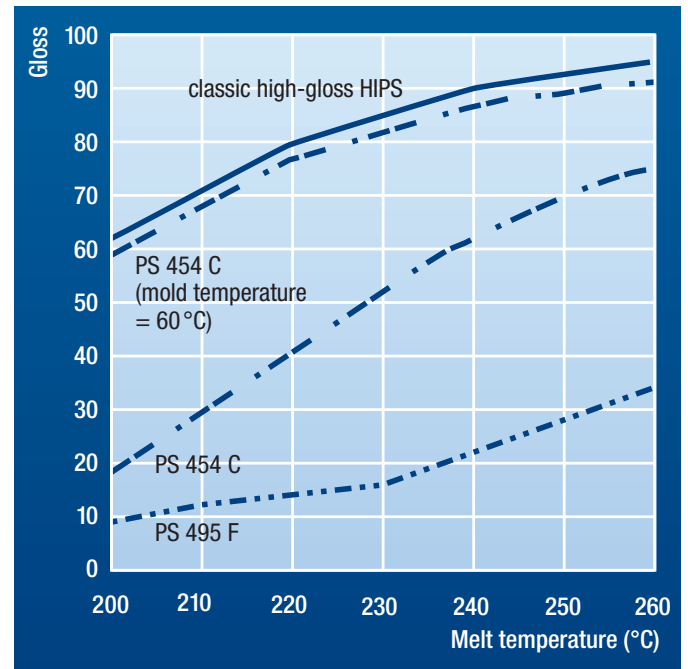


Fig. 18: Surface gloss

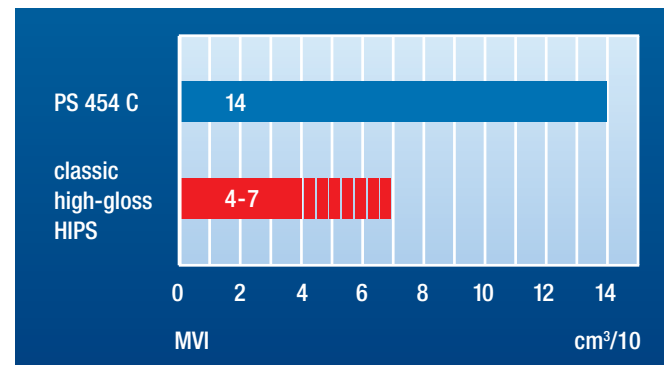


Fig. 19: Flowability

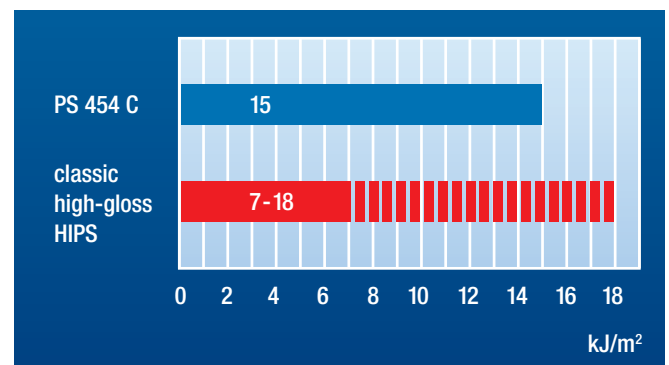


Fig. 20: Impact strength



Polystyrene grade with increased environmental stress cracking resistance

Polystyrene ESCRimo™

Polystyrene generally has only moderate resistance to certain media which trigger environmental stress cracking. However, Polystyrene ESCRimo™ has significantly better environmental stress cracking resistance, as is shown very clearly in Fig. 21. For example, refrigerator compartments and door linings made from this grade can be back-foamed directly with polyurethane foam without the protection against foam blowing agents, e. g. cyclopentane, which is usually required for high-impact polystyrene.

Partially halogenated hydrocarbons (HCFC) generally behave more aggressively and need to be looked at on a case-by-case basis.

Polystyrene ESCRimo™ is also significantly more resistant to environmental stress cracking in the presence of fats and oils than is conventional high-impact polystyrene.

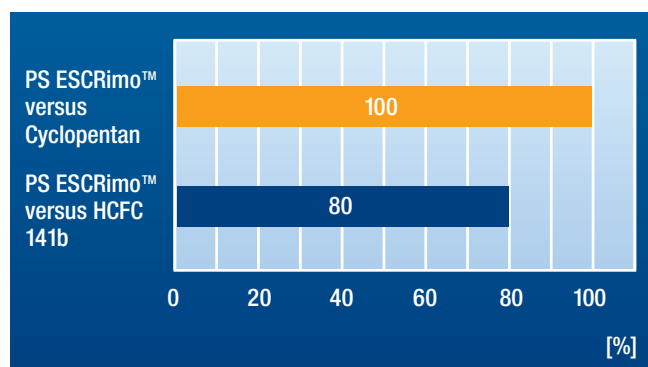


Fig. 21: Stress cracking resistance

Styrolux[®] and its characteristic properties

Mechanical properties

Important criteria for characterizing Styrolux[®] grades include mechanical properties that describe toughness and stiffness, together with the level of transparency. Another significant property of Styrolux is easy blending with a wide variety of polymers. The blend most frequently encountered uses general-purpose polystyrene (GPPS), permitting highly cost-efficient production of transparent sheet and finished products with tailored combinations of properties.

Styrolux[®] compared with general-purpose polystyrene

The Styrolux line includes grades with various combinations of stiffness and toughness (Tab. 3). Stiffness of the products reduces as toughness increases. Values for modulus of elasticity (stiffness) and tensile strain at break (toughness)—determined from the tensile test—are important parameters for these properties. Stiffer products with higher modulus such as Styrolux 656 C are mainly suitable for injection-molding applications. The amounts of GPPS blended with these grades are generally very small or zero. Tough to very tough grades such as Styrolux 3G 46, Styrolux 684 D or Styrolux 3G 55 are mainly used in extrusion to give films or thermoforming sheet, since this is where extremely easy blending with GPPS is a prime requirement.

Table 3: Guideline values for stiffness and toughness of Styrolux [®] products compared with GPPS		
Styrolux	Stiffness	Toughness
	Moduls of elasticity [MPa]	Tensile strain at break [%]
656 C	1800	20
3G 46	1550	>100
684 D	1500	160
693 D	1300	260
3G 55	900	>300
GPPS	3300	2-3

measured by the ISO 527 tensile test.

Stress-strain performance

The stress-strain graph (Fig. 22) to ISO 527 illustrates the performance of Styrolux compared with GPPS for short-term single-axis tensile stress and low deformation rate.

Alongside stiffness and toughness, the stress-strain curve here also gives the yield stress and fracture energy, which is the area under the stress-strain curve. GPPS typically has a steep, almost straight-line curve and fractures after very slight deformation. This characterizes GPPS as a stiff and dimensionally stable, low-extensibility material with high tensile strength and low tensile strain at break.

In contrast, the Styrolux curve has a flatter gradient, meaning lower stiffness. Once the yield point has been reached there is no rise in stress as tensile strain continues to increase. This very distinct deformation behavior leads to fracture as tensile strain increases further. This type of curve is characteristic of very tough materials. Because Styrolux 3G 55 has lower stiffness than Styrolux 656 C, the stress values on the curve are lower.

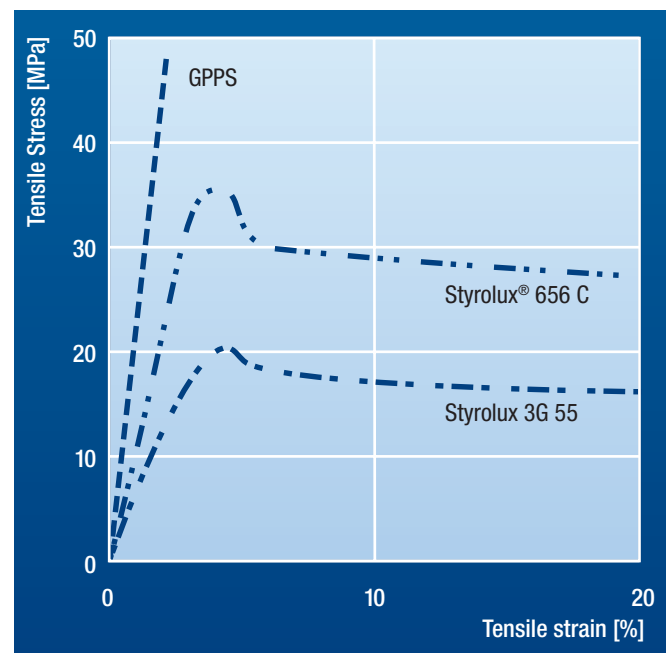


Fig. 22: Stress-strain curves for Styrolux 656 C, Styrolux 3G 55, and GPPS measured by the ISO 527 tensile test.

Stiffness in blends with GPPS

Styrolux® is very often blended with GPPS for practical applications. As GPPS content increases, the effect on stiffness (Fig. 23) is an almost linear rise in modulus of elasticity or yield stress. This is particularly desirable for extrusion applications.



Toughness in blends with GPPS

In contrast to stiffness, the toughness of Styrolux/GPPS blends reduces when GPPS is added. The sequence of toughness reduction in blends is the same as that for pure Styrolux products:

Styrolux 3G 55 > 693 D > 684 D > 3G 46

This reduction in toughness can also be described using the tensile strain at break obtained from the tensile test (Fig. 24).

The sharp reduction in tensile strain at break when GPPS content in the blend is more than 40% can be clearly seen. Blends with less than 20% of Styrolux show hardly any improvement in tensile strain at break.

Tensile strain at break in the extrusion direction is generally relatively low—a consequence of orientation of the rubber phase in Styrolux. Lamellar morphology of Styrolux in blends with GPPS parallel to the direction of extrusion reduces the amount of additional strain available on stretching in that direction. Depending on the Styrolux grade, blends of from 30 to 70% of Styrolux with GPPS have proven successful in most extrusion applications.

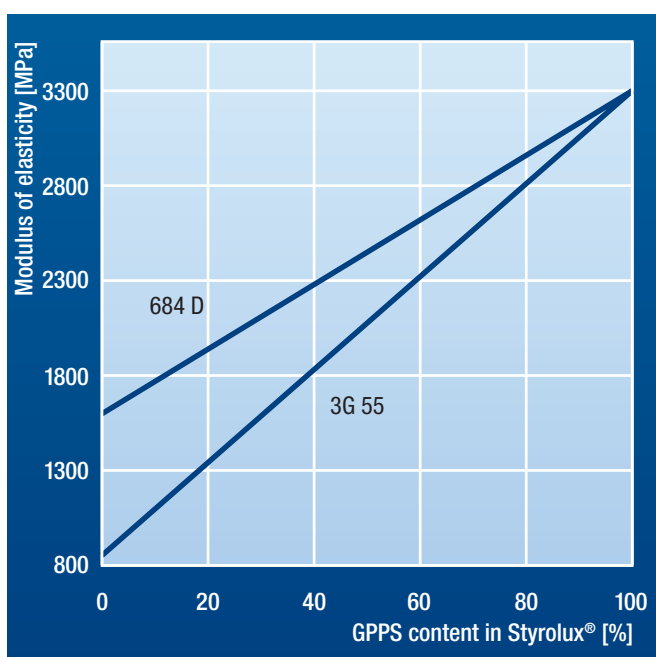


Fig. 23: Stiffness of Styrolux®/GPPS blends; modulus of elasticity measured to ISO 527.

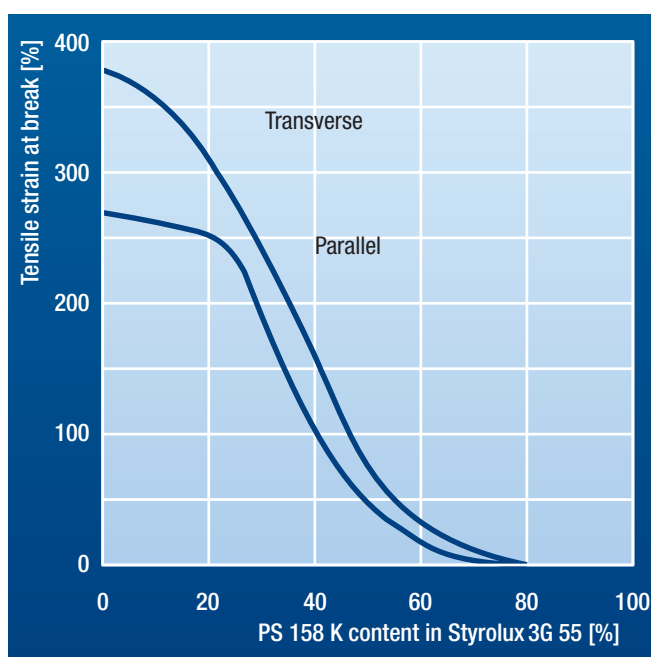


Fig. 24: Tensile strain at break as a function of GPPS content (PS 158 K) in Styrolux 3G 55; measured on 1 mm sheet to ISO 527.

Styrolux® and its characteristic properties

Impact strength of Styrolux® products

In circumstances contrasting with the relatively low deformation rate in the tensile test high deformation rates subject the test specimens to much more powerful fracture stresses. The Charpy (ISO 179) flexural impact test carried out on test specimens of the tougher Styrolux® grades produces fractures only if the specimens have been previously V-notched (ISO 179/1eA) (Tab. 4).

Flexural impact parameters determined on injection-molded test specimens are higher than those for low-orientation specimens, because the direction of stress is identical with the preferential direction of orientation. The flexural impact test is therefore mainly used for comparative evaluation of product toughness.

Multiaxial impact strength

Styrolux and high-impact polystyrene (HIPS)

Stress under practical conditions is much more likely to be multiaxial—with no preferential direction—rather than monoaxial. The automated ISO 6603-2 penetration test relates to this situation, with central impact on a flat surface—of an extruded sheet or injection-molded plaque, for example.

The fracture energy is the area below the force-displacement curve, and this shows that toughness is markedly higher for Styrolux grades than for comparable grades of high-impact polystyrene (Fig. 25).

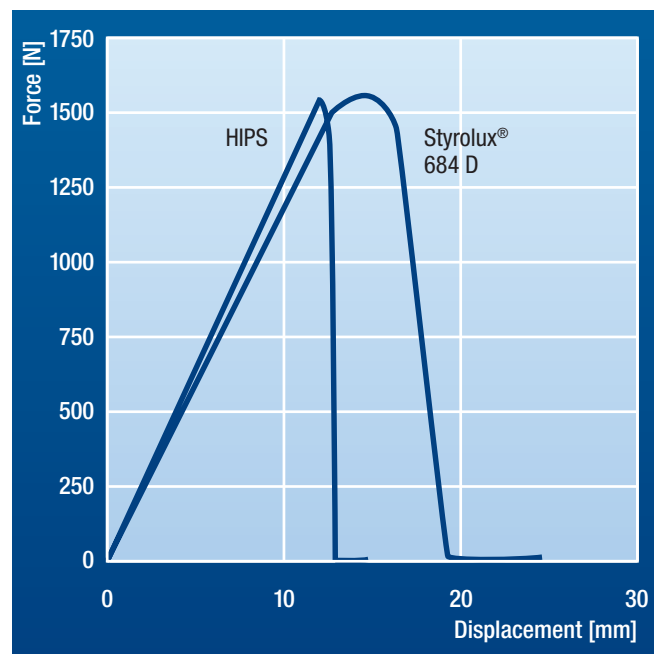


Fig. 25: ISO 6603-2 penetration test on disks (diameter 50 mm, thickness 1 mm) for Styrolux® 684 D compared with high-impact polystyrene.

Table 4: Guideline values for impact strengths of Styrolux® grades at 23 °C; nf: no fracture

Values in [kJ/m ²]	Impact strength ISO 179 / 1eU	Notched impact strength ISO 179 / 1eA
656 C	25	2
3G 46	nb	3
684 D	nb	4
693 D	nb	5
3G 55	nb	> 80-nb

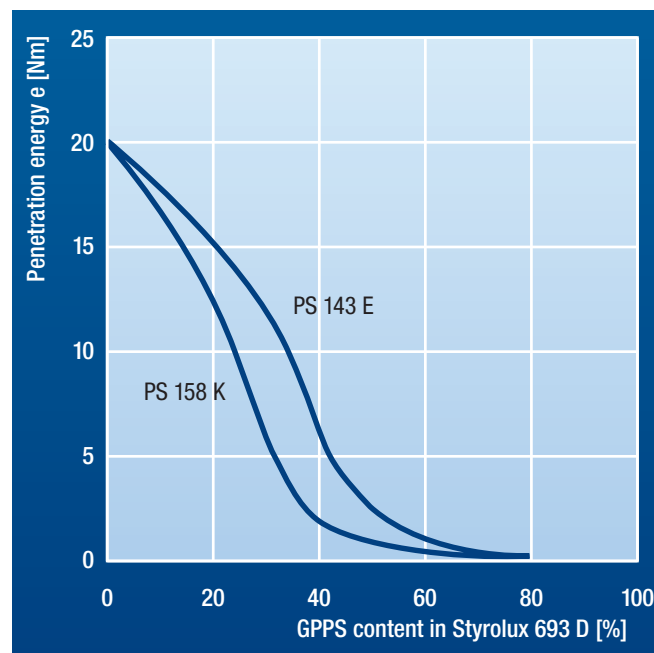


Fig. 26: Penetration energy as a function of GPPS content to ISO 6603-2; measured on 1 mm sheet.

Puncture resistance on sheets made from Styrolux®/GPPS blends

Like tensile strain at break (see Fig. 24), puncture resistance as a function of Styrolux®/GPPS blending ratio reduces with increasing GPPS content. Figure 5 shows this fracture behavior for 1 mm sheet made from Styrolux 693 D/GPPS blends. Here it is clear that the oil-containing polystyrene grade PS 143 E gives higher toughness.

Influence of blend components

The mechanical properties of blends are affected both by the Styrolux used and by the GPPS grade used.

Styrolux grades

The variation in properties of Styrolux/GPPS blends reflects the reduction in stiffness and associated increase in toughness within the Styrolux line. Styrolux 3G 55 has particular toughness efficiency properties in blends with GPPS.

When comparison is made with conventional grades, such as Styrolux 693 D, Styrolux content in terms of the amount of SBS used can be reduced by up to a quarter in blends with GPPS, e. g. PS 158 K (see Fig. 27). These blends using Styrolux 3G 55 are just as stiff as conventional blends. Styrolux 3G 55 therefore helps to reduce costs of finished parts made from Styrolux/GPPS.

GPPS grades

GPPS containing lubricant—PS 143 E for example—gives higher toughness values than oil-free GPPS grades such as PS 158 K.

Sheet toughness can be raised further by using a lubricant-modified polystyrene grade with relatively high molecular weight such as PS 165 H, giving the relative values shown in the diagram of Fig. 28 for the example of a sheet made from Styrolux 693 D and GPPS blended in a ratio of 40:60.

The toughness and transparency properties of the sheet here generally vary in opposite directions, so although sheet produced using PS 165 H is tougher at the same blending ratio a slight loss of transparency has to be accepted.

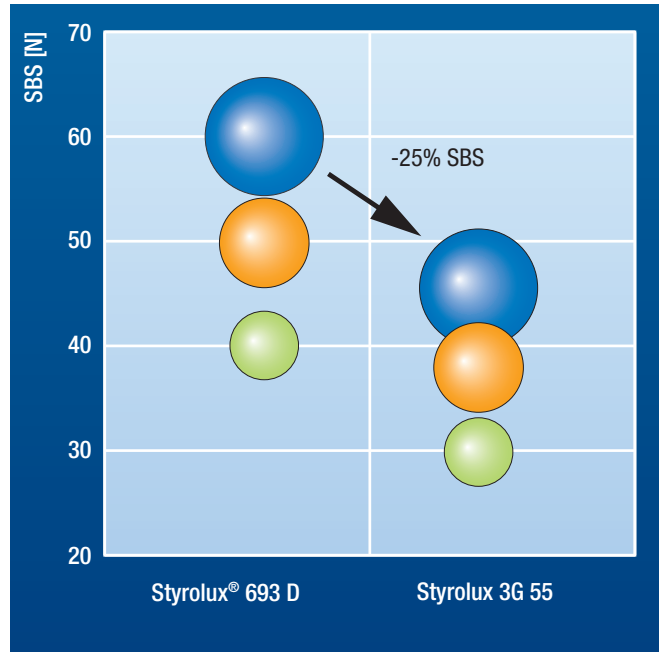


Fig. 27: For comparable toughness: reduction in Styrolux® content by up to 25 % using Styrolux 3G 55 (size of circles = measure of toughness).

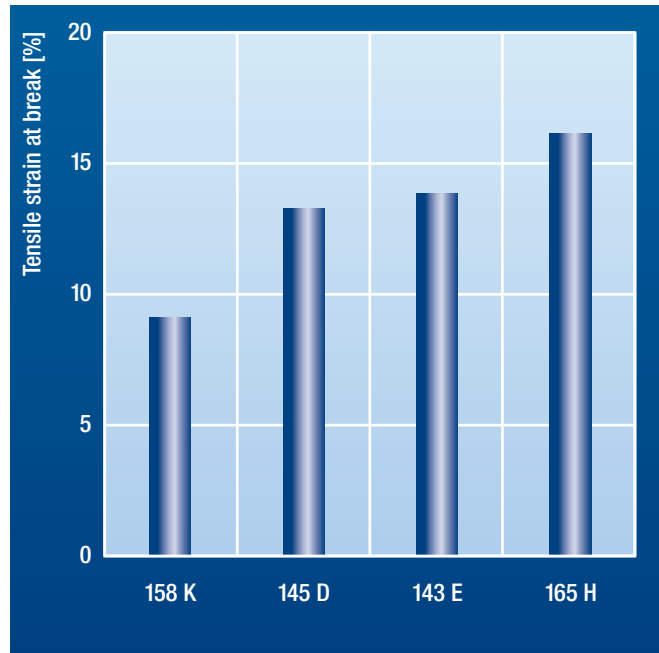


Fig. 28: Influence of polystyrene grade on toughness of sheet made from Styrolux 693 D and GPPS (blending ratio 40:60); measured to ISO 527.

Styrolux® and its characteristic properties

Optical properties

Excellent transparency is one of the key properties of Styrolux® products. The gloss of moldings made from Styrolux is also high, comparable with that of GPPS.

Two physical variables describe transparency: light transmission and haze. Transmission measures the intensity of light passing through a test specimen after taking into account reflection losses at the two surfaces. Haze is the proportion of light scattered by more than 2.5° from the incident direction on passage through a test specimen.

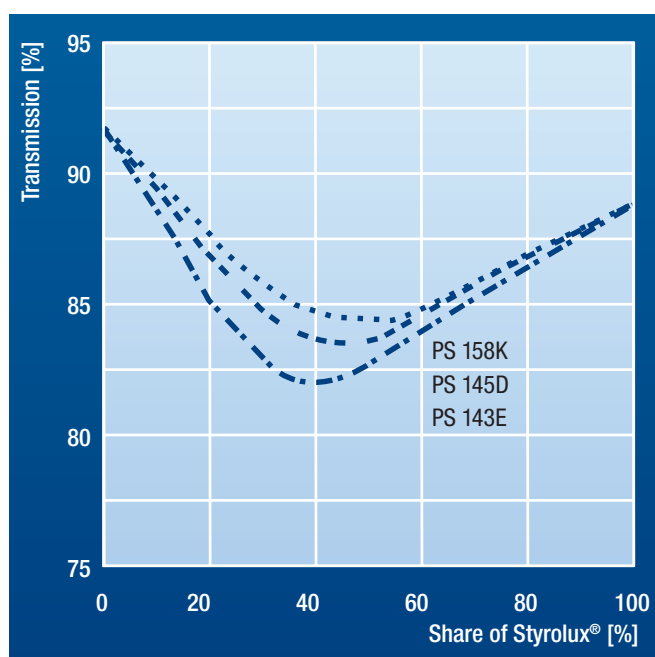


Fig. 29: Transmission of Styrolux® 684 D as a function of GPPS content and of GPPS grades; measured on sheet of thickness 1 mm to ASTM D 1003.

Transmission and Haze

Styrolux grades

All Styrolux grades have very good light transmission of about 90% in the visible region (400 - 800 nm) (Tab. 6). Haze rises slightly as the toughness of the products increases.

Blends made from Styrolux® and GPPS

The transparency of blends made from Styrolux and GPPS depends on the Styrolux grade (see Table 6), the blending ratio, the GPPS grade, and the homogeneity of the blend.

Blending ratio

The content of the two components has a particular effect on sheet transparency. The approximately parabolic function (Fig. 30) has a minimum where the Styrolux/GPPS blending ratio is about 40:60. Other blends have increasing transparency. The relative position of the transmission values is determined by the GPPS grades used.

Haze values likewise follow an approximately parabolic curve with increasing content of Styrolux, this time with a maximum at a 40:60 Styrolux/GPPS blend.

Styrolux 3G 46 can be mixed very well with standard polystyrene (GPPS). The extremely high transparency and the extremely low haze are retained at GPPS levels of up to 40 percent. But even when the polystyrene makes up more than 40 percent, the visual properties of Styrolux 3G 46 are decisively better than those of the comparable SBS grades (styrene-butadiene block copolymers).

Table 5: Transmission, haze, and refractive indices of Styrolux® to ASTM D 1003

Guideline values	Transmission [%]	Haze [%]	Refractive index $n_{D,23}$
656 C	90	1.5	1.58
3G 46	90	1.0	1.57
684 D	90	1.5	1.58
693 D	89	2	1.57
3G 55	89	3	1.57

measured on plaques of thickness 2mm

GPPS grades

Oil-free GPPS grades such as PS 158 K give the best transparency in blends with Styrolux®. Although toughness increases with oil-containing grades such as PS 143 E at the same blending ratio, transparency reduces. Blends made from Styrolux and PS 145 D give the best compromise between high toughness and very good transparency. PS 145 D gives higher flowability than PS 158 K and PS 143 E. For identical blending ratios the sequence of increasing transparency within the BASF product line is:

PS 165 H < 143 E < 145 D ≈ 158 K

Homogeneity

Inhomogeneity reduces the transparency of Styrolux/GPPS blends. Good mixing performance by the extruder is an important precondition for the production of highquality sheet and high-transparency injection moldings without flow streaks.

Thermal properties

The heat distortion resistance of parts made from Styrolux depends on the manufacturing conditions and on the nature and duration of thermal stress to which the material is subjected. Table 5 shows guideline heat resistance values for Styrolux products under standard test conditions.

Styrolux grades with higher toughness have lower heat resistance. Average deflection temperatures of about 70–80 °C are achieved for short exposure to heat with no external load.

In most applications, Styrolux is processed in a blend with general-purpose polystyrene (GPPS). Mechanical and optical properties, and also thermal properties, depend on the mixing ratio and on the GPPS grade used. For example, heat resistance of blends of Styrolux and GPPS rises linearly with GPPS content. Higher Vicat values can be achieved with oil-free GPPS grades such as PS 158 K than with oil-modified grades such as PS 143 E (Fig. 29). Average linear coefficient of thermal expansion for Styrolux in the range from -20 °C to +70 °C is 80 [10⁻⁴/K], and thermal conductivity is similar to polystyrene at from 0.15 to 0.17 [W/mK].

Electrical properties

Styrolux is a good electrical insulator, similar to general-purpose Polystyrene.

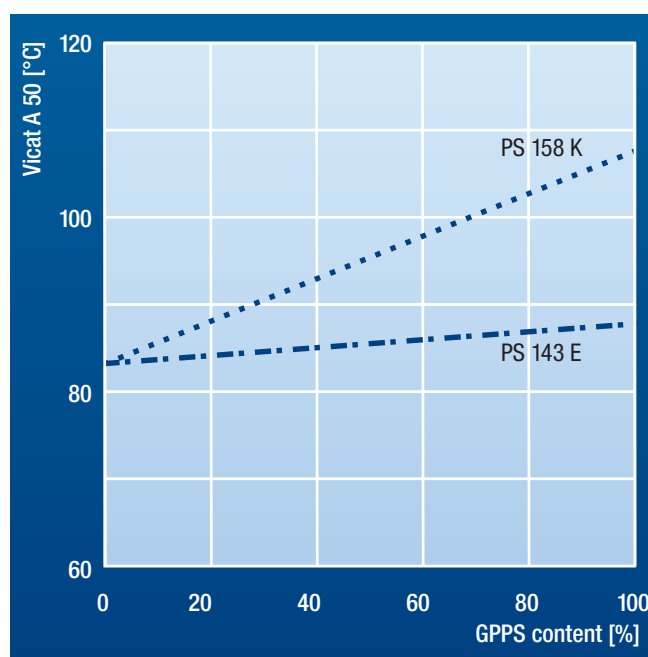


Fig. 30: Vicat softening points of blends of Styrolux® 684 D and GPPS.

Table 6: Heat resistance of Styrolux®

Values in [°C]	HDT A	HDT B	VST/A/50
	ISO 75-2	ISO 75-2	ISO 306
656 C	67	77	90
3G 46	58	75	81
684 D	65	75	83
693 D	59	72	81
3G 55	51	62	67

HDT A: Deflection temperature under load of 1.8 MPa
 HDT B: Deflection temperature under load of 0.45 MPa
 VST/A/50: Vicat softening point

Styrolux[®] and its characteristic properties

Rheology

Styrolux[®] features good flow performance. Figure 31 shows an example of dependency of melt viscosity on shear rate for the Styrolux grades 3G 55 and 684 D.

The recommended processing temperature range of 200-240 °C should not be exceeded, otherwise crosslinking can occur, resulting in haze, streaking and gel formation. A specific stabilizer system gives Styrolux excellent thermal stability and a very low fish-eye level.

Crosslinking can be measured via extrusion pressure at a range of temperatures (Fig. 32). However, these data do not provide a good guide to residence times or melt temperatures for processing purposes.

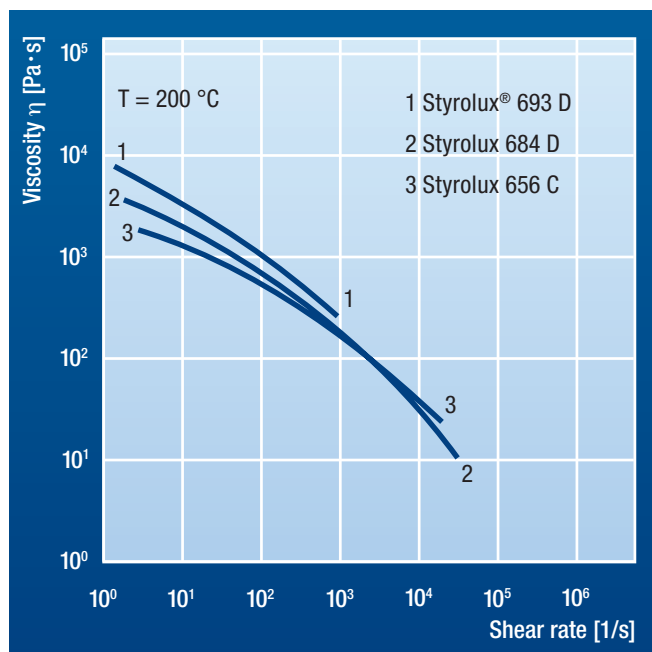


Fig. 31: Viscosity of Styrolux[®] as a function of the shear rate at 200 °C.

Chemical resistance

Styrolux is resistant to water, alkalis and dilute mineral acids, and also to aqueous solutions of most salts. It is solvated or dissolved by organic solvents, in particular chlorinated and aromatic hydrocarbons, esters, ethers and ketones. Concentrated sulfuric acid and powerful oxidizing agents – such as nitric acid – also attack Styrolux. If parts made from Styrolux come into contact with other fluids, resistance should be tested.

Stress cracking

Substances which generally promote stress cracking in polystyrene, for example fats and oils based on unsaturated fatty acids, can also damage Styrolux. The extent of damage depends on the type of processing used, and on the external stress to which the moldings are exposed. When blends of Styrolux and standard polystyrene are used with fluids that cause stress cracking, the best possible compromise has to be devised

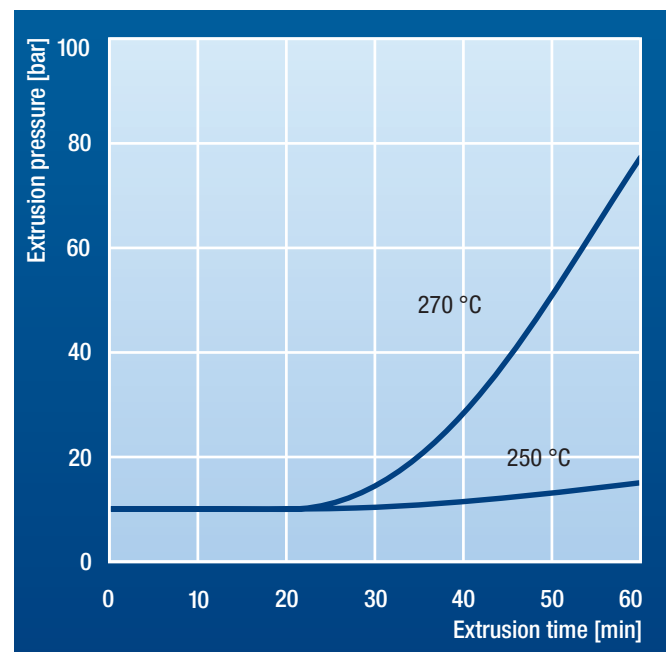


Fig. 32: Stability of Styrolux 684 D.

Permeability

Compared with other plastics, Styrolux® has very high permeability to gases and vapors (Figures 33 and 34). This has to be considered for example when packaging contents with strong odor or flavor. Changes in the packaged product can occur due to outward diffusion of aroma components or ingress of oxygen. However, this very high permeability of Styrolux can also be extremely useful for fresh-food packaging. An example – in packs for fruit and vegetables Styrolux permits exchange of gases and moisture with the immediate environment so that natural ripening processes can continue.

Organoleptic properties

Styrolux has been used successfully for many years as a packaging material in the food sector. However, before Styrolux is used to pack flavor-sensitive foods it is advisable to test for organoleptic effects. We do not recommend sealed containers. We recommend a coextruded composite with PETG as barrier layer when packaging products containing oils or fats.

Aging

Styrolux has effective stabilization to inhibit aging on exposure to oxygen and high temperature. In diffuse light, parts made from Styrolux retain their optical and mechanical properties for many years. However in outdoor applications the material can be degraded by the high energy content of sunlight, resulting in yellowing and deterioration of mechanical properties. Styrolux is not recommended for outdoor applications. The time to onset of yellowing can be considerably prolonged by using UV stabilizers.

Sterilizability

Styrolux can be sterilized either with high-energy radiation (g- or b-radiation) or with ethylene oxide (ETO). Styrolux retains most of its mechanical properties during this process.

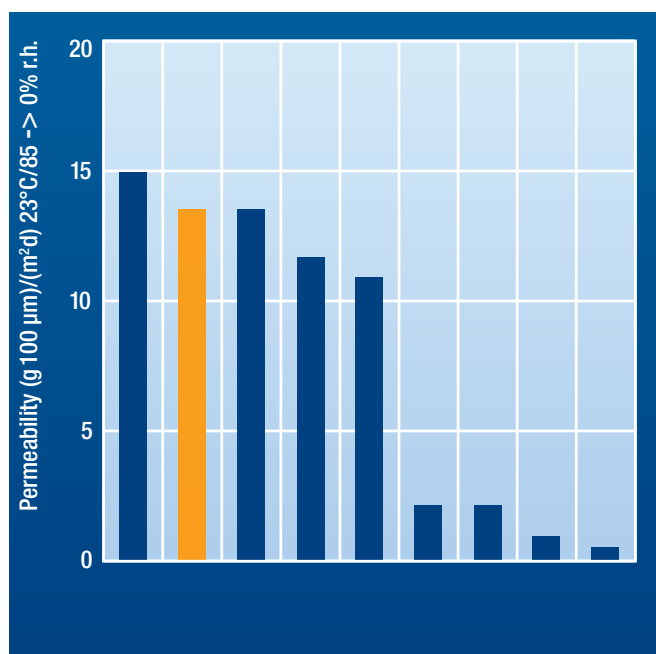


Fig. 33: Water vapor permeability of various plastics.

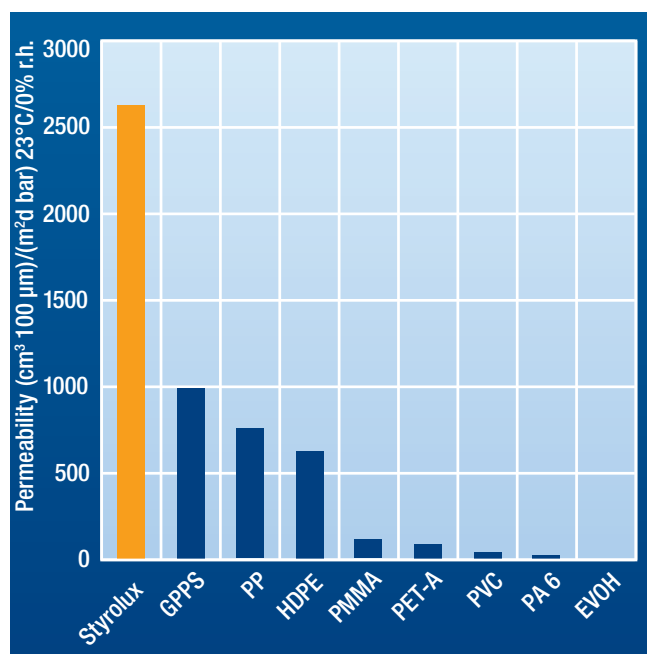


Fig. 34: Oxygen vapor permeability of various plastics.

Processing of Polystyrene and Styrolux®

General information

Polystyrene can be processed by all techniques customarily used for thermoplastics. It has good thermal stability and can be processed under a wide range of conditions.

Predrying

Polystyrene molding compositions do not normally have to be predried before injection molding, but predrying is advisable if they have been stored in an outdoor hopper. (predrying at 60-80 °C for 2-3 hours.)

Since even small amounts of moisture can cause problems in extrusion, it is always advisable to carry out predrying or to employ vacuum-vented screws.

Compatibility

All Polystyrene grades are compatible with one another. It is possible to change from one Polystyrene grade to another, e.g. from semi-high-impact to high-impact Polystyrene, without any special measures being needed. On the other hand, Polystyrene is incompatible with acrylonitrile-containing products and with polyethylene, polyamide, polyester, acetylcellulose and other thermoplastics. In these cases, the machinery must be thoroughly purged before a change of material.

Recycling

Scrap is obtained in the form of trimmings in extrusion, punching scrap in thermoforming, sprues in injection molding, flash in blow molding and reject parts in all four processing methods. These can add up to a total of as much as 50%.

Polystyrene regrind is fully reprocessable as long as the recycled material has not been damaged by excessively high shear or temperature. The usability of regrind should nevertheless be carefully checked in each case for parts which have high quality requirements.

Indications of product damaging having occurred are:

- An increase in the monostyrene content
- A decrease in the molecular weight of the matrix
- Rubber crosslinking
- A change in the rubber morphology (fragmentation)
- Conspicuous tendency to yellowing.

In such a case, advice should be sought from BASF's Technical Service team.

The regrind must be free of contamination. To protect the regions of the processing machine which come into contact with the melt, it should where possible be passed through a magnetic sieve before being introduced into the feed hopper. Regrind with particles of widely differing substance and with a low bulk density can cause problems in maintaining a stable extruder throughput.

Fines have a particularly detrimental effect, resulting in screw slip. They should be removed in a cyclone.

Injection molding

Polystyrene molding compositions are injection molded predominantly on screw-type machines. Only in exceptional cases (e.g. moldings with a marble effect) are injection molding machines with special screws or plungers employed.

Owing to their amorphous structure, Polystyrene molding compositions have not only a wide processing range but also low tendency to distort and low shrinkage.

Injection unit

Screw geometry

Conventional all-purpose screws can be used. Good results are obtained using three-zone screws having an L:D ratio of from 16:1 to 20:1 and the features indicated in Table 5. Although longer screws melt the granules more uniformly, they at the same time increase the residence time of the molding composition in the barrel.

Nonreturn valves

The only reliable means of ensuring a constant cushioning effect and follow-up pressure is to install a nonreturn valve that prevents the melt from flowing backward into the front screw flights during the injection and follow-up phases. Since designs giving excellent flow are available, a nonreturn valve should always be used as a matter of principle when manufacturing precision parts. However, the screw must then not be allowed to rotate during injection, since otherwise damage to the machine may result.

Nozzle

Since Polystyrene melts are more viscous than, say, nylon melts, they allow open nozzles to be used. Open nozzles offer the advantage of a very simple design that favors easy flow.

Nozzles with shutoff devices can be recommended if the back pressure is high, cobwebbing is to be avoided and moldings with thick walls are to be produced.

Thick-walled moldings frequently require cycle times of several minutes. If, in such cases, the injection molding composition is not removed completely from the nozzle bore, it may cool excessively there and thus give rise to streaking in the next shot. Best results have been given by nozzles with mechanically or hydraulically actuated needle valves, although the pressure drop in such a nozzle is not inconsiderable.

Injection molding tools

Gating and mold design

In principle, all conventional types of gating are possible. The gate cross section must be sufficiently large to avoid unnecessarily high melt temperatures and injection pressures which could lead to streaking, burn marks, voids and sink marks. The VDI 2006 guidelines for gating and mold design also apply to the Polystyrene molding compounds.

Demolding

As a rule, Polystyrene can be demolded without difficulty.

A taper of 1:100 or 30' on one side is a sufficiently large draft. In fact, if the mold is polished in the machine direction, drafts of down to 10' are adequate.

Use of inserts

Metal inserts do not obstruct the smooth flow of Polystyrene, but they should be heated to 80-120 °C before being placed in the mold in order to avoid molded-in stresses. They must be thoroughly degreased and secured in the mold by means of milled edges, circumferential grooves or the like. The metal edges should be well rounded off.

Mold temperature control

A well-designed mold temperature control system is of great importance because the effective surface temperature of the mold exerts a critical effect on the finish (gloss, brilliance and absence of flow lines), the strength of weld lines, the resistance to warpage, the shrinkage and the adherence to tolerances.

Depending on requirements, temperatures of from 10 to 70 °C are customary. Very thin-walled parts which have to be produced with short cycle times can also be injection molded at mold surface temperatures of less than 10 °C. At even lower mold temperatures, brine has to be used as coolant.

One means of counteracting any tendency of the molding to warp is to cool the two halves of the mold separately to different temperatures.

Table 7: Typical values for the screw geometry (injection molding)

Length of function sections		Depths of flights		
		D*	h _E	h _A
Total length	L 16 - 20 D	D* mm	h _E mm	h _A mm
Feed section	L _E 0,5 L	30	5	2,5
Compression section	L _K 0,3 L	50	6	3
Metering section	L _A 0,2 L	70	8	4
		100	10	5
		130	12	6

D* = screw diameter;

h_E = depth of flights in the feed section;

h_A = depth of flights in metering section

Processing of Polystyrene and Styrolux®

Injection molding / Polystyrene

Injection temperature

Polystyrene can be injection molded at melt temperatures between 180 °C and 260 °C.

The melt temperature has a significant influence on the toughness of the finished parts, particularly that of the rubber-modified Polystyrene molding composition.

If the residence time of the melt in the barrel is relatively long, the temperature should not be in the upper end of the range or even above it, since otherwise thermal degradation and/or an increase in the residual styrene content can result (Fig. 35).

Thermal degradation can usually be recognized by silver streaks or burn marks. A change in color can also occur. The melt temperature is best monitored by means of a penetration thermometer on the pumped-out composition.

Feed characteristics

The feed characteristics of Polystyrene are influenced by screw geometry and rotational speed, back pressure, the temperature settings in the plastification and feed sections and also by the shape and nature of the granules (externally lubricated or unlubricated).

As a rule, Polystyrenes can be plastified uniformly and without thermal degradation even at high screw speeds. Normally, the plastification capacity increases with a rise in temperature.

Frequently, the individual heating zones of the plastification barrel can be set to the same temperature. However, if the processing temperature is in the upper end of the batch and/or if the cycle times are long, the temperature of the first heating strip (close to the hopper) should be set at a somewhat lower value. This prevents premature melting of the granules in the feed section (bridging).

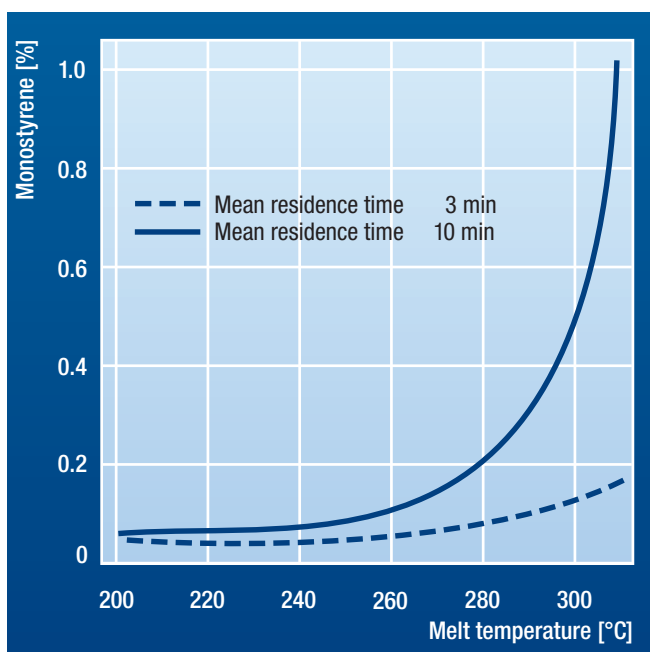
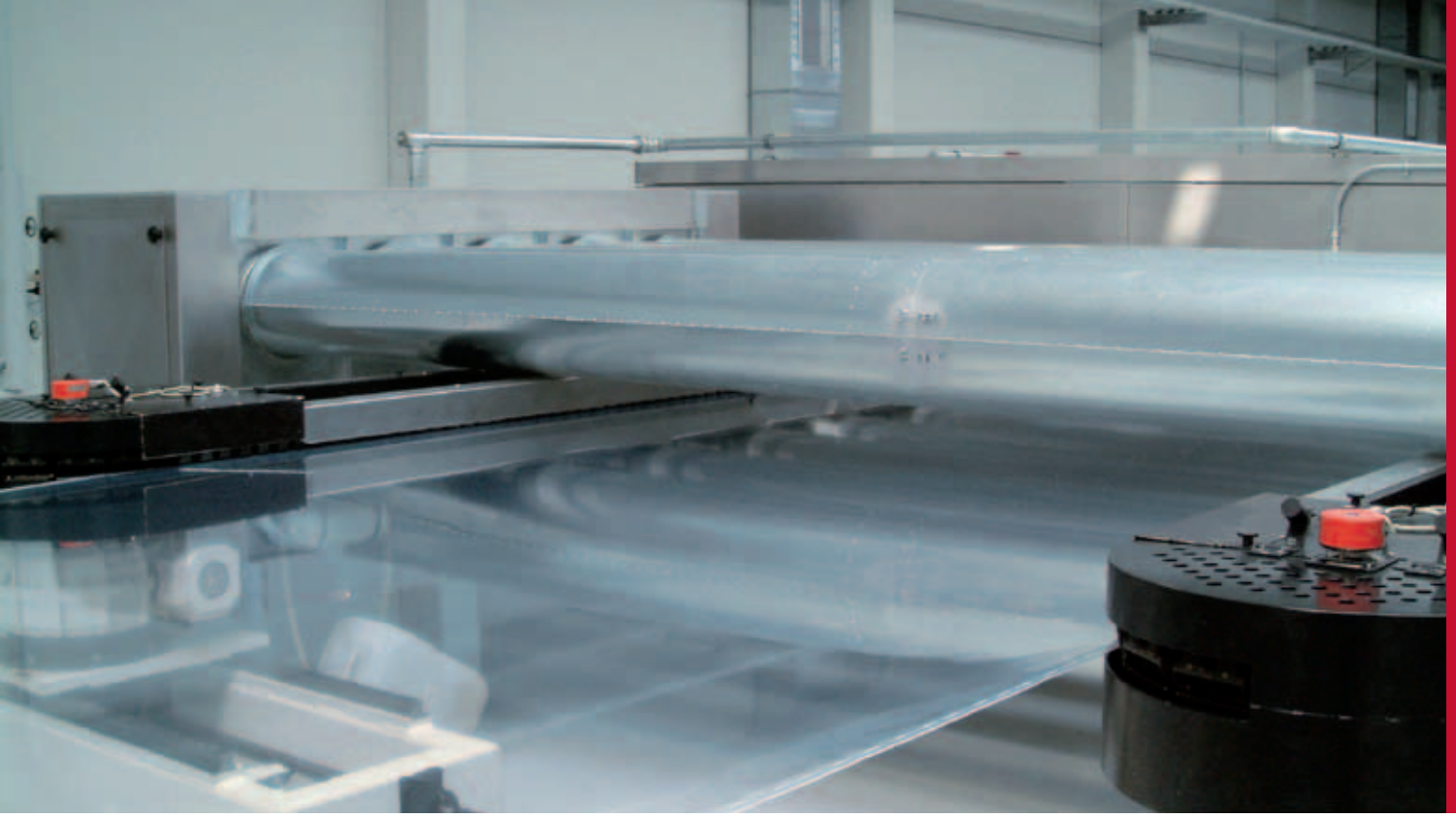


Fig. 35: Monomeric styrene content as a function of melt temperature and residence time.



Refrigerator inserts



Filling of the mold

A general rule for Polystyrene is that the mold must be filled as rapidly as possible to prevent marks at the weld lines and to ensure that the weld lines are as strong as possible. Another advantage of a high injection rate for most Polystyrenes is that it yields glossy and brilliant moldings. The only Polystyrenes for which very fast injection can have a detrimental effect are the high-impact grades with high heat distortion resistance, in which case matt concentric zones around the screw may occur under some circumstances. Dark-colored products are particularly prone to this effect. Fluctuations in the injection rate may also cause matt streaks in these products. In such cases, slower injection at higher melt and mold temperatures leads to more uniform flow and improves the surface.

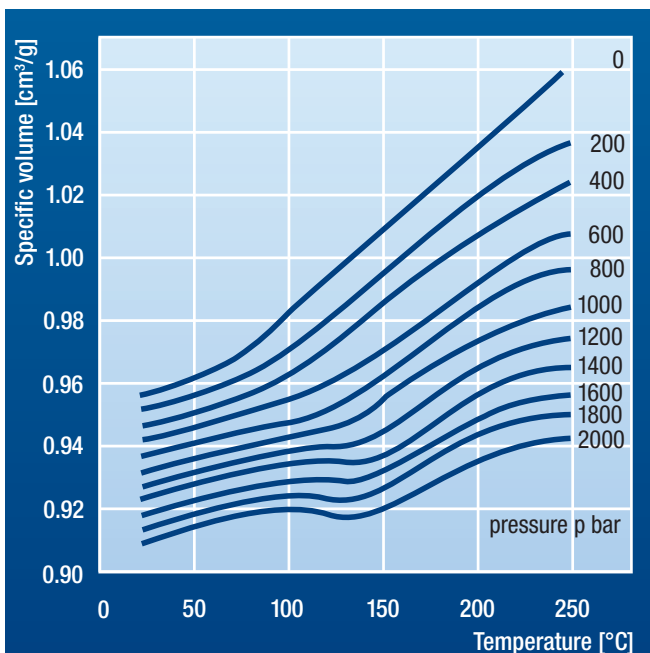


Fig. 36: Specific volume of general-purpose Polystyrene as a function of temperature and pressure.

Steps must be taken to ensure that air can easily escape from the mold at suitable points to prevent burning as a result of compressed air (diesel effect).

To obtain perfect injection-molded parts and to prevent void formation, the follow-up pressure and screw forward time must be sufficiently high to compensate for the volume contraction on cooling of the melt. This requires the gates to be large enough to prevent the melt from solidifying in their vicinity before the screw forward time has elapsed and thereby stopping the follow-up pressure from acting on the molding while it is still plastic in the interior. However, the volume expansion experienced by Polystyrene as a result of heating can be more than compensated for by high pressure. The dependence of the specific volume vs on temperature T and pressure p is shown for general-purpose Polystyrene in Fig. 36.

It can be seen from this graph that the volume expansion caused by heating from 20 °C to 200 °C is just compensated at a pressure of 1400 bar. If the melt solidifies at a point of higher pressure within the mold cavity, the volume element concerned has to accommodate more compound than it actually can. This state is known as overloading.

Overloading gives rise to molded-in stresses which may cause general-purpose Polystyrene moldings to rupture on demolding. The impact-modified grades, on the other hand, can take up the stresses more readily because of their higher ductility. The risk of overloading exists mainly in the vicinity of the sprue at high injection rates and high follow-up pressures.

Processing of Polystyrene and Styrolux®

Flow

The Polystyrene product line includes grades having different flow characteristics. The measure usually used for the flow is the melt volume index in accordance with ISO 1133. The product overview at the end of the brochure gives information about the flow behavior of the individual Polystyrene grades.

Information of great practical significance is obtained from flow tests in which coils of various thicknesses are produced in a spiral mold (Figs. 37 and 38). At a given melt temperature, mold surface temperature, screw advance rate and the corresponding injection pressure, the length of the spiral can be regarded as a measure of the flow of the product.

Cycle time

A factor that decidedly affects the duration of the injection cycle is the time taken for the Polystyrene to cool from the melt temperature to the solidification point. The lower this temperature difference, the shorter the cooling time and thus usually also the cycle time. The difference between melt temperature and solidification point depends on the particular Polystyrene grade.

A measure of the solidification point is the Vicat softening temperature. The higher the flow of Polystyrene, the lower the temperature at which it can be processed, so Polystyrene grades which flow easily and at the same time solidify rapidly can be processed most quickly.

Shrinkage

Polystyrene undergoes considerably less shrinkage than partially crystalline plastics. Although it is primarily a material property, it is also decisively influenced by the geometry of the moldings (restricted or free shrinkage) and by processing conditions such as melt temperature, mold surface temperature and follow-up pressure.

Local interplay between these parameters may cause great differences in shrinkage within one and the same molding.

As a rule, the processing shrinkage is between 0.4 and 0.7%, but in exceptional cases it can be significantly below 0.4%. It may even be zero in zones within the molding that are subjected to a high follow-up pressure (vicinity of the sprue).

After-shrinkage can be neglected in most applications; it accounts for about 10% of total shrinkage.

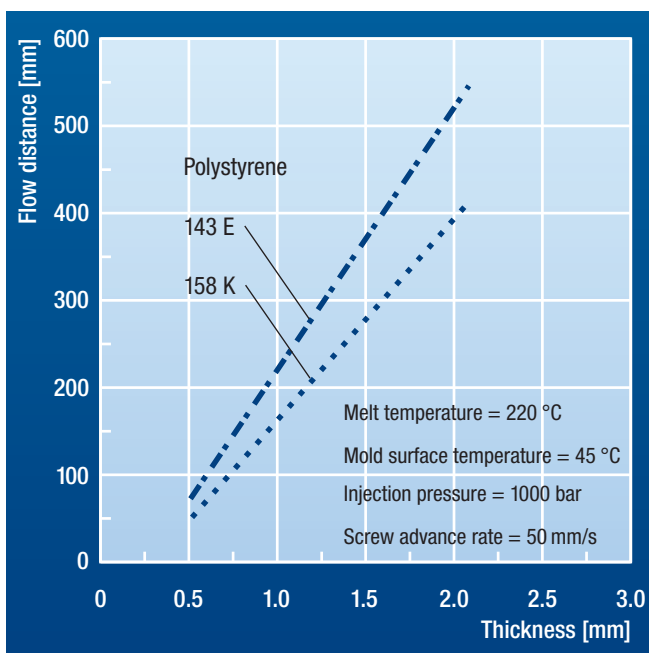


Fig. 37: Flow in a spiral mold, general-purpose Polystyrene.

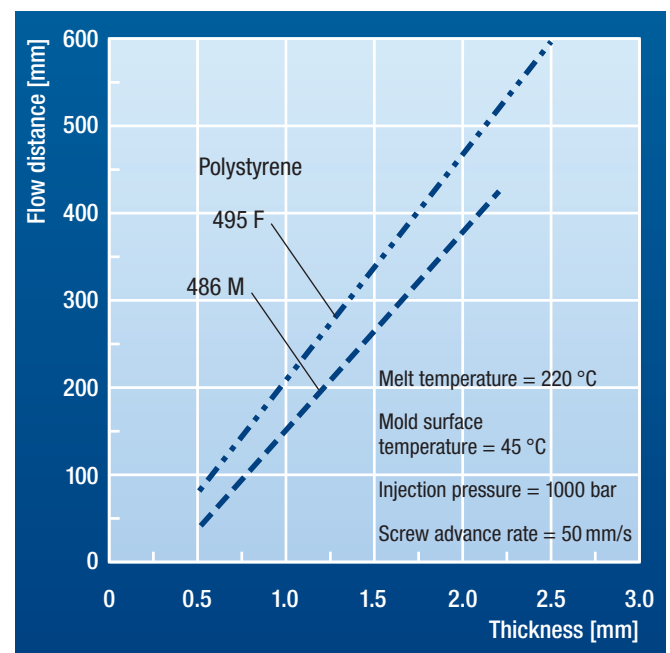


Fig. 38: Flow in a spiral mold, high-impact Polystyrene.

Processing by injection molding

The tough and rigid Styrolux® grades 656 C and 684 D are the preferred choices for injection molding. In order to improve the stiffness and dimensional stability under heat, in injection molding as well, Styrolux is sometimes blended with up to 40% general-purpose polystyrene (GPPS); the production of highly transparent parts calls for a plasticising unit that is capable of good mixing.

Injection molding unit

Universal screws with a length of 16 D to 20 D are suitable. The pitch along the entire length should be constant at a value between 0.8 D and 1 D.

Injection molding tools

The shaping tool surfaces have a great influence on the transparency and gloss of the injection molded parts. The tiniest flaws on the tool surfaces are reproduced, as a result of which high-gloss and polished surfaces are recommended. Care should be taken to ensure that the draft is at least 1°. For the mold parting surfaces, a compromise should be sought between a tight seal – for the eventuality of flashes – and sufficient venting.

The tool surface temperatures should be set between 20 °C and 50 °C [68 °F and 122 °F], depending on the grade of Styrolux. Too low a temperature can give rise to streaks and flow marks. Too high a temperature leads to adhesion, which also causes cracks or fissures. Here, mention should be made once again of the polish in the de-molding direction in order to effectuate the best possible de-molding.

Processing instructions

Generally speaking, a low ratio of the barrel contents to the shot volume, a low rotational speed of the screw and working with little or no back pressure are advantageous.

In the case of short production downtimes, it is usually sufficient to lower the melt temperature and then to pump off the melt; at the end of longer pauses, in contrast, we recommend flushing with high-viscosity general-purpose polystyrene.

The melt temperatures should not exceed 250 °C [482 °F] and the residence time in the cylinder should not be too long. An injection time that is as high as possible is a decisive factor for the optimal transparency and brilliance of injection molded parts. Here, a slight loss in toughness will have to be accepted.

Any commonly employed type of gate, also hot runner systems, can be employed. With a hot runner system, the configuration must be such that no localized overheating ($T > 250\text{ °C}$ [482 °F]) can occur. Adequately dimensioned runners and gates prevent thermal overloads.



Fruit bowl

Processing of Polystyrene and Styrolux®

Feed characteristics

The feed characteristics of Styrolux® are not problematic. It is best for the temperature gradient from the hopper to the tip of the screw to rise slightly. The cross head must be cooled.

Flow characteristics

The flow test with the test spiral at wall thicknesses of 1 mm to 2 mm reveals an almost linear dependence of the flow lengths on the melt temperature (Fig. 39). At a wall thickness of less than 1 mm, only short flow lengths are possible since the flow resistance rises disproportionately as the wall thickness decreases. Melt temperatures of more than 250 °C [482 °F] cause cross-linking of the material and consequently the flowability drops once again. The onset of cross-linking is also indicated by turbidity and yellowing.

De-molding

Owing to its morphology, Styrolux adheres more strongly to steel surfaces than high-impact polystyrene does. Therefore, it requires a greater force in order to overcome the static friction during the first phase of de-molding. It is helpful to select a high injection pressure and back pressure. Due to the high compressibility of Styrolux, the part is slightly compressed. Following pressure relief, the part relaxes and is easier to release from the core. Excessive injection pressure and back

pressure cause greater deformations in the part. A possible consequence after the pressure relief is that the part could become jammed in the mold cavity. This should be optimized by means of experimentation.

In comparison to general-purpose and high-impact polystyrene, the lower dimensional stability and softening temperature of Styrolux mean that the cooling times, and hence the cycle times, will be longer, even in the case of intense cooling. The demolding behavior can also be improved by adding Styrolux Batch ASE in an amount of 2 % to 4 %.

Shrinkage

The shrinkage values of Styrolux lie between 0.3% and about 1%. They are the lowest parallel to the direction of flow, somewhat higher transversally to the direction of flow near the gate and highest far away from the gate (Fig. 40). The shrinkage and the shrinkage differences can be influenced by regulating the melt temperature. High melt temperatures yield lower shrinkage values and smaller differences between the positions near and far away from the gate.

The temperature of the tool surface and the injection speed are less decisive for the shrinkage.

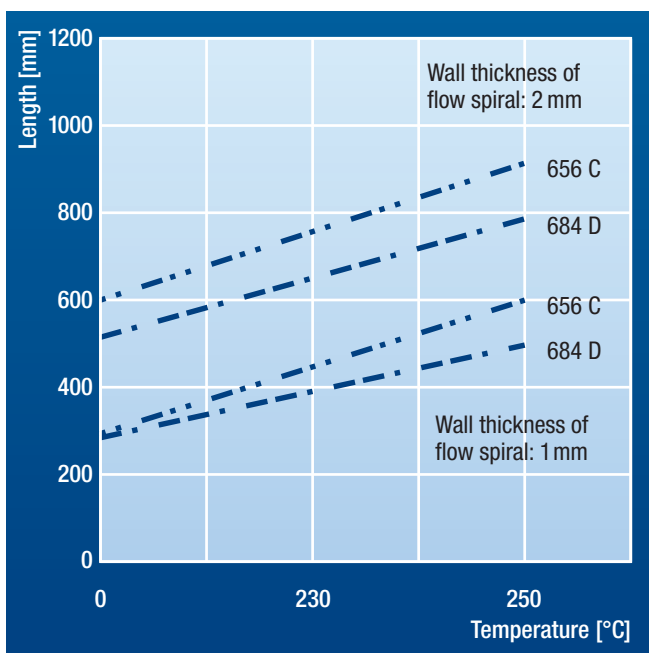


Fig. 39: Flowability of Styrolux® in the spiral flow test, injection pressure of 1500 bar.

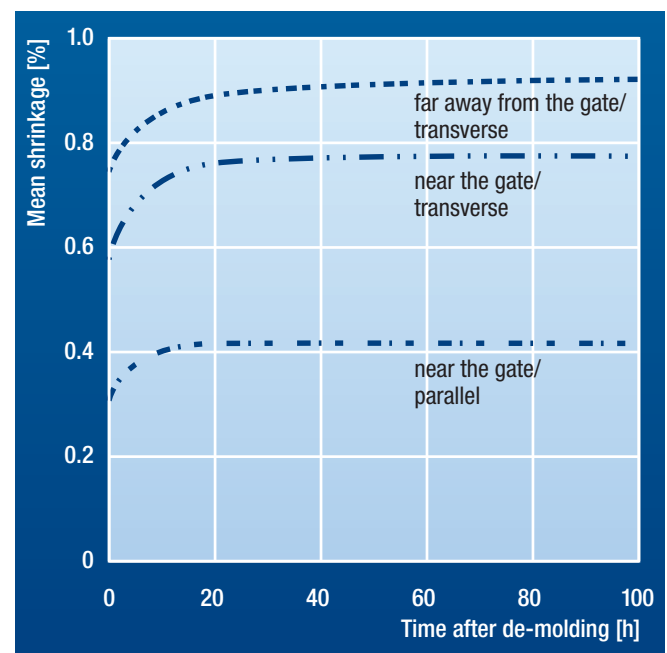


Fig. 40: Shrinkage of Styrolux® 656 C.

Compressibility and warpage

Styrolux® is considerably more compressible than high-impact polystyrene. This is why centrally gated rectangular parts can exhibit larger internal stress differences between the shortest and the longest flow distances. In conjunction with the lower dimensional stability, the molded parts can undergo warpage even hours after the de-molding. Since there is a direct relationship between the warpage and the modulus of elasticity, a Styrolux grade with a high modulus of elasticity should be selected for parts where low warpage is critical.

Extrusion / Polystyrene

The most suitable Polystyrenes for extrusion are those with a high viscosity, i. e. products with a melt volume index MVI 200/5 in the lower end. However, materials with a higher MVI are also used for multilayer composites.

The desired ratio of rigidity to toughness can be obtained by blending high-impact and general-purpose Polystyrene. An important point to observe for ensuring a homogeneous melt is that the flow characteristics of the blend components do not differ too widely (the flow is indicated by the final letter in the product designation). Equipment items required are a metering and mixing device upstream of the extruder inlet and a mixing element in the melt region upstream of the die.

Examples of preferred combinations for packaging material are:

- Polystyrene 486 M and Polystyrene 165 H
- Polystyrene 145 D combined with impact-resistant polystyrene is particularly well-suited for FFS films.
- If Polystyrene 143 E is already being used for the extrusion of high-gloss composites, it can also be blended with 486 M to reduce inventories.
- On the other hand, Polystyrene 158 K could be considered for blending with 486 M if the heat distortion resistance of the mixture is to be increased at the same time. The mixing ratio depends on the application and is usually between 1:1 and 4:1 (= PS-I:PS).



Plastic fish plate

The bursting pressure test on finished, thermoformed cups gives a good guide to the toughness of the material used. The bursting index as a function of the mixing ratio is shown for two examples of blends in Fig. 41. This demonstrates the advantage of the higher impact toughness of 486 M in blends with 165 H compared to mixtures of 165 H and conventional high-impact polystyrene.

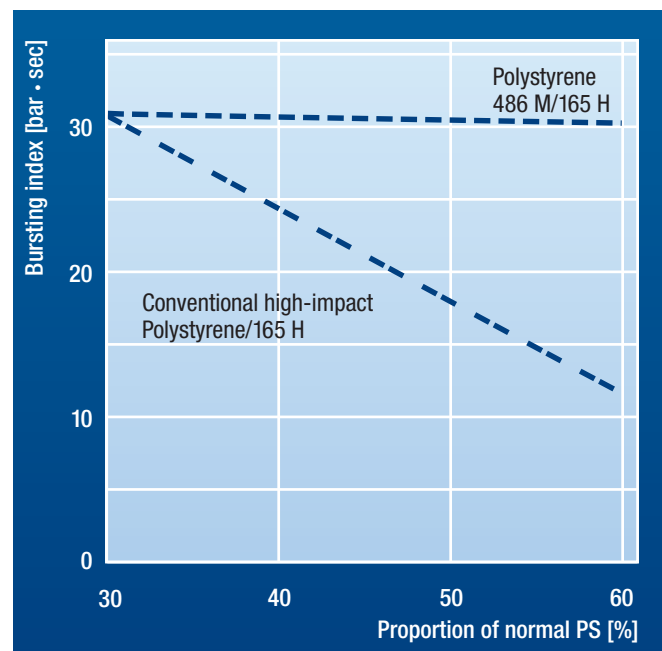


Fig. 41: Bursting pressure test on drinking cups.

Processing of Polystyrene and Styrolux®

Processing conditions

The processing temperatures for Polystyrenes lie between 180 and 240 °C, in individual cases even a little higher. As a rule, the grades with a higher viscosity are extruded at a higher temperature. Pressure and temperature of the polymer should be measured where possible by means of suitable devices. In practice, the screw pressure ranges from 100 to 200 bar. For safety reasons, a maximum pressure warning device should be fitted.

Vented extruders

Vented extruders allow the extraction of volatile constituents (e.g. low molecular weight fractions, moisture) from the melt and the removal of entrapped air.

The “classical” vented extruder screw can be likened to two three-zone screws arranged in tandem (Fig. 42). The length of modern vented extruders is in the range 30-36 D. The compression ratio should generally be between 1:2 and 1:2.5 for Polystyrene.

Compression ratios of 1:3 can also be employed when processing up to 50% of regrind.

Venting occurs between the two screw sections; substances are collected in the form of liquids or pastes in the condenser between the venting port and the vacuum pump. The venting effect is initiated by the pressure drop that occurs downstream of the first metering section and is reinforced by a partial pressure increase that is brought about by raising the melt temperature in front of the venting section.

In many cases, a shear ring is installed at the end of the first screw section to aid venting. The geometry of the shear ring has to be matched to the plastic in order to avoid thermal degradation of the material; this applies particularly when processing SBS copolymers (Styrolux®).

In the upper range of screw speeds, some of the air present in the interstices between the granules may no longer be able to escape through the feed hopper. The trapped air leads to bubbles and holes in the extrudate. The vents on high-performance extruders should therefore be designed with generous dimensions. The vent should be horizontal or inclined slightly downward to prevent condensed, thermally degraded material from falling back into the screw channel.

In principle, Polystyrene can also be extruded without the use of a vented extruder. In this case, the granules should be predried, depending on the Vicat softening temperature of the Polystyrene used, at temperatures of 60-70 °C for 3-4 hours, e.g. in a hot air drier or a vacuum drying oven.

It has been found in practise that predried granules cause fewer production and quality problems in the long term, although films which have been produced without the use of a vented extruder have inferior organoleptic characteristics.

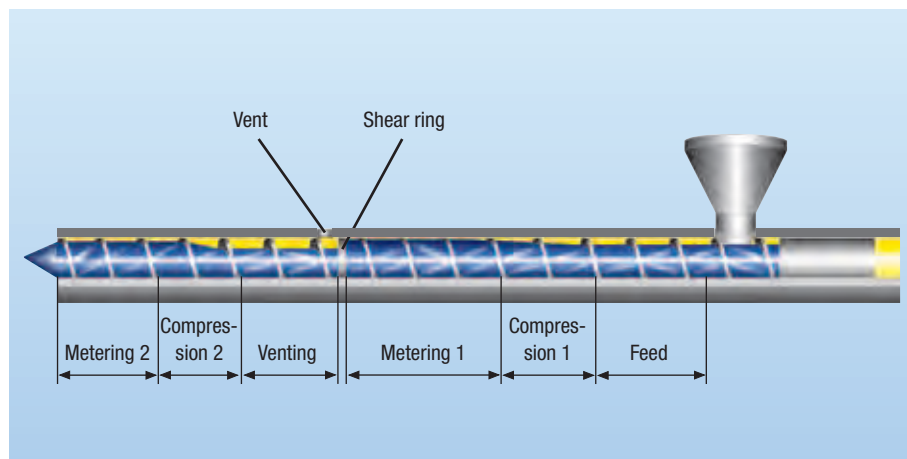


Fig. 42: “Classical” vented extruder screw.

Design of vented extruder screws

Vented extruder screws generally have smooth feed sections. Lightly grooved feed sections are sometimes also used for better and more stable feed and transport behavior. Virtually no use is made of actual grooved bushings, e.g. with rectangular grooves, since melting in the first stage and transport in the second stage are generally unsatisfactory for the high grooved bushing throughputs. Moreover, extrusion of recycled material (reground from extrusion of thermoforming and other sheet) comes up against processing limits (constancy of transport) when grooved bushings are employed.

Since both stages of a vented extruder screw are rigidly coupled to one another, the throughputs of the two screw sections have to be matched. If this is not the case, the following problems occur:

- Melt may exude from the vent if the throughput of the first screw section is too high (flooding)
- Surging if the throughput of the first screw section is too low (excessively large partially filled regions in the second stage).

Experience has shown that both phenomena can be described with sufficient accuracy by means of a screw simulation program (REX). The decisive parameter is the pressure profile in the region of the extruder through which melt flows. Fig. 43 shows the two pressure profiles for flooding (pressure at the vent is too high) and surging (pressure buildup is too late). The figure also shows an ideal pressure profile between the these two phenomena.

Melt pump

A melt pump is a further extruder component which can improve the quality of the extrudate. Installation of a melt pump enables the throughput to be made uniform and the second screw section is largely relieved of the task of building up the pressure to overcome the resistance of the die. Only the minimum pressure for trouble-free operation of the melt pump has to be generated, thus lowering the pressure in the extruder.

Consequently, high-performance screws for vented extruders with melt pumps can be designed for higher plastification capacities than those for vented extruders without melt pumps. However, this means that a higher melting capacity is required in the first screw section. It is also necessary to take into account that the melt pump introduces shear and thereby slightly increases the melt temperature.

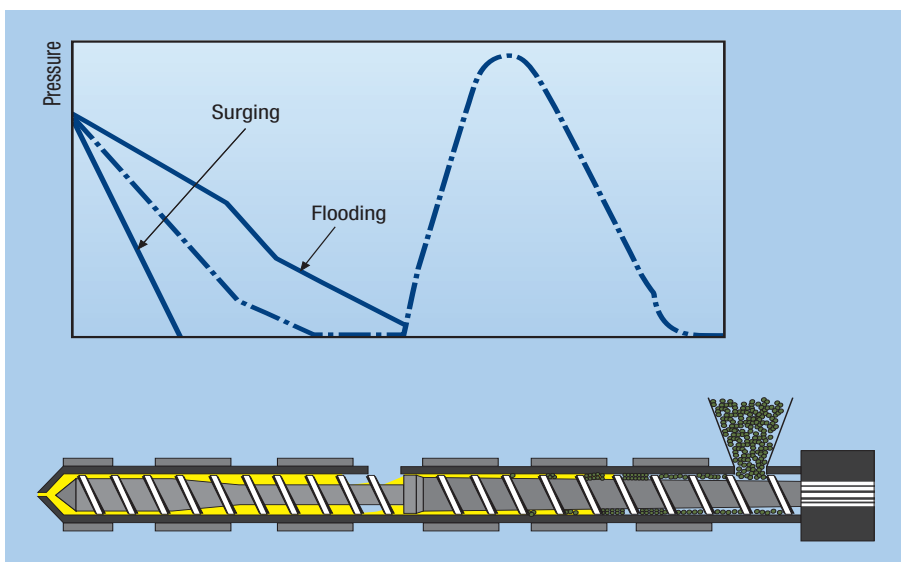


Fig. 43: Different axial pressure profiles.

Processing of Polystyrene and Styrolux®

Melting

Apart from achieving the desired throughput (without flooding or surging), complete and correct melting is of decisive importance in judging a plastification unit. There is little value in achieving a maximum throughput unless complete melting can be achieved before the vent so that satisfactory venting can take place.

The percentage of melt and the dimensionless solids bed width Y are calculated by means of the simulation program. Y is defined as the solids bed width X divided by the channel width b (based on the solids channel in the case of barrier screws). Fig. 44 shows an example of a calculated melting profile.

The melting profile enables predictions to be made as to the ratio of transport and melting capacity of the screw and also makes possible a qualitative estimate of the achievable homogeneity of the melt in front of the screw.

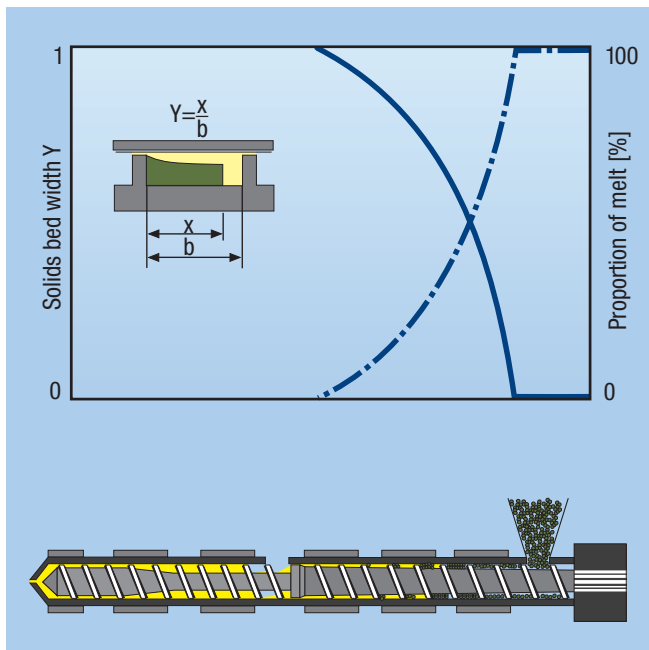


Fig. 44: Examples of a calculated melting profile (material: PS 486 M).

Design variants

Relatively recent screw concepts or modifications (e.g. barrier zones or increases in pitch) are being tested with the aim of further increasing the throughput or melting capacity at the same screw diameter. A higher throughput necessitates a simultaneously higher melting capacity.

Fig. 45 shows the effect of a higher pitch in the second screw section on the pressure profile under otherwise identical conditions (same throughput). In this example, the increase in pitch can prevent flooding of the vent.

A further possible design of vented extruder screws incorporates barrier zones in the first screw section so as to ensure complete melting by the end of the first screw section.

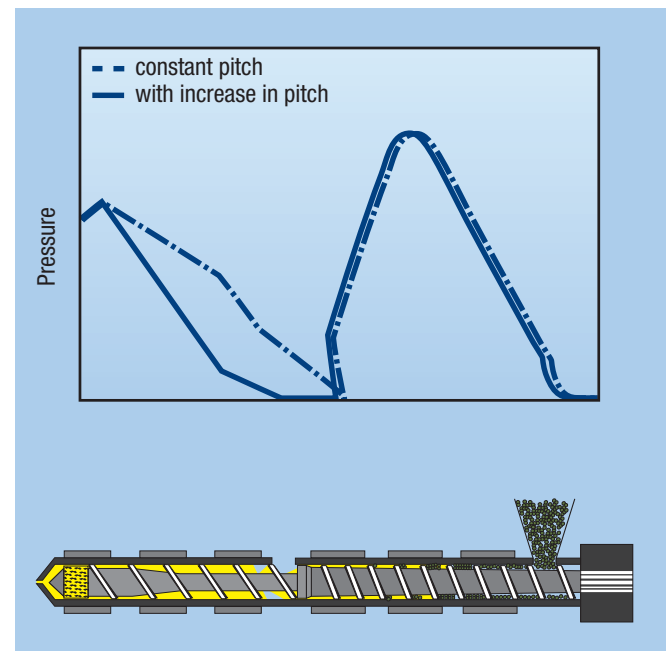


Fig. 45 Effect of pitch on the pressure profile (material: PS 486 M).

Barrier screws

Owing to the relatively uncomplicated extrusion behavior of Polystyrene, barrier screws have rarely been encountered on the market. Nevertheless, in particular cases they can be an interesting alternative because of their specific melting characteristics.

All barrier zone extruders function in the same way. The characteristic feature is the division of the screw channel into a solids channel and a melt channel (Fig. 46). The solids channel is separated from the melt channel by the barrier flight. The gap between the barrier flight and the barrel is greater than for the main flight so that only molten material or particles which are (at least in one direction) smaller than the gap can get into the melt channel. When passing over the barrier flight, these particles are subjected to additional, defined shear which leads to further melting of the remaining solid particles. In addition, the barrier flight contributes to homogenization of the melt.

Advantages of the barrier section are the controlled melting process and the increased number of degrees of freedom in the design of the screw geometry. The latter feature enables the screw geometry to be more closely matched to a particular application, although the system does also have more possible sources of error which have to be ruled out.

Good results have been achieved in recent years in the extrusion of other thermoplastics using the barrier screw concept. Efforts are being made at present to apply this experience to the field of vented extruder screws with the object of increasing plastification.

Vented extruder screws with barrier zones should, like other screw designs too, be provided with a mixing section at the tip of the screw in order to achieve sufficient homogenization when processing blends.

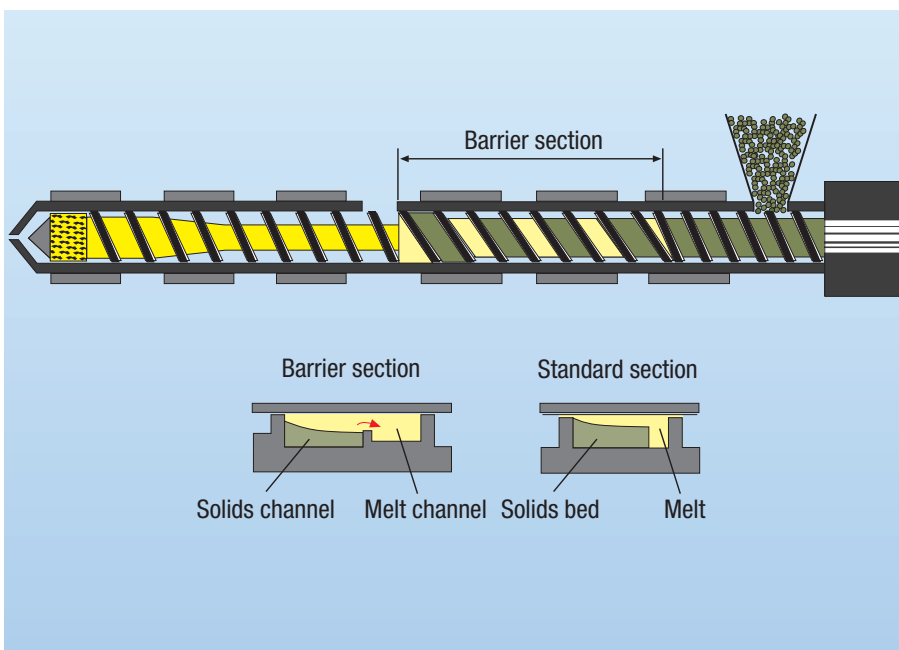


Fig. 46: In-principle illustration of a vented extruder screw with barrier section.

Processing of Polystyrene and Styrolux®

Mixing elements

Examples of proven dynamic mixers are faceted mixing sections and toothed disk or slotted disk mixing sections (Fig. 47), but other types are also used. The mixing sections should cause as low as possible a pressure drop so that the throughput of the second screw section is not reduced too much.

Particularly in the case of retrofitting, the homogeneity of the melt can be increased by means of a static mixer which can be used in addition to the dynamic mixing section.

Dies

Slit dies are used for the extrusion of both flat film and sheet.

In both cases, the length of the parallel zone is about 20 times the slit width. Sheets are usually produced using an adjustable choker bar, while films are produced without it. When a choker bar is employed, it is set obliquely as shown in Fig. 48.

The lower lip is interchangeable in order to cover a greater thickness range.

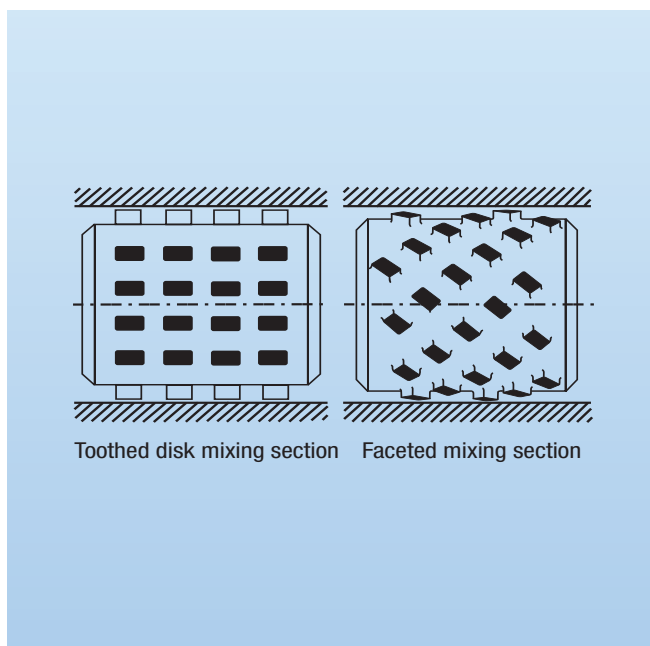


Fig. 47: Examples of mixing sections.

Calibration rolls

On leaving the die, extruded sheet is led through calibration rolls. The roll temperature should be as high as possible to keep molding-in stresses to a minimum during cooling. A rule of thumb is that the temperature at the surface of the center roll should be about 5 K below the limit at which the extruded sheet sticks to the surface of the steel. This gives an idea of the most favorable temperature settings on all the rolls for a given product under given conditions. If the melt is fed downward, the temperature of the upper roll should be set to a value well below that of the center roll, e. g. 10 K, because of the small contact area at the upper roll (theoretically, the contact is merely linear). The temperature setting on the lower roll should be between those on the upper and center rolls.

If curvature of the sheet occurs after passing through the rolls, the temperature settings need to be optimized. As a general rule: the concave side corresponds to a roll which is too hot and, conversely, the convex side corresponds to a roll which is too cold.

Orientation

The orientation or even prestressing of sheet intended for further shaping can be assessed by heat treatment as described in ISO 11501. Increasing the melt temperature is the most effective means of achiev-

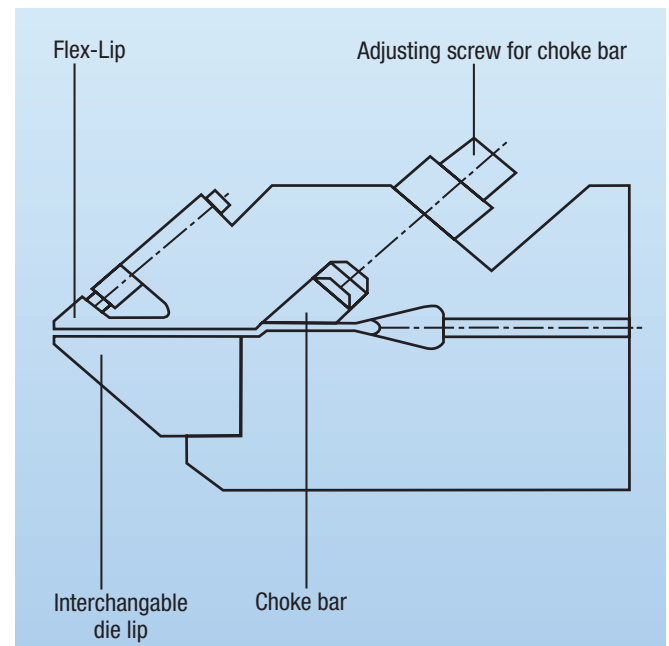


Fig. 48: Sheet die with choker bar and flex-lip.



ing low shrinkage, but this must obviously be kept to a level which does not cause appreciable degradation of the product.

Other available parameters, which have varying degrees of effectiveness, are die gap, distance between die and roll, roll temperature and tension on the sheet.

Coextrusion

Coextrusion enables the properties of several materials to be combined. It requires matching of the flow properties of the materials used. The extruded product is a multilayer composite in which the individual layers should adhere to one another. If the adhesion of the layers to be combined is nonexistent or inadequate, a layer of bonding agent has to be interposed. A distinction is made between adapter and die coextrusion. In adapter coextrusion, the composite is built up in front of the die and is extruded as if it were a single-layer melt.



Clothes hanger

In die coextrusion, the layers are formed separately in a special die and are subsequently joined. General-purpose Polystyrene is often used as a gloss layer on a high-impact substrate. In this combination with high-impact Polystyrene, no bonding agent is necessary. In most other cases, a bonding agent has to be used and the choice depends on the components of the composite.

Workplace emission and venting residues

An exhaust hood with condenser and collector should be installed above the die.

Under normal extrusion conditions, the condensed residues from the vent amount to 100-300 ppm of the product throughput, the actual figure depending on the melt temperature and the shear.

The condensed products consist essentially of water, lubricants, stabilizer, monostyrene and oligomeric styrene.

The nonaqueous fraction of the condensate can be disposed of under the same conditions that apply to waste oil. However, it should not be mixed with waste oil, since the latter is usually reprocessed.

There have been no reports of adverse effects on health which have resulted from correct processing of Polystyrene in well-ventilated areas.

Processing of Polystyrene and Styrolux®

Blow molding

The optimum conditions for blow molding bottles and other articles depend greatly on the type of machine and the nature of the molding and should always be determined beforehand. As in the case of injection molding and extrusion, changing the color of a given molding compound may require alterations in the processing conditions.

Thermoforming

Owing to their wide viscoelastic range, Polystyrene sheet and film are particularly suitable for thermoforming. The forming temperature should be between 130 and 150 °C.

Polystyrene extrusion grades can achieve high draw ratios. Thus, draw ratios of, for example, 5:1 in production of beakers and in the thermoforming of interior containers of refrigerators are common. This value can sometimes be even higher, as for the reinforcing ribs at the bottom of components or the depressions in the corrugations.

This high drawing capability can be seen particularly clearly in Fig. 49 which shows a plot of the AGK 5 hot elongation.

In this test, loads of 2 g/mm² are applied to test strips which are heated at 50 °C/h in an oven. The elongation is recorded as a function of temperature. Together with ABS, Polystyrene displays the most uniform increase in elongation and thus offers a wider processing window even at relatively high draw ratios than do the polyolefins. In the latter, the increase in elongation is significantly more abrupt, as a result of which the wall thickness distribution is considerably more difficult to control by means of different heater temperatures.

Another advantage of Polystyrene is that it absorbs less heat up to the thermoforming temperature, which has a favorable effect on the energy balance and the cycle time. Furthermore, heat absorption is uniform and can therefore be more easily controlled.

This behavior is shown in graph form in Fig. 50 where the heat capacity (enthalpy) is plotted against temperature.

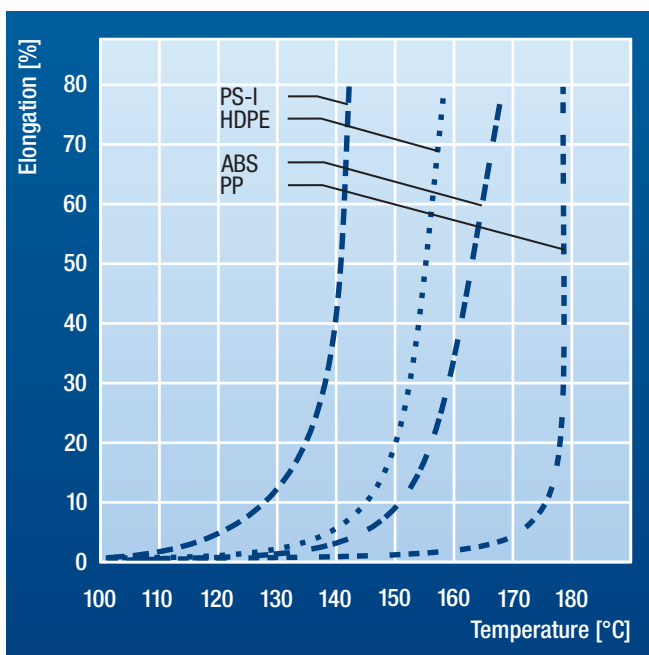


Fig. 49: AGK 5 hot elongation; load = 2 g/mm², heating rate = 50 °C/h.

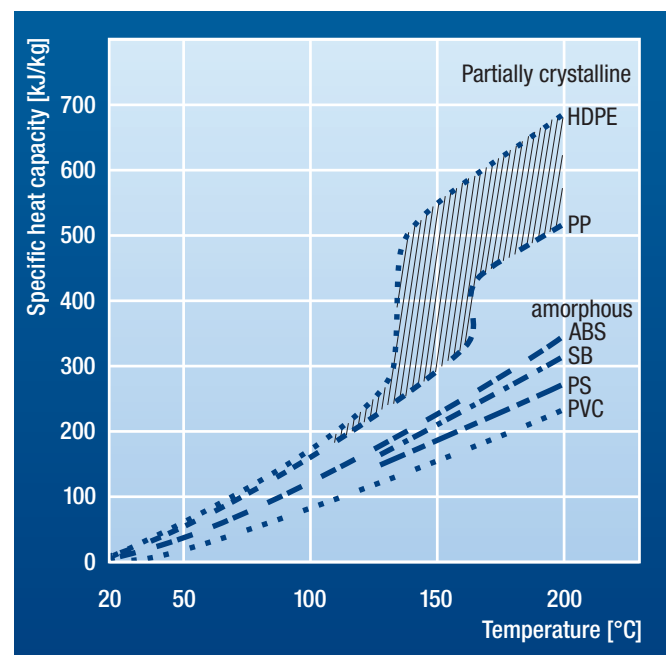


Fig. 50: Heat capacity of thermoplastics (reference point: 20 °C).



Refrigerator inner container

Machining

Semifinished Polystyrene parts can easily be machined by punching, sawing, drilling, milling, turning, etc., using the tools and machines customary for metalworking or woodworking.

Owing to the low thermal conductivity and the relatively low softening temperature, the cutting surfaces have to be cooled by a current of air or with water. The high-impact Polystyrenes have a lower tendency to splinter and can be machined more easily.

Joining methods

- **Welding**

Preference is given to ultrasonic welding.

- **Adhesive bonding**

Polystyrene parts can be bonded together with the aid of solvents such as toluene or methylene chloride, but only to parts made of the same material. We recommend that all questions regarding adhesive bonding be directed to a commercial adhesives manufacturer.

Surface treatment

- **Printing, surface coating**

Polystyrene can be easily and durably coated and printed by various techniques.

We recommend that manufacturers of surface coatings or printing inks be consulted in individual cases.

- **Metallizing**

Polystyrene articles can be provided with a mirror-like, metallic surface by high-vacuum metallizing.

Processing of Polystyrene and Styrolux®

Processing by extrusion

Styrolux® / GPPS-blends

In extrusion processing, particularly the tough Styrolux® grades 684 D, 693 D and 3G 55 in blends with general-purpose polystyrene (GPPS) are extruded to form films and then thermoformed into dimensionally stable finished parts. The mechanical and optical properties of the film and of the deep-drawn parts are determined to a large extent by the Styrolux grade, by the mixing ratio and by the GPPS type (see technical information, "Styrolux: mechanical and optical properties").

The biaxial stretching during the thermoforming considerably increases the toughness of the finished parts; therefore, highly stretched parts such as, for instance, beverage cups can be successfully manufactured with high contents of GPPS (> 50%). Blends containing 50% to 80% Styrolux have proven their worth for the majority of thermoforming applications.

Efforts should be aimed at optimizing the homogenization of the components, and this is achieved by a good mixing action of the screws used. Here, the viscosity of the GPPS component in the blend plays a role; it should preferably be close to the viscosity of the Styrolux and it should lie in the melt volume-flow rate (MVR) range of 8 to 16 [cm³/10 min].

Pre-drying

As a rule, the Styrolux granules do not have to be pre-dried. However, in the event of unfavorable storage or transportation conditions involving severe temperature fluctuations, moisture can condense on the surface of the granules and this then has to be removed in a pre-drying step. The granules should be pre-dried in a dry-air dryer for 3 to 4 hours at a temperature of about 50 °C [122 °F].

Extruder and Screw geometry

Styrolux and blends with GPPS can be processed on all conventional extrusion installations that are also suitable for high-impact polystyrene, polyethylene or PVC. A high L/D ratio is advantageous for the homogenization and for reducing the sensitivity to pressure fluctuations. However, with an eye towards keeping the residence times short, this ratio should not be too large either. As a rule, L/D ratios between 24:1 and 36:1 meet both of these requirements.

Vented extruders are recommended for the production of high-quality packaging films. They permit the extraction of volatile components and moisture from the melt as well as the removal of entrapped air.

Screws with medium compression ratios (2.5:1 to a maximum of 3.5:1)

have been found to be optimal, that is to say, universal screws (PE, PP) can also be employed. Excessively high shearing elements (barrier zones, shear sections), however, can cause damage to the product (cross-linking, gel specks). Generally, the use of a melt pump is recommended.

Flat film extrusion dies and polishing stacks

Chrome-plated and polished flat film extrusion dies with an adjustable die gap (flex lip) and choke bars are recommended, and the die gap should be set at +5% to +10% above the desired film thickness in order to minimize orientation in the film. The line speed should be set in such a way that the melt cushion in the bead of plastic material remains very small. Otherwise, if a larger melt volume were fed in, there would be a risk of wave formation and other visible surface flaws. Optimal roller temperature control is important for attaining high quality in terms of the transparency, gloss and surface finish of the films. It is recommended to initially set the first deflector roller at a temperature up to the sticky limit and then to lower the temperature by 10 °C [18 °F]. For this purpose, the temperature of the polishing stacks should be regulated individually (up to about 80 °C to 90 °C [176 °F to 194 °F]). Polishing stacks that are too cold leave markings on the surface.

Production of film reels

When film reels are produced, care should be taken to ensure that the film temperature is lowered as far as possible, for instance, to about the ambient temperature (between 25 °C [77 °F] and 35 °C [95 °F] at the maximum) and that the winding tension is kept as low as possible. If the films are wound at a temperature that is too high, then the shrinkage that occurs during cooling causes high tensions in the roll of film. In the worse case, this can lead to a partial or total blockage of the films. Therefore, if the machines are operated at high through-put rates or if the lines are operated at high speeds, it is generally recommended that post-cooling rollers be used.

Recommended Temperature profile

for the processing of Styrolux® by means of extrusion:

zone 1	160-180 °C [374°F to 392°F]
zone 2	190-200 °C [374°F to 392°F]
zone 3-5	190-200 °C [374°F to 392°F]
adapter	195-210 °C [374°F to 392°F]
die	210-230 °C [374°F to 392°F]

Temperatures above 230 °C [446 °F] should be avoided.

Cleaning the extruder

In spite of the outstanding stabilization of Styrolux, product damage can occur in case of long residence times in the extruder (dead spots, accumulations in the mixing section). An indication of this is the greater incidence of gel specks, which often only appear for a few seconds but which nevertheless greatly impair the film quality. Such problems require that the extruder be flushed, preferably with standard polystyrene. This procedure is also recommended when the product is changed or before the extruder is switched off in order to reduce the thermal stress to the Styrolux melt caused by the downtimes.

Co-extrusion

The special property of Styrolux, namely, that it forms a composite with a number of other plastics even without adhesion promoters, makes this material a good choice for co-extrusion. Organoleptically sensitive products such as chocolate or foods with a high fat content are best packaged, for example, with composites having PET-G as the cap layer and Styrolux GPPS blends as the carrier layer. The PET-G layer imparts the composite with a very good stress cracking resistance and increased gas tightness; composite films having such a structure are odor-proof and neutral in flavor.

In addition symmetrical film composites with Styrolux GPPS as the carrier layer and PE-LD or PP as the cap layer, which attain a good bond without additional adhesion promoters, have been tested under actual processing conditions. The Styrolux/PE-LD composite combines the excellent surface gloss and the good shrinkage characteristics of Styrolux with the high toughness of PE-LD. The Styrolux/PP composite unites especially the good sealing behavior and shrinkage characteristics of Styrolux with the dimensional stability under heat of PP.

Furthermore, Styrolux multilayer films with an EVOH/PE barrier layer have been developed for special packaging solutions (MAP, CAP).

However, cap layers are also often co-extruded in order to improve the scratch resistance and destacking properties. Easy-flowing general-purpose polystyrene grades are especially well-suited for this purpose. In this context, the GPPS cap layers should be uniformly co-extruded over the film width at a thickness of not much more than 0.01 mm since excessively thick cap layers of the brittle GPPS reduce the impact resistance of the entire composite.

Cap layers can also serve as carriers of special finishes. For instance, it is often both technically and economically advantageous to coextrude a thin cap layer of antistatic agents or UV stabilizers as well as other additives, for example, that enhance the scratch resistance or the de-stacking properties or that have an antiblocking effect. In this case, the carrier material for the cap layer can be the same as that of the core layer, or else it can have a different composition.

Problems areas: film blocking and unsatisfactory de-stacking properties

The Styrolux extrusion grades 693 D and 3G 55 contain a very active wax system that markedly reduces the blocking of film reels; nevertheless, we recommend processing Styrolux 3G 55 by inline thermoforming whenever possible. The already recommended high roller temperatures also activate the wax system that migrates to the surface, where it forms a very thin film. This wax film, however, can be a hindrance if the films are going to be printed on or decorated, which is why a corona treatment might be needed after the extrusion or, if applicable, immediately before the printing (see above, printing and decorating).

For processing problems that can be ascribed to the blocking of film reels or to unsatisfactory de-stacking properties of deep-drawn parts and that cannot be solved satisfactorily through our processing recommendations alone, we also offer additive batches.

■ Styrolux® Batch NB 10

Styrolux Batch NB contains an extremely active wax system, which should be added in amounts of 0.5-2% so as to remedy problems with film blocking.

Processing of Polystyrene and Styrolux®

■ Styrolux® Batch ASE

Highly effective lubricants in Styrolux® Batch ASE serve primarily to improve the de-stacking properties of deep-drawn parts and to reduce the scratch sensitivity of Styrolux. The addition should not exceed 4%; in most cases, 2% is enough to form a lubricating film.

Thermoforming

Thanks to their broad visco-elastic range, panels and films made of Styrolux/GPPS blends are particularly well-suited for thermoforming and very high deep-drawn ratios can be achieved. The thermoforming temperatures should lie between 120 °C and 150 °C [248 °F and 302 °F]. The machine tool accessories as well as the adjustment of the IR radiant heaters or ceramic band heaters and the achievable high cycle times correspond to those that are customary for the thermoforming of GPPS/HIPS blends. In order to obtain highly transparent molded parts without markings and streaks, the following should be observed: The geometry of the molded parts should not have excessively sharp corners or excessively narrow radii and generally speaking, a draft of at least 3° is recommended. The thermoforming tools are made of highly polished aluminum and should be well vented. The temperature of the tools should preferably be set between 20 °C and 60 °C [68 °F and 140 °F], preferably at 40 °C [104 °F]. Uniform temperature control and especially cooling are required in order to produce dimensionally stable molded parts without warpage. The assisting plunger and the top plunger should be made of syntactic foam, polysulfone or PTFE in order to avoid markings on the inner wall of the molded part.

Printing and decoratin

Films or deep-drawn parts made of Styrolux/GPPS can be printed on with the colorants normally used for styrene plastics. Occasional problems of insufficient colorant adhesion can occur due to blooming of the antiblock additives or waxes. Therefore, it is recommended that surface treatments by oxidation such as corona treatment, plasma treatment or flame treatment be carried out whenever possible immediately before the printing since, as a rule, the wax additives tend to continue to migrate. This phenomenon of blooming depends to a great extent on the storage conditions.

Blown film extrusion

As a starting point into the realm of blown film extrusion, we recommend Styrolux 684 D in view of its high melt stability. The film properties, also in the case of thin films, depend on the Styrolux grade, on the GPPS type—here, primarily the easy-flowing types are employed—and on the mixing ratio; any differences in transparency are practically neg-

ligible at film thicknesses of 10 µm to 100 µm. For most applications, mixing ratios between 70% and 100% Styrolux have proven their worth. The melt temperature is of great relevance for the production of high-quality films; under no circumstances should it exceed 220 °C [428 °F].

Typical processing conditions for Styrolux are compiled below:

Feed [°C / °F]	140-160 / 284-320
Melt zone [°C / °F]	160-180 / 320-356
Metering zone [°C / °F]	160-180 / 320-356
Die [°C / °F]	160-180 / 320-356
Melt temperature [°C / °F]	170-200 / 320-356
Blow-up ratio [-]	1:1,1 to 1:3
Distance between die and nip rolls* [m]	2.00-4.00
Film thickness [µm]	10-250

* depends on the throughput and film thickness

The dies should be configured in such a way that they do not have large melt volumes or dead spots. The cross section of the channel tapers towards the die gap.

Preference should be given to air cooling rings with a mounted iris diaphragm since they improve heat transfer. A small distance (4 mm to 5 mm) between the die and the lower air cooling ring lip is advantageous for the film bubble stability. In order to prevent the occurrence of creases, Styrolux should be laid flat at a temperature of 50 °C to 60 °C [122 °F to 140 °F]. A rotating take-off/winding combination or a rotary extruder create Styrolux reels that are free from hoops, and a short film path between the take-off unit and the center winder is always advantageous.

The mechanical properties of the film are determined to a great extent by the blow-up ratio and the take-off speed. Thus, the elongation at break and the tensile stress at yield in the lengthwise and crosswise directions rise as the blow-up ratio increases.



Drinking bottles made from Styrolux®

Blow molding

Under continuous extrusion, Styrolux® 684 D can be processed into blow-molded parts having a length of up to about 500 mm. Striking aspects here are the smooth, brilliant surface and the uniform and good transparency.

The melt temperature should be between 180 °C and 190 °C [356 °F and 374 °F]. Here, too, care should be taken to ensure that the flow channels of the film-blowing die do not have any “dead spots” and that they are not configured too large. It is recommended to use center-fed film-blowing dies dimensioned for rigid PVC. The film-blowing dies should have a polished surface provided with venting slits of the type employed for polypropylene. The pinch-off areas can be designed in the same way as for processing high-density polyethylene.

Blends with up to about 30% general-purpose polystyrene are possible if one is willing to accept a certain reduction in the clarity.

Recycling

Styrolux waste generated during processing such as, for example, edge strips or web scrap, can be returned to the process after a simple grinding step and thus re-utilized for the same application. Consequently, hardly any production waste is created that would then have to be disposed of properly.

Styrolux belongs to the group of particularly processing-stable styrene plastics and can be processed several times with general-purpose polystyrene (GPPS) as well as with high-impact polystyrene (HIPS).

When used articles such as, for instance, disposable packaging, are recycled, Styrolux can be admixed to the melt stream of polystyrene and it even improves the toughness of the recycled material.

Safety information; Safety precautions during proces



Fruit bowl

Safety precautions during processing

When Polystyrene and Styrolux® are injection molded, thermoformed or extruded, small amounts of monostyrene and other degradation products are given off into the surrounding air; the actual amounts depend on the processing conditions.

Inhalation of relatively high concentrations of styrene can, like other organic solvents, have a reversible effect on the nervous system (tiredness, loss of concentration, etc.). Such effects are not to be expected if the workplace concentrations are below the prescribed threshold limit value of 20 ml/m³ (ppm) (cf. TRGS 900).

In our experience, the styrene concentration will not exceed 1 ml/m³ (ppm) if the workplace is well ventilated and extracted (e. g. 5 to 8 air changes per hour).

A review of emissions of volatile compounds in the processing of thermoplastics may be found in M. J. Forrest et al., Ann. occup. Hyg. Vol. 39, No. 1, 35-53 (1995).

The possibility of a carcinogenic effect of styrene has been addressed in a recently published assessment by leading members of the German Commission on Maximum Workplace Concentrations. They propose classifying styrene in a new category: "Substances which have a car-

cinogenic and genotoxic action but whose action is considered to be so weak that no appreciable contribution to the cancer risk for human beings is to be expected if the maximum workplace concentration (20 ppm for styrene) is adhered to".

(Published in: Deutsche Forschungsgemeinschaft. MAK- und BAT-Werte-Liste 1998; Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe; Bulletin 34; Wiley-VCH; p. 121).

Food Contact Applications

The composition of the standard grades of the polystyrene and Styrolux product lines complies with the currently valid legislation in Europe and in the United States pertaining to plastics that come into contact with food. Furthermore, these products are in compliance with the requirements set forth in the recommendations of the German Federal Institute for Risk Assessment (BfR), formerly BgVV/BGA.

Should you need an up-to-date certificate of conformity pertaining to the currently valid statutory regulations or detailed information about the food contact status of a specific standard grade, please contact BASF directly: www.PlasticsPortal.com

Medical Devices and Pharmaceutical Applications

The BASF manufactures high-quality styrene polymers that meet the various requirements of its customers. BASF provides its customers with competent assistance and works together with them to obtain innovative results.

However, BASF has not designed or tested its plastics with respect to all of the special requirements related to their use in medical devices and pharmaceutical applications.

In particular, BASF does not supply any of these plastics for the manufacture of implants or for applications that fall under Risk Class III according to the Medical Device legislation.

Subject to an evaluation and a release in each individual case BASF is prepared to supply plastics for medical applications within Risk Class I or for pharmaceutical applications such as solid dosage forms for oral applications.

Provided an agreement can be reached which takes into account the circumstances of each individual case and a disclaimer is accepted by the customer BASF is prepared to supply plastics for individual medical applications within Risk Class II (with the exception of implants) including packaging of parenteral and ophthalmic products as well as inhalers.

Customers themselves must make all decisions, exclusively on their own responsibility, about employing BASF plastics in any particular medical or pharmaceutical application. All manufacturers of medical devices or products intended for pharmaceutical applications must decide on their own responsibility whether the medical device or pharmaceutical product manufactured using BASF plastics is safe, lawful and technically suitable for the intended use. Therefore BASF makes

no warranties, express or implied, concerning the suitability of any BASF plastics for use in any medical device and pharmaceutical applications.

If you are planning such a use in medical applications, please inform BASF to this effect at styrenics.infopoint@basf.com.

Recycling

Plastics offer advantages not only in a great variety of technical properties but also in terms of ecological considerations. After use, Polystyrene and Styrolux® represent a valuable raw materials source and thus make a contribution to the conservation of fossil resources. There are various possible recycling methods and the method employed depends on the nature of the used plastic.



Deodorant

Nomenclature

Each Polystyrene grade is designated by three digits and a letter:

1st digit

Polystyrene class

- 1 = general-purpose Polystyrene
- 4 = high-impact Polystyrene
- 6 = Styrolux®

2nd digit

Mechanical properties

The higher the second digit, the higher the impact toughness of the material. However, the toughness of the high-impact grades is at a fundamentally higher level than that of general-purpose Polystyrene.

3rd digit

Heat distortion resistance

The higher the third digit, the higher the heat distortion resistance of the product.

Letter

Flow

A indicates the highest flow, Z the lowest flow.

Examples:

Polystyrene 143 E

- 1 = general-purpose Polystyrene
- 4 = intermediate strength
- 3 = low heat distortion resistance
- E = good flow

Polystyrene 486 M

- 4 = high-impact Polystyrene
- 8 = high impact toughness
- 6 = high heat distortion resistance
- M = normal flow

Styrolux 684 D

- 6 = Styrolux
- 8 = good heat distortion resistance
- D = good flow

Modifications are indicated by adding further letters to the base grade designation of the product.



Colors

Polystyrene and Styrolux® are supplied exclusively in undyed form. These products can be dyed so as to be transparent or opaque. (Colorflex® program). Color batches or color concentrates on the basis of Styrolux or polystyrene can be employed for this purpose. When colorants based on a different polymer are used, it is necessary to check whether transparency and brilliance are retained.

Forms supplied and storage

Polystyrene

General-purpose Polystyrene and high-impact Polystyrene are normally supplied as Granules 2 (cylindrical granules having a length of about 3 mm and a diameter of about 3 mm). Externally lubricated Granules 21 (same granule size as Granules 2) are also available on request for general-purpose Polystyrene.

Extrusion and injection molding are normally carried out using Granules 2. In particular cases, the externally lubricated Granules 21 can be employed in injection molding.

The bulk density is
about 0.57 g/cm³ for Granules 2,
[about 0.63 g/cm³ for Granules 21]

Polystyrene should be stored in the original containers in a dry place which is not too hot. Direct exposure to sunlight must be avoided. Storage in a hopper or silo is also possible

Styrolux®

Styrolux is supplied as cylindrical granules having a length of 2.5 mm and a diameter of 2 mm. The bulk density is 0.636 g/cm³ and the angle of repose is 21° (approximate figures).

Standard packaging:
25 kg paper sack; can be supplied in bulk on request.

Styrolux does not undergo any changes when stored in a dry place at normal temperatures. The product may absorb moisture under unfavorable conditions but this can be removed again by predrying (see processing section).

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 processor from carrying out own investigations and tests neither do these data imply any guarantee for 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 does 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. (September 2010)

Please visit our websites:

BASF Plastics:

www.plasticsportal.com (World)

www.plasticsportal.eu (Europe)

Additional information on specific products:

[www.plasticsportal.eu/name of product](http://www.plasticsportal.eu/name%20of%20product)

e.g. www.plasticsportal.eu/polystyrol