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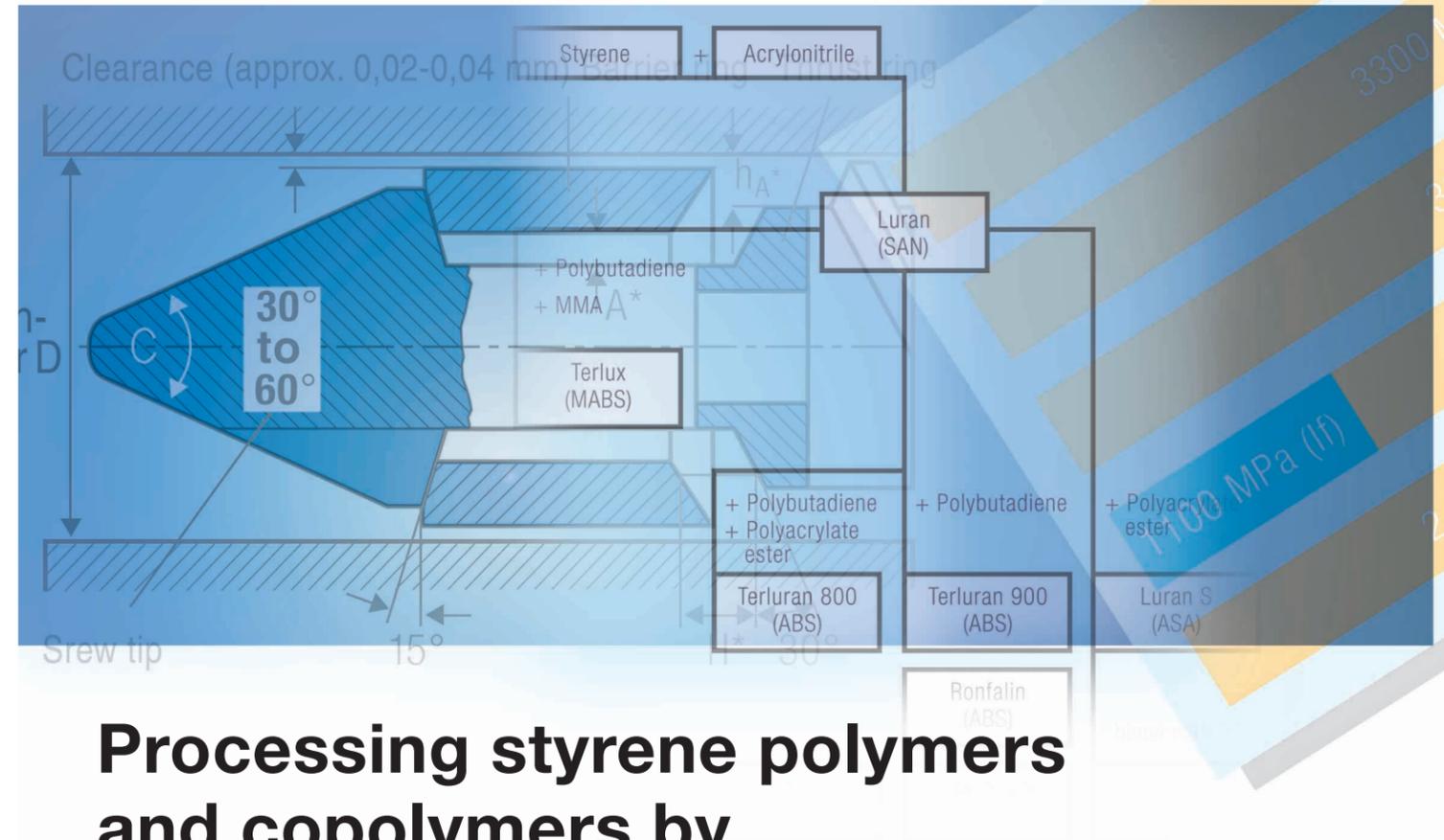
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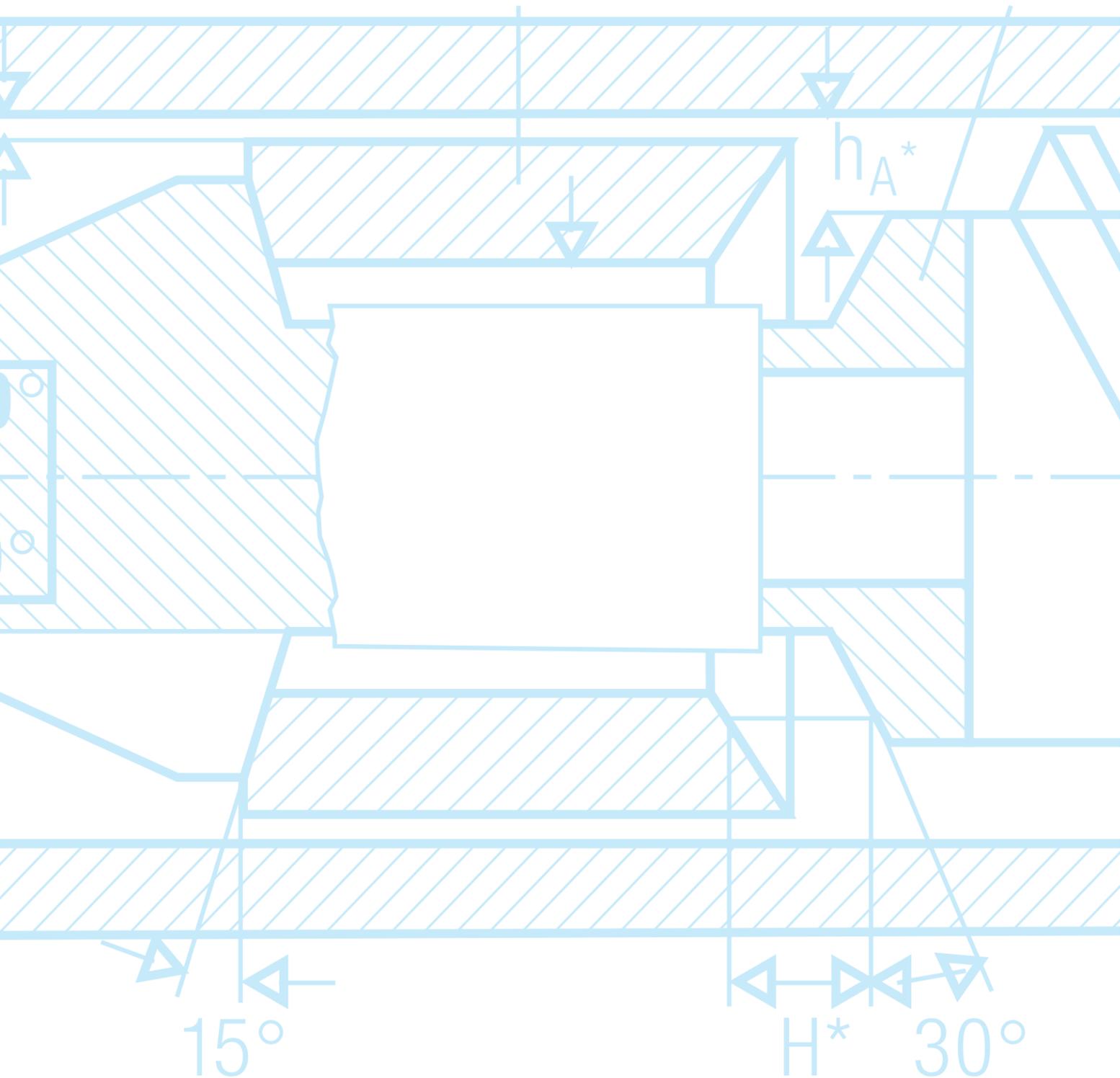
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## Processing styrene polymers and copolymers by injection molding

2–0,04 mm) Barrier ring Thrust



ow cross sections in these regions mu  
approximately the same

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# 1. Introduction

The following is a brief survey of the styrene polymer and copolymer product range. The aim of this publication is to provide the processors of our products with information of both a general nature and specific to the various products in relation to injection molding machines, molds and processing.

# 2. Styrene polymer and copolymer product range

## 2.1 Composition of styrene polymers and copolymers

Styrene polymers and copolymers are materials capable of being processed by thermoplastic transformation.

**Figure 1** shows the BASF styrene polymer and copolymer product range.

Crystal polystyrene (PS) and polybutadiene – modified polystyrene (high-impact polystyrene or HIPS) are the main focus of the styrene polymer family.

Styrene copolymers contain, in addition to styrene (S), other monomers in the principal polymer chain. Styrene-acrylonitrile copolymers (SAN, trade name Luran®) form most important representative and basic building block of the entire copolymer product class.

Luran® SAN is a rigid, hard and heat-resistant thermoplastic which is as clear as glass due to its amorphous structure. In contrast with partially crystalline thermoplastics molded parts produced from SAN or Luran

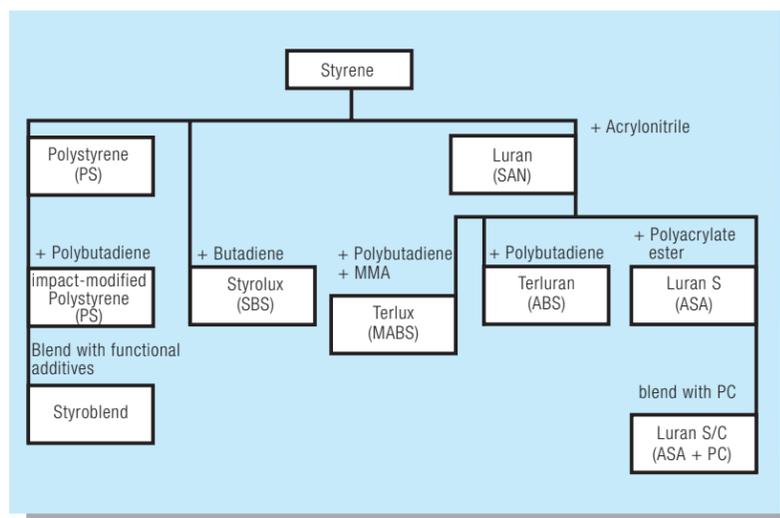
possess high dimensional stability while shrinkage and water absorption are low.

By adding rubbers to SAN either ABS (acrylonitrile-butadiene-styrene, trade name Terluran) or ASA (acrylate ester-styrene-acrylonitrile, trade name Luran S) polymers are obtained depending on the type of rubber component employed. Luran S/C is manufactured from Luran S and polycarbonate.

The styrene copolymer range is further supplemented by SBS (styrene butadiene and block copolymers, trade name Styrolux) and MABS polymers (methyl methacrylate-acrylonitrile-butadiene-styrene, trade name Terlux). The chemical names, abbreviations and trade names are shown in **Figure 2**.

- Crystal polystyrene (PS)
- High-impact Polystyrene (HIPS)
- Styrolux (SBS)
- Luran (SAN)
- Terluran (ABS)
- Luran S (ASA and ASA/PC)
- Terlux (MABS)

**Fig. 1:** Product range



**Fig. 2:** Styrene copolymer product range

## 2.2 Product range

### 2.2.1 General-purpose polystyrene

General-purpose PS is a transparent, colorless material. **(Fig. 3)** It is hard, stiff and has very good dielectric properties (ie, it is an electrical insulator). The general-purpose grades are differentiated by the unique combination of stiffness, heat resistance and flowability that characterizes each grade.

Polystyrene, due to its amorphous structure, exhibits high dimensional stability and low shrinkage. It absorbs very little moisture. Polystyrene is easy to mold and subsequently print, weld, paint and emboss. Its neutral taste and odor are particularly important when it comes to food packaging applications.

### 2.2.2 Impact-modified polystyrene

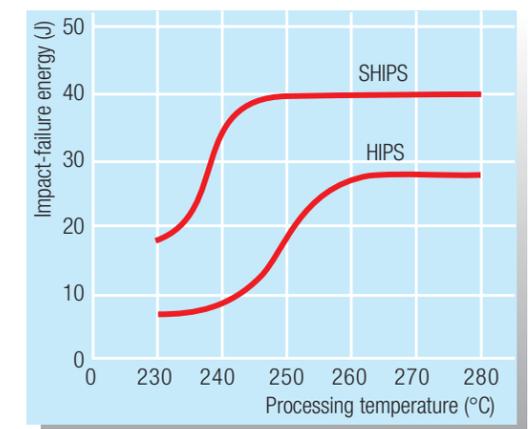
Impact-modified polystyrene is made by polymerizing styrene in the presence of polybutadiene rubber, an elastomer that gives the polymer its impact strength **(Fig. 4)**. The stiffness and impact resistance of impact grades is determined by the amount of polybutadiene present. HIPS is naturally opaque, its surface appearance can range from matt to high gloss.

### 2.2.3 Styrolux

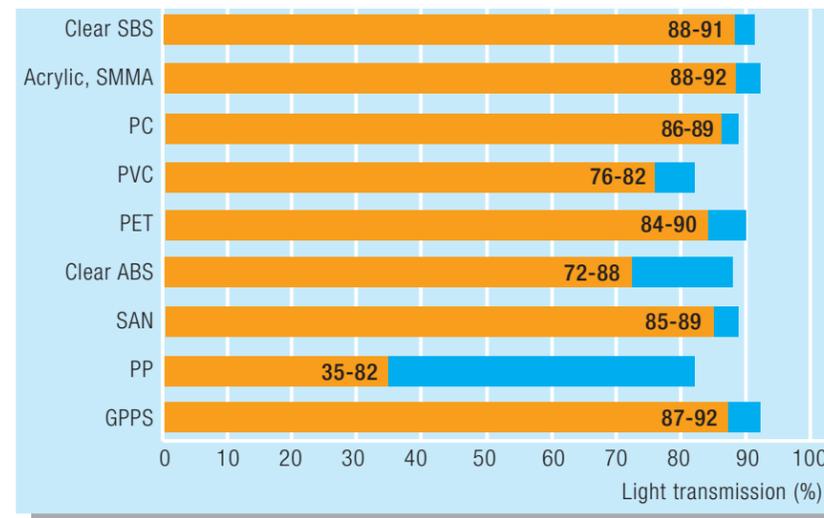
Styrolux is a styrene-butadiene block copolymer that combines excellent

clarity and impact strength. **(Fig. 5)** Styrolux is universally applicable, is easy to thermoform and can be printed, welded and embossed. Also, it absorbs very little water, is physiologically harmless and gamma-ray sterilizable.

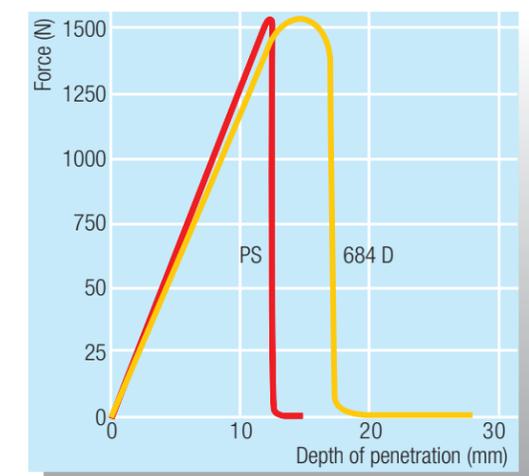
In many applications, Styrolux is mixed with general-purpose polystyrene to custom modify physical properties. A high degree of clarity is realized with high and low styrolux levels when blended with GPPS. **(Fig. 6)**



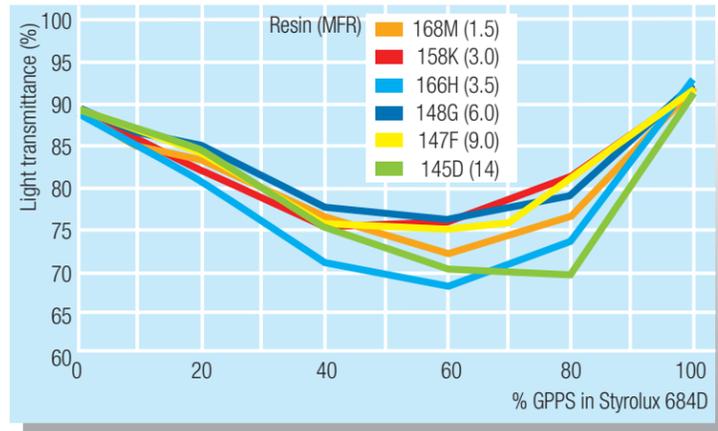
**Fig. 4:** Impact resistance of a high impact polystyrene compared to a super high impact polystyrene



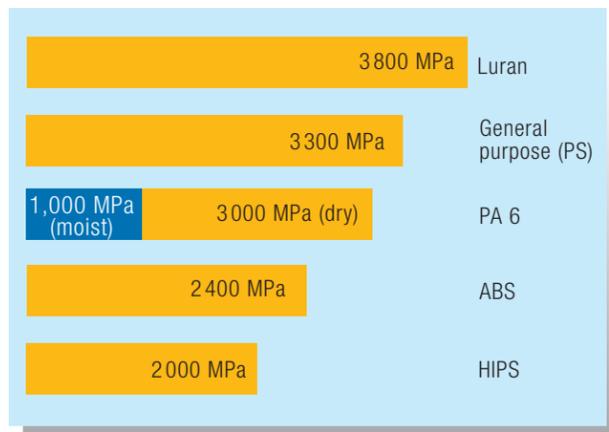
**Fig. 3:** Transparency of clear thermoplastics in %



**Fig. 5:** Impact properties of Styrolux 684D and Polystyrene compared



**Fig. 6:** : Light transmittance as a function of % GPPS in blends with Styrolux 684D



**Fig. 7:** Comparison of modulus of elasticity of different thermoplastics

#### 2.2.4 Luran SAN

As a styrene-acrylonitrile copolymer, Luran is both an individual plastic in its own right as well as the basis for some other styrene copolymers (Terluran, Luran S).

The most prominent properties of Luran are:

- outstanding transparency,
- good chemical resistance
- thermal resistance
- high strength
- rigidity (see Fig. 7),
- dimensional stability
- resistance to fluctuating temperatures.

For years Luran has proved to be very effective in numerous applications in the field of household articles and tableware, cosmetics packaging, hygiene and toilet articles as well as for writing implements and office supplies. The Luran color range extends from a large number of transparent and smoky topaz shades through bright solid colors having a high surface gloss.

#### 2.2.5 Terluran ABS

All types of ABS are styrene-acrylonitrile copolymers modified with finely divided butadiene rubber which have high impact strengths and notched impact strengths (even at relatively low temperatures). They are distinguished by high surface gloss, good scratch resistance and good thermostability.

#### Terluran "World Grades"

Terluran "World Grades" were specially developed for the needs of global customers. They are standard, injection-molding and extrusion grades supplied in light, extremely constant self-colors, in a limited number of standard colors.

#### 2.2.6 Luran S (ASA and ASA/PC)

In contrast with Terluran, the ductile phase in the case of Luran S consists exclusively of an acrylate ester rubber. As a result of this, excellent resistance to UV and heat aging (Fig. 8) is obtained resulting in very good resistance to yellowing. Accordingly, Luran S is primarily suitable for outdoor applications. In addition, it has high resistance to chemicals.

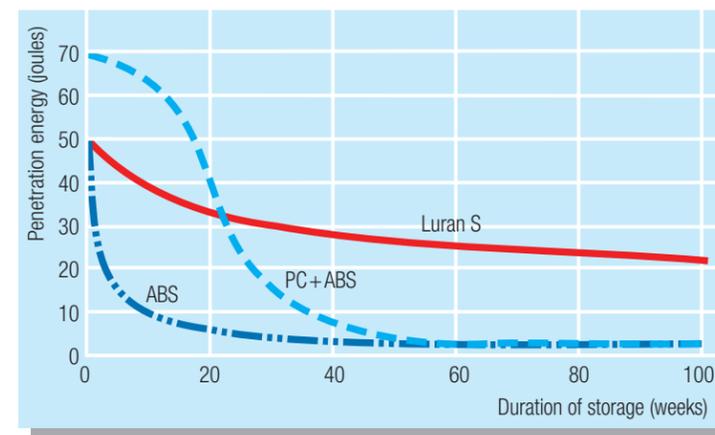
Properties such as flowability, heat resistance or impact resistance are adjusted differentially according to Luran S grade. Processing of Luran S at high temperatures is also possible without difficulty. The Luran S range also includes blends of ASA and polycarbonate. In these cases the ASA component contributes its excellent resistance to weathering and aging. By comparison with ASA the ASA/PC blends exhibit increased impact resistance and thermostability at comparable rigidity and dimensional stability.

In contrast with polycarbonate chemical resistance is better and processability is distinctly enhanced. A fire-protection grade free of chlorine, bromine and antimony rounds off the product range.

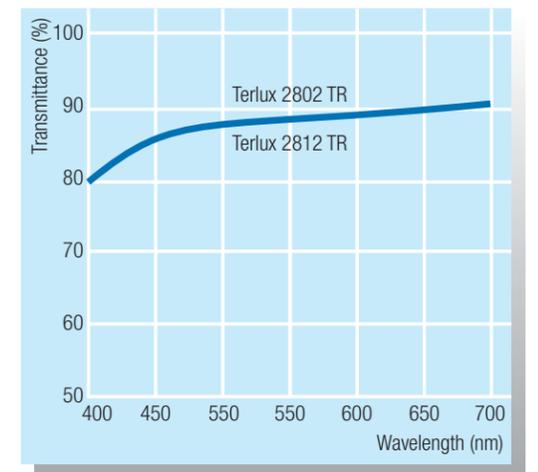
#### 2.2.7 Terlur (MABS)

Terlur is transparent, amorphous thermoplastic based on a MABS polymer. Thus Terlur combines in ideal manner typical ABS properties, such as a balanced relationship between toughness and rigidity, with the transparency familiar from PMMA molding compounds (Fig. 9).

This combination of properties singles out Terlur as a specialty in the field of transparent thermoplastics.



**Fig. 8:** : Impact resistance of ABS, Luran S and blends after heat aging at 90 °C (Penetration energy for circular disks 2 mm thick)



**Fig. 9:** Light transmittance of Terlur 2802 TR and Terlur 2812 TR as a function of wavelength (measured on injection-molded test specimens 2 mm thick)

### 3. The injection molding machine and mold

#### 3.1 The screw injection molding machine

It is customary nowadays to employ screw injection molding machines for the processing of styrene polymers and copolymers. In these machines, the screw assumes the roles of conveying, plasticizing and injection. Other types of machines (e.g. plunger injection molding machines) are now used only for special applications (for the production of marbled effects, for example).

#### 3.2 Injection molding screws

##### 3.2.1 Single-flighted three-section screws

The screw employed in the plasticizing unit affects the properties of the molded part. In certain circumstances the choice of a screw which is unsuitable for the material results in inhomogeneities in the melt (temperature, color distribution, non-uniform melting). As a result of an unfavorable screw geometry, the melt can be exposed to high shear stresses and thus be damaged both thermally and mechanically. In addition to short-

comings in visual appearance, this has the consequence of diminishing the mechanical properties of the molded part.

What are known as three-section screws have proved to be highly effective in practice for the processing of styrene polymers and copolymers. As the name already indicates this type of screw is divided into three different zones (feed, compression and metering section) each of which has to execute different tasks. Located at the tip of the screw there is additionally a nonreturn valve which during the injection and holding phase prevents back flow of the plasticized melt.

Standard modern screws generally have an effective length of 20–23 D, the length of the feed section being approximately half the length of the screw. (Fig. 10) The compression and metering sections are of approximately the same length. The pitch is usually 0.8–1 D. The flight depth ratio of the feed and metering sections ranges from 2 to 3. A compression ratio of 2 to 2.5 has proved to be effective for the processing of styrene polymers and copolymers in injection molding applications. The flight depths recommended by BASF for three-section screws are shown in Figure 11 as a function of the screw diameter.

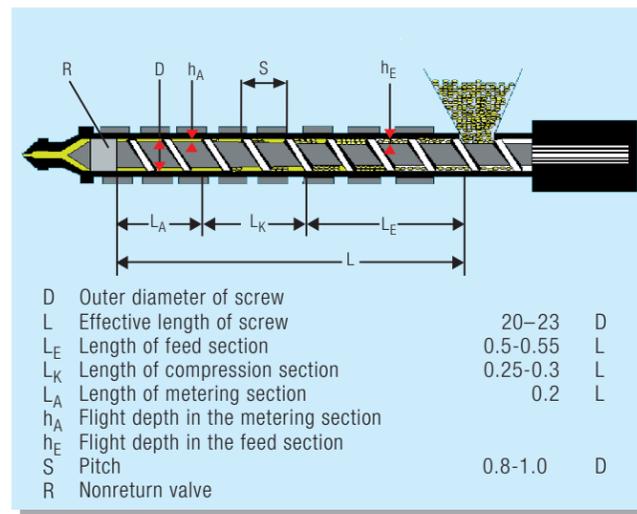


Fig. 10: Plasticizing unit with three-section screw

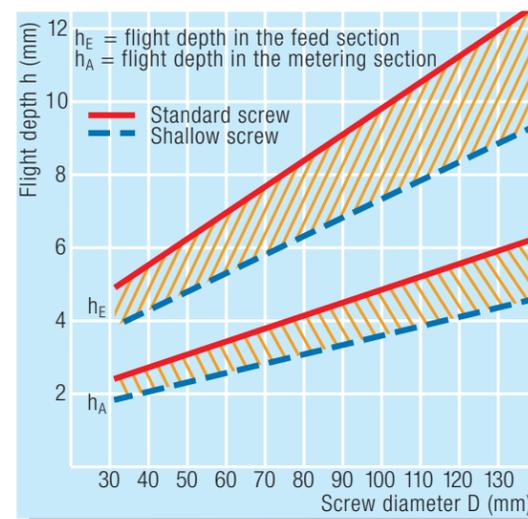


Fig. 11: Flight depths for three-section screws

In the flight depths illustrated in Figure 11, a distinction is made between standard screws and shallow-flighted screws. Shallow-flighted screws pick up less material, and as a result of which the residence time in the plasticizing unit is shortened. This can be advantageous when handling thermally sensitive materials.

##### 3.2.2 Other screw geometries

Standard or universal screws, such as the three-section screw, are still encountered most frequently in practice and even today still cover a large portion of the spectrum of requirements and materials. In recent years, however, applications have increasingly appeared in which higher demands are imposed on the quality of the melt, than can be provided by a three-section screw. This may be encountered, for example, in critical product formulations and also in in-plant coloring using master

batches or pigment concentrates. In order to achieve the required homogeneity, additional shearing and/or mixing parts as well as barrier zones can be and are employed.

Common to all the shearing and mixing parts are the basic principles of screw clearance and the division and recombination of the melt stream. The Maddock and spiral shear sections together with the toothed disk or diamond pattern mixing section are primarily employed (Fig. 12). Furthermore, in a pilot plant trial good results were obtained with the Twente mixing ring (TMR), a combination of nonreturn valve and mixing part, developed by the University of Twente in the Netherlands (Fig. 13) and available commercially in North America.



Fig. 13: Twente Mixing Ring

Using this system in contrast with two other shear and mixing sections studied in parallel, molded parts free from streaks were producible especially in the case of critical colors and low-concentration pigment pastes.

These mixing and shear sections should be designed as far as possible to be pressure-neutral. This design keeps the material throughput, minimizes wear and avoids detrimental effects on the melt temperature.

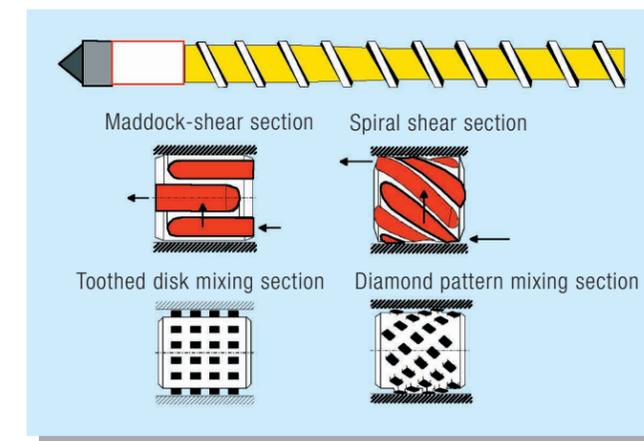
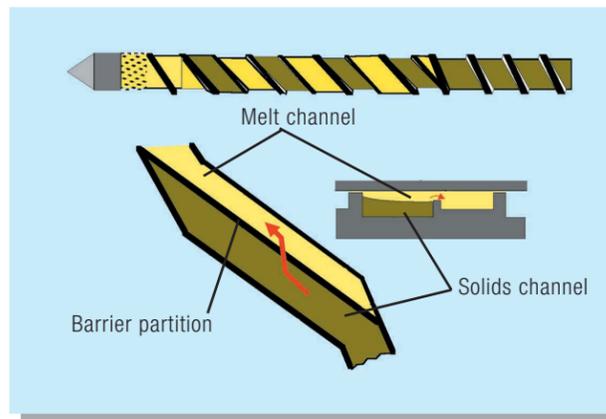


Fig. 12: Three-section screw with shear and mixing sections

### 3.2.3 Barrier screws

The mode of operation of all barrier screws is in principle the same. The characteristic feature is the division of the screw channel into a solids channel and a melt channel (**Fig. 14**). The solids channel is separated from the melt channel by the barrier partition. The barrier partition has a greater gap width than the main or barrier flight so that only fused material or particles which are smaller than the gap width in at least one direction can get into the melt channel. In flowing over the barrier partition, these particles are exposed to an additional defined shear stress resulting in further fusion of the remaining particles of solid. The barrier partition contributes moreover to the homogenization of the melt.

As the channel length of the barrier section increases, the cross section of the solids channel decreases while at the same time the channel cross section of the melt channel increases. This change in the cross section of both channels is achieved in the different types of barrier sections by a change in the dimensions of the flight depths and/or flight widths.



**Fig. 14:** Illustration of the principle of a barrier screw

The length of screw or which barrier approach should be employed must be determined according to application. The requirements, relating in particular to homogeneity, can vary greatly from case to case.

Very large plasticizing units that make use of only a small part of the available swept volume result in long residence times of the melt in the cylinder. This can result in thermal damage to the product. Furthermore, even small fluctuations in the stroke of the screw can give rise to considerable variations in the shot weight.

Larger shot volumes are achieved at low cost and by structurally simple means like enlarging the metering length. Enlargement of the metering length has the consequence that the effective screw length shortens. This can result in unmelted material and inhomogeneities in temperature. A further risk with larger metering length is that even more air can be drawn in, especially during injection.

The more air drawn in due to enlarged metering or injection strokes, the more difficult it is for this air to escape again to the hopper and not to move into the space in front of the screw. Indrawn air which is included in the melt and gets into the mold causes streaking in the molding, an effect which must be prevented. The minimum precondition for qualitatively flawless parts is that the maximum possible metering stroke and the effective length of the screw have a limited ratio to one another (i.e., for example, that the maximum metering stroke for a screw 20 D long should be restricted to 3 D).

### 3.3 Screw tip, nonreturn valve

The designs of the tip of the screw and nonreturn valve are important for the troublefree flow of the melt in the plasticizing unit.

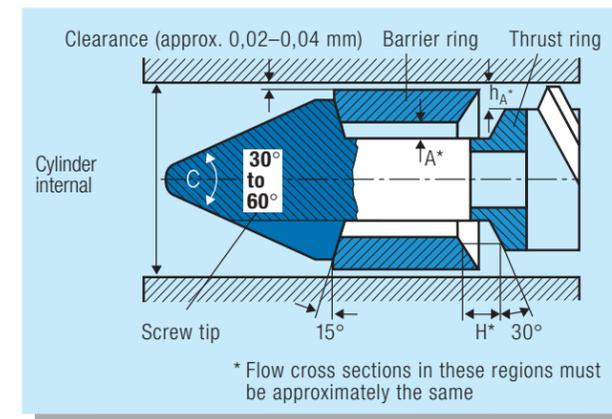
A constant melt cushion and long holding pressure times can only be maintained by means of nonreturn valves. The clearance between the cylinder and nonreturn valve should lie between 0.02 and 0.04 mm (**Fig. 15**) at the operating temperature. In order to avoid any back pressure from the melt, the flow cross sections in the different regions (A,  $h_A$  and H) must be of the same size.

The screw tip has to be designed in a manner to promote flow (**Fig. 15**). The angle C at the screw tip and nozzle inlet should be the same so that as little melt as possible can settle in the cylinder head or in the nozzle. In a poorly designed screw tip, the melt can be thermally damaged by a relatively long residence time in the plasticizing cylinder. In this case mechanical and optical impairment of the material cannot be precluded.

### 3.4 Injection nozzle

#### 3.4.1 Open nozzles

Due to flow-related advantages, open nozzles (**Fig. 16**) allow simple cleaning and rinsing as well as rapid change of materials and colors. In order to prevent thermal damage, the opening of the nozzle bore should be at least 3 mm wide. The angle at the nozzle inlet should be the same as that of the screw tip.



**Fig. 15:** Nonreturn valve

A shut-off nozzle and/or subsequent retraction of the screw can be used to prevent escape of melt during plasticization operations.

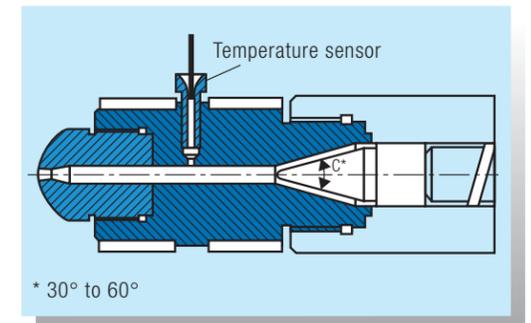
When using open hot runner systems, retraction of the screw is advisable so that the pressure in the hot runner is released and escape of the melt from the hot runner is prevented.

There is, however, the danger that air is drawn in between the hot runner system and the injection nozzle. This can be prevented, for example, by using a long-reach nozzle.

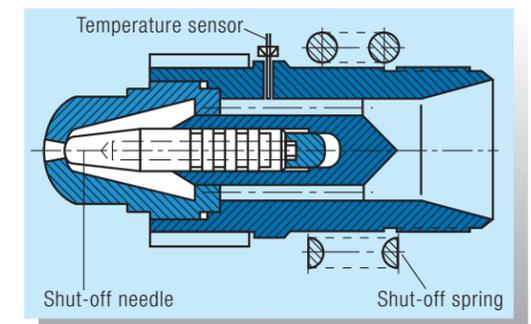
#### 3.4.2 Shut-off nozzles

The use of shut-off nozzles allows the injection nozzle to be retracted during plasticization. As a result of this, the transfer of heat between the temperature-controlled injection nozzle and the cooler mold is cut off.

Shut-off nozzles are also advantageous when operations must be conducted with elevated back pressure and unwanted stringing is to be avoided. Mechanically or hydraulically operated needle shut off nozzles are highly suitable for styrene polymers and copolymers (**Fig. 17**). By comparison with open nozzle systems shut-off nozzles suffer from the disadvantage of higher-pressure losses.



**Fig. 16:** Open nozzle with temperature sensor



**Fig. 17:** Spring-loaded needle valve nozzle

### 3.4.3 Directions for installing the injection nozzle

In order to ensure troublefree demolding of the molded part, care has to be taken during installation of the nozzle that the radius of the nozzle head is always smaller than that of the sprue bushing the mold. The diameter of the nozzle bore must always be smaller than the diameter of the runner of the sprue bushing (Fig. 18).

A thermocouple for measuring the melt temperature should be installed in all nozzle structures. This provides the processor with evidence of the melt temperature actually prevailing in the space in front of the screw (Figs. 16 and 17).

### 3.5 Injection mold / Molded part design

#### 3.5.1 Sprue design

In the design of injection molds for styrene copolymers, care should be taken that runners and gates are of an adequate size. Flow resistance during injection and holding has to be kept as low as possible. Undersized gates can cause streaking, charring due to shear and delamination. Premature solidification of the melt in the sprue frequently results in sink marks and voids in the molded part since the contraction in the volume of the melt during the holding pressure phase cannot be compensated for.

#### 3.5.2 Design of molds and wall thicknesses

The wall thickness needed is determined by the requirements for strength and rigidity as well as for an economical cycle time for the component. In Figure 19, the effects of wall thickness, melt and mold surface temperatures are shown for an amorphous and a partially crystalline product. The maximum and minimum cooling times of a product are obtained by using the maximum and minimum melt and mold surface temperatures found on pages 16 and 18, respectively. It is evident that the wall thickness of the molded part plays the dominant role in determining the setting time.

In order to prevent or reduce sink marks, gating should be placed as close as possible to the region of the greatest wall thickness because here the holding pressure can act for the longest time.

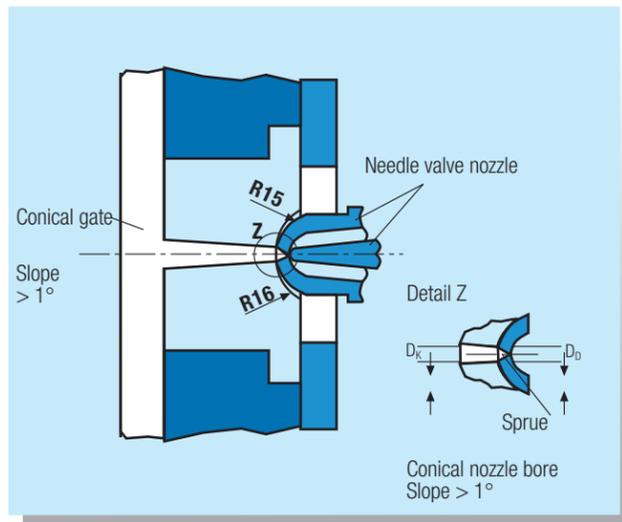


Fig. 18: Conical gate and sprue

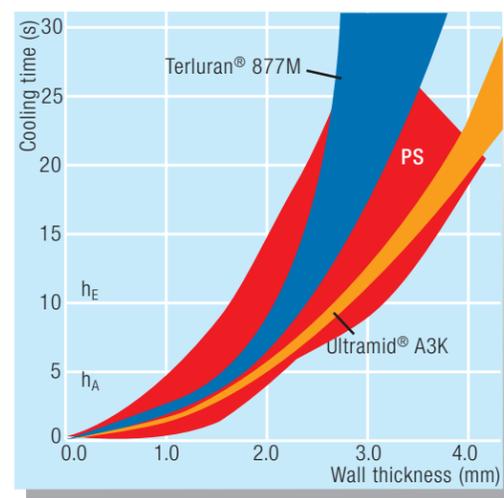


Fig. 19: Theoretically determined setting times for plaques of differing thickness until the maximum wall temperature reaches the demolding temperature

If gating is placed in regions of thin wall thickness, volume contractions in the thicker regions can no longer be compensated for since the thin walls freeze earlier. Gating in this way generally results in more distinct sink marks.

As a matter of principle, reinforcing ribs should be constructed with a lower wall thickness than the basic wall thickness and be tied by a certain radius to the base wall. The tie radius prevents flow problems and notch effects. A tie radius which is too large can, however, have an effect on the cycle time (Fig. 20) and/or the quality of the molded part (sink marks due to accumulation of melt).

#### 3.5.3 Venting

Molds must also be vented. When the two mold halves close, a volume of air is trapped in the mold cavity. During injection of the polymer, this air, if not removed, will compress and rise in temperature. The temperature can rise enough to cause autoignition of the air/polymer volatiles mix. This is called dieseling and results in a burn mark through the plastic. In extreme cases, the mold cannot be filled. The removal of the trapped air is accomplished using vents.

Figure 21 shows an example of a mold venting scheme.

Vents are typically placed around the circumference of the parting line, spaced as close as 3-4 inches apart. The vent consists of a "land" area approximately 0.0004" deep by 1/4" to 1/2" wide by 1/8" to 1/4" long. The 0.0004" is a "steel safe" starting thickness that allows air to escape but not viscous plastic. Beyond the 1/8" to 1/4" dimension, the tool steel is removed to a greater depth to facilitate gas flow and is channeled to the perimeter of the mold. On occasion,

due to the gate placement, gas entrapment can occur away from the outside edge of the cavity space. In those cases a vent pin, which is similar to an ejector pin but with a 0.0005" (to start with) flat cut on one side, can be used to vent gas out the back of the core into the ejector box. Sintered metal plugs have also been used successfully when vented through the mold body.

During construction, care has to be taken that the venting channels run into an adequately sized exhaust channel so that cleaning of the channels is rendered practically unnecessary. Nevertheless, the venting channels should be checked regularly and cleaned if necessary in order to prevent any decrease in the efficiency of venting with progressive usage of the mold caused by deposits.

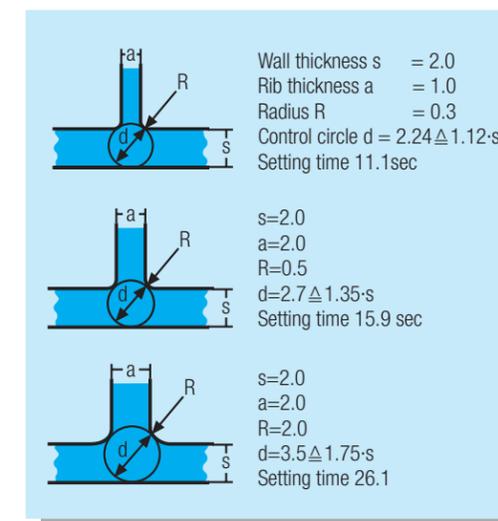


Fig. 20: Effect of rib and wall thicknesses and radii of curvature on cooling times of a rib-reinforced injection-molded part

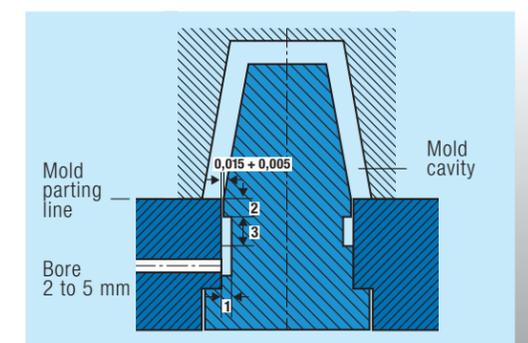


Fig. 21: Structural scheme for venting a mold

## 4. Processing advice for styrene polymers and copolymers

### 3.5.4 Demolding

For styrene polymers and copolymers demolding drafts of 1° are generally sufficient. Under no circumstances, however, should they be less than 0.5°. The knock-out pins or stripper plates should be designed with as large an area as possible so that the finished part is not deformed on demolding. This may also allow earlier demolding and hence a shorter cycle time.

### 3.5.5 Temperature control

As early as determining the position of the molded part in the mold, consideration should also be given to the uniform temperature control of the molded part. The effective temperature of the mold at the surface of the mold cavity has a substantial effect on the cycle time, surface quality (gloss, brilliance and prominence of the weld line), shrinkage and warpage and thus on the tolerance of the molded parts.

Mold cooling is achieved by installing cooling channels in the cavity and core plates in order to circulate water or an ethylene glycol solution through the mold. The channel diameter and placement, along with the circulating capacity of the cooling system, will determine overall effectiveness of the design. The bore diameter for cooling channels are typically drilled to accept 0.25-0.375 inch pipe. Interconnecting hoses should have the same internal diameter to assure the flow rate through the system remains in the turbulent regime. Turbulent flow achieves three to five times as much heat transfer as does non-turbulent flow.

The size of the coolant channel, its position relative to the surface of the molding, the flow rate and temperature of the coolant are important for uniform cooling of the molded part. Often, segments on the mold surface must have their temperature controlled by different cooling circuits. Uniform cooling, providing a temperature gradient of no more than 10°F across the mold, will allow for uniform parts.

### 3.5.6 Materials of construction

The choice of material to construct a mold is based on several factors. These include the number of parts to be produced, the size and shape of the part, surface durability, cost and molding force required. Depending on the gating system used and the wall thickness of the part, thermoplastic molding can generate pressures of between 2 and 5 tons/in<sup>2</sup> in the mold cavity. These pressures can distort or crack a mold if improperly designed.

For prototype work where a small number of parts will be produced, lead/zinc alloys are often used. These materials are inexpensive, can be cast into near net shape to reduce machining cost, and can be remelted and recast again. This family materials are not durable because the lead/zinc structure does not possess high tensile strength, toughness, or durability against erosive effects. These materials also exhibit much higher rates of heat conductivity versus steel, which could affect final part properties. This effect would be especially critical in blends or alloys of thermoplastic materials where the cooling rate affects domain size of the blend constituent. It is also very important to remember that this family of mold materials loses physical properties, primary tensile strength, and surface toughness at temperatures above 80°C (175°F).

While there are many materials that production molds can and have been made from including aluminium alloys, bronze, and stainless steel, the most common material choice for molding thermoplastic resins is P-20 steel. P-20 is chosen for its unique combination of toughness combined with surface hardness that can be further enhanced by heat treatment methods. P-20 can be machined using standard methods; and the low sulfur grades, through harder to machine, are typically used because of improved surface finish when polishing and photo etching is required.

The cooling rate of the part is effected by the material of construction. Aluminium and beryllium copper can conduct heat twice as fast as tool steel and four times as fast as stainless steel mold.

### 4.1 Moisture content of pellets and drying of the material

In order to produce moldings having a satisfactory surface and good properties, the moisture content of the pellets must not exceed a certain value. **Figure 22** shows the permissible moisture level in the pellets for processing.

The moisture content in the containers rises as a function of the ambient storage conditions and time. Especially in the winter months when the material is transferred from a cold storage area into a heated processing shed, condensation from the cooling ambient air on the pellets can occur when the container is opened immediately. The occurrence of condensing moisture is prevented by storing the closed container in the processing shed for a certain time or by bringing it to room temperature in an intermediate store.

	Drying time (h)	Drying temperature (°C)	Max. permissible moisture content of granules (%)
Circulating air drier			
Polystyrene*			
Luran			
Terluran			
Luran S	2-4	70-80	<0.1
Styrolux	2-4	60	<0.1
Luran S/C	2-4	100-110	<0.1
Terlux	2-4	70	<0.1

\* Normally not required

Fig. 22: Processing of styrene copolymers

In order to ensure the production of components free of streaks and have a flawless surface with a good level of gloss and properties, the pellets should be dried using the times and drying temperatures listed in **Figure 22**. Circulating air driers are often sufficient for drying the pellets. Since dry air can absorb a relatively large amount of moisture, dry air driers are generally more effective.

Partly filled containers have to be carefully closed immediately after withdrawal of pellets. The pellet hopper on the machine has to be covered by the lid.

The pellets should be predried to reduce moisture to an acceptable level to assure satisfactory part quality. Directions for predrying can be found in the processing section of the relevant product brochure.

### 4.2 Temperature control on the cylinder

The quantity of heat needed for melting the pellets is introduced from outside by heating the plasticizing cylinder and also by friction from the rotation of the screw. The possibilities for temperature control given in **Figure 23** are for setting the band heater temperatures.

A fixed temperature control profile is used when, as a result of a short residence time or utilization of the full plasticizing capacity, a lot of heat has to be supplied as quickly as possible.

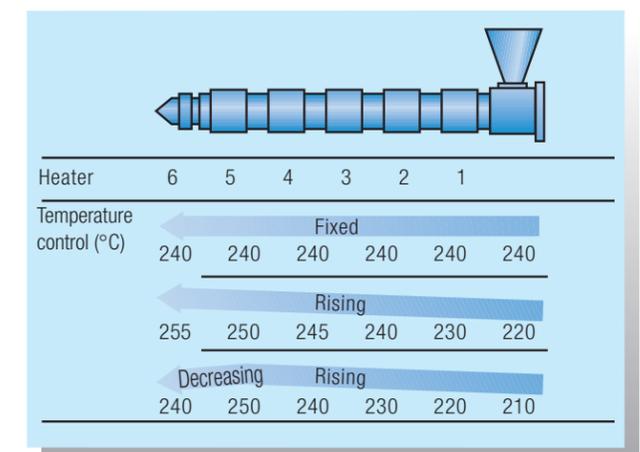


Fig. 23: Temperature control profile on the cylinder

A rising temperature control profile is employed when residence times are relatively long. This permits relatively gentle fusion of the material.

The initially rising temperature profile which then falls on approaching the nozzle is used primarily for open nozzles in order to prevent the melt running out or to prevent stringing. The aim of all temperature profiles has to be the setting of that melt temperature in the space in front of the screw which is required for processing. By means of the thermocouple fitted in the nozzle head, the actual melt temperature can be measured and the temperature profile of the band heaters together with the rotary speed of the screw can be corrected.

### 4.3 Melt temperature

Apart from a few exceptions, styrene polymers and copolymers can be processed over a broad range of melt temperatures.

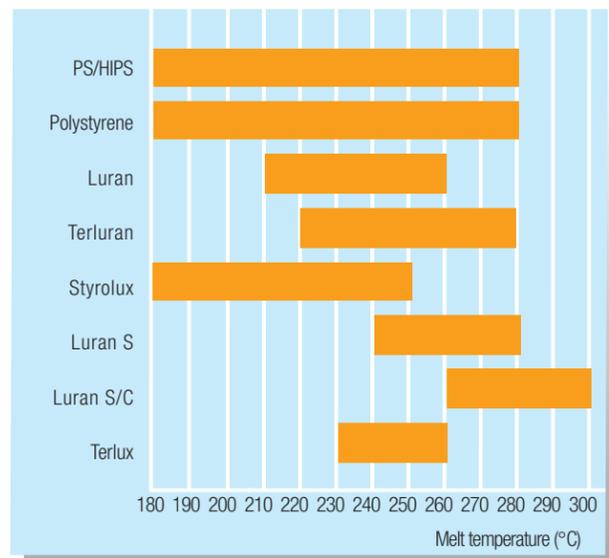


Fig. 24: Processing temperature ranges for styrene copolymers

Figure 24 shows a summary of the processing temperature ranges for styrene polymers and copolymers.

If possible, processing in the median temperature range is preferred in order to protect the material. To check on this, we recommend that the melt temperature be measured by means of a needle thermometer in the purged-off melt.

While processing is done in the upper temperature range, residence times should be short in order to prevent yellowing of or damage to the material. Furthermore, when high processing temperatures and/or long residence times are used the temperature of the first band heater (close to the hopper) should be set a little lower. This will prevent premature melting of the pellets in the feed section.

#### 4.3.1. Special product-specific characteristics

BASF polystyrene products should be processed between 180 and 270°C (356 - 518°F). Temperatures above 280°C (536°F) and long residence times can cause thermal degradation. A number of molded article properties can be controlled by adjusting the melt temperature (Fig. 25).

##### Styrolux® SBS

The maximum processing temperature for Styrolux is 250°C. Above this temperature, the rubber component of Styrolux starts to crosslink, causing poorer melt flow and haze in the molded article.

##### Luran

Especially when processing lightly colored, transparent Luran formulations, changes in the shade of the finished part can occur when the melt is subjected to excessive thermal stress. This effect, peculiar to SAN materials, can only be prevented by processing under gentle conditions.

##### Terluran® ABS

At melt temperatures above 260°C (500°F), particularly in the case of long residence times of the material in the cylinder or high heat production through shear, products containing polybutadiene can suffer a decrease in impact strength due to thermal damage.

##### Luran S

By comparison with Terluran, the Luran S and Luran S/C grades exhibit higher stability to temperature and processing. Nevertheless when processing is carried out in the upper temperature range, care should be taken to keep residence times as short as possible in order to prevent any thermal damage to the material. This may be recognized in the case of bright colors by a change in color, usually towards a somewhat lighter shade.

##### Styrolux

Styrolux feeds easily in the barrel. The temperature profile should increase gradually in the direction of the screw tip. The feed zone should be cooled. The back pressure should be only as high as necessary. Melt temperatures must not exceed 250°C (482°F). Excessive temperatures damage the material by causing crosslinking, which produces poorer flow and turbidity. Residence times in the barrel should be kept short to prevent such effects. In addition to a good mold surface, transparency and gloss are also favored by a high injection rate. Note, however, that a high injection rate may lead to a slight loss in impact strength.

##### Terlux® MABS

Terlux is slightly cloudy immediately after demolding (while the temperature of the molding is still high). Only on cooling does the transparency of the product become apparent. Optimum transparency is achieved at melt temperatures of 230–260°C (446-500°F) and with a mold surface polished to a high gloss. Long residence times can cause slight yellowing. Mixtures with any other thermoplastics result in permanent clouding of the product.

#### 4.3.2. Effect of processing temperatures on mechanical strength

Depending on which product is being processed, the processing temperature has a greater or lesser effect on mechanical strength (notched impact strength, see Fig. 26). Particularly noteworthy is the impact strength maximum of Terluran GP 22 at 260°C (500°F). In

the example of Luran S 778 T, a slight increase in impact strength can be discerned as the melt temperature rises. The highest impact strength is reached at 250°C (482°F). By comparison, with ABS, only a marginal decline in impact strength occurs even at high processing temperatures up to 280°C (536°F).

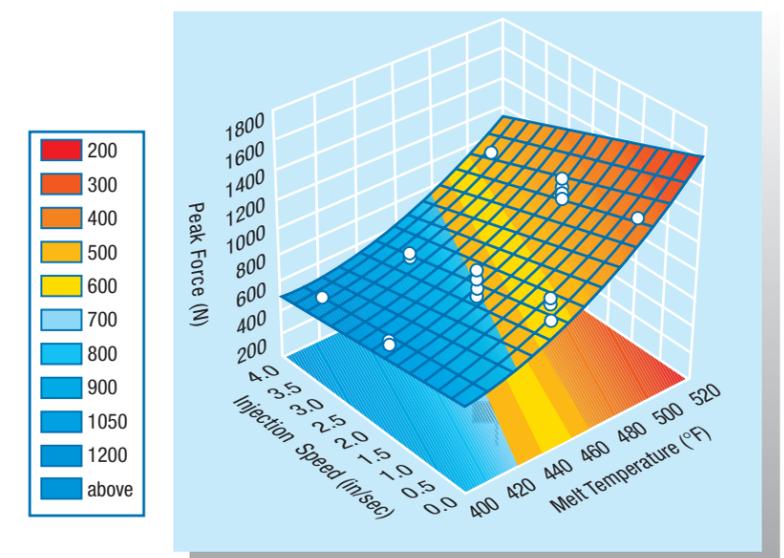


Fig. 25: Instrumented impact of high impact polystyrene vs. melt temperature and injection speed

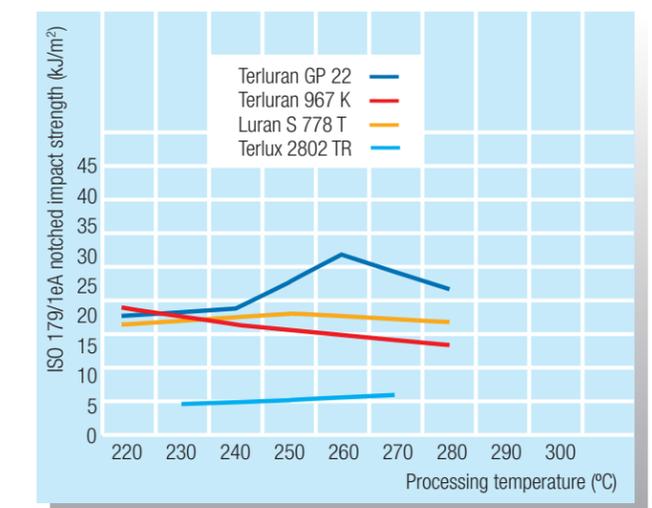
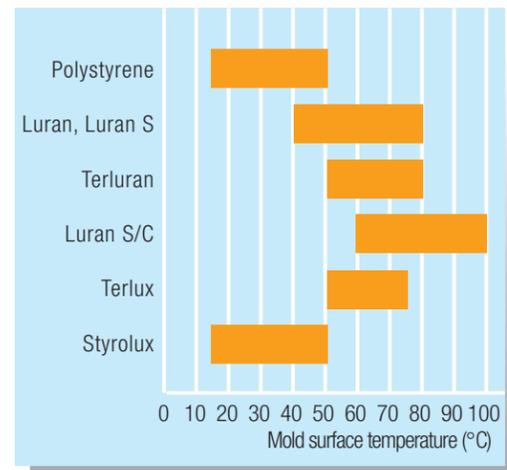


Fig. 26: Notched impact strength as a function of processing temperature

#### 4.4 Mold surface temperature

The surface temperature of the mold is among the most important parameters in the injection molding process. **Figure 27** presents BASF's recommendations for the mold surface temperatures. Apart from surface quality, (gloss and weld line marks) the effective mold surface temperature also affects the mechanical properties, weld line strength and the dimensional tolerances of the molded part (**Fig. 29**). Locally different mold temperatures result in different rates of cooling of the molding and hence in differences in shrinkage caused by cooling and in warpage.

In general a higher mold surface temperature brings about slower freezing of the melt. Shrinkage can be compensated for with longer cooling times resulting in lower residual stresses.



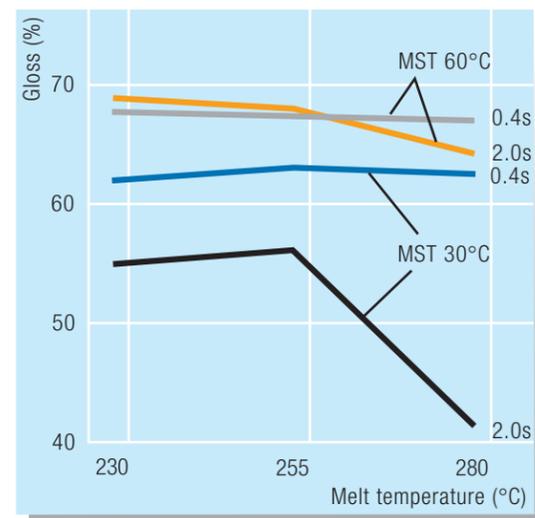
**Fig. 27:** Recommended mold surface temperatures for styrene copolymers

**Figure 28** shows the effect of the mold surface temperature (MST) on the surface gloss of a molding made from Terluran 967 K. Increasing the mold surface temperature from 30°C to 60°C (86°–140°F) resulted in the case of a test mold with an appropriately polished surface in an increase in gloss of 24% (melt temperature 230°C).

However, in the case of Terluran, a high melt temperature in combination with a low injection rate and low mold surface temperatures can result in distinct deterioration of the surface gloss. Increasing hold pressure and mold temperature can have a significant effect on peak force (Fig. 29).

#### 4.5 Peripheral screw speed

The rotary speed of the screw can be selected in such a way that the time available in the cycle for plasticization is utilized to the greatest possible extent. As **Figure 30** shows the peripheral screw speed  $V_U$  should be



**Fig. 28:** Gloss for the example of Terluran 967 K

about 0.2 m/s and as far as possible, even in intensive use, not exceed 0.3 m/s. When using a screw having a diameter of 80 mm for example, this corresponds to a speed range of 48 to 72 rpm.

#### 4.6 Back pressure

In order to prevent air intake and to produce a sufficiently homogeneous melt, it is necessary to work with back pressure. In doing so, the level of back pressure should be as much as possible, but not exceed a hydraulic pressure of 10 bar (150 PSI). A back pressure which is too high results in excessive heating by friction and thus in an uncontrolled and generally excessive processing temperature. This can result, for example, in thermal damage to the melt and consequently in considerable losses in the quality of the molded part.

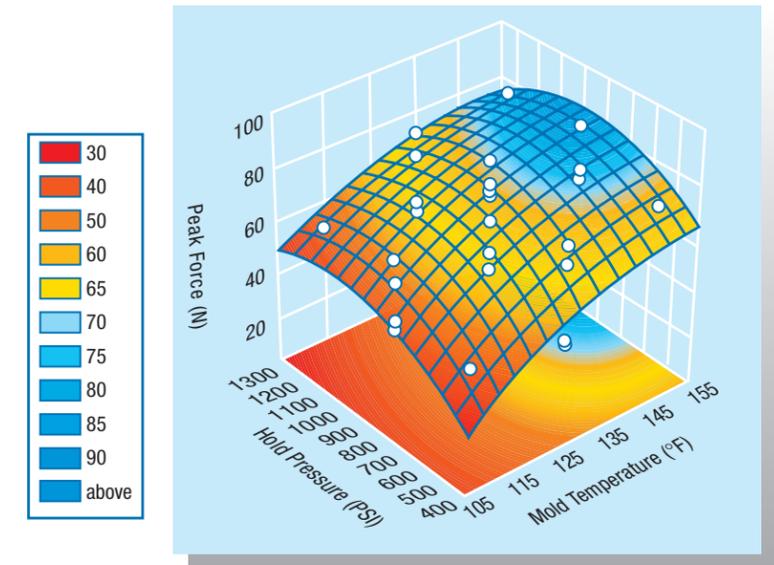
#### 4.7 Injection pressure / Injection speed

A good molding surface can be achieved by filling the mold uniformly. To prevent the injection speed from falling below the desired value throughout the injection process, a high injection pressure has to be set. A drop in the injection rate at the end of the injection phase indicates that the injection pressure is too low or the target speed is too high.

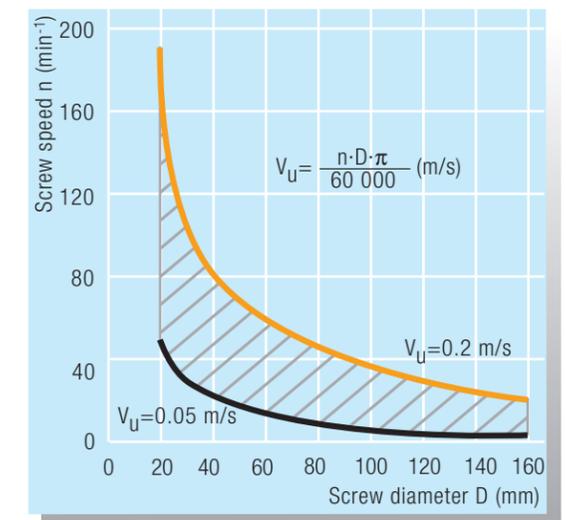
Marked differences in wall thickness while the injection speed remains the same result in nonuniform filling of the mold and hence in flow marks. If necessary, the injection speed has to be varied in steps or the component geometry has to be revised.

Especially in the case of thin-walled moldings, high injection speeds should be chosen. As a general rule, high injection speeds result in a higher melt temperature and a higher surface gloss (**Fig. 28**). They bring about improvements in flowability and especially in the case of glass-fiber reinforced product improvements in surface quality. High injection speeds give rise to a more uniform solidification process. In many cases, weld lines are less visible and the impact strength of the products is enhanced.

At a higher injection speed, the pressure requirement rises and the demands on mold venting become more stringent. In the case of a relatively cold melt, there is a danger of damage to the melt and of higher stresses in the molding.



**Fig. 29:** Instrumental impact of high impact polystyrene vs. hold pressure and mold temperature



**Fig. 30:** Recommended screw speed as a function of screw diameter and peripheral screw speed ( $V_U$ )

#### 4.8 Holding pressure / Holding pressure time

The holding pressure is intended to compensate for the shrinkage of the solidifying plastic. For this purpose it is important that the changeover to the holding pressure occurs exactly at the volumetric filling of the cavity.

Depending on the geometry of the component, voids and sink marks can be very largely balanced out by choosing an appropriate holding pressure value and a holding pressure time. On account of their amorphous structure, the holding pressure times for styrene polymers and copolymers are distinctly lower than for partially crystalline polyamide for example.

If the geometric design or choice of gate are unsuitable, an extremely high holding pressure or an extremely long holding pressure time can result in overfeeding of the moldings and hence in a lower impact strength of the components (Fig. 31). As a rule, high stresses can be demonstrated, especially in the sprue region and these are frequently the cause of premature failure of the molded part. This can give rise to demolding problems. The problem of overfeeding can possibly be minimized by means of a staged holding pressure profile.

#### 4.9 Cooling time

The criterion for an optimum cooling time is the demolding of the injection molded part without any lasting or subsequent deformation of the component. The cooling time can be determined for many geometries with the aid of computer programs.

#### 4.10 Shrinkage and warpage

The shrinkage of a component is determined both by the nature of the material as well as by the processing conditions and the geometry of the molding (shape of the molding, wall thickness and position of sprue). Interactions among these factors make it difficult to predict the exact shrinkage.

Accordingly, the shrinkage values set out in the material data sheets apply only to the specified processing and mold surface temperatures and the geometry used for the component. At the same time, a distinction has to be made between the values for free and impeded shrinkage parallel and at right angles to the direction of flow of the melt.

At 0.3–0.7%, the free shrinkage of amorphous materials is smaller by a factor of three or more than that of partially crystalline plastics which is 1–3%. Figure 32 shows the values of free shrinkage for the processing temperatures in question. These were measured on a 110 x 110 x 2 mm (4.3" x 4.3" x 0.08") plaque.

Shrinkage also affects molded parts in two ways other than part dimensions, namely sink marks and voids. Both of these molding problems are caused by the shrinkage of the hot melt as it cools on the inside of the molded part. In the case of sink marks, as the polymer cools and shrinks, material is pulled away from the wall of the part, creating a depression in the surface of the part. Voids occur from the same root cause, shrinkage of material on the inside of the part; but in this case, the walls have frozen solid and cannot be pulled away from the walls. As the material shrinks and volume decreases, a void is created on the inside of the part. Correction of both of these problems requires increased packing of the molded part to compensate for the shrinkage. Often, mold design changes are required to avoid thick sections in the part and minimize shrinkage to acceptable levels.

The processor can control shrinkage substantially by selective changes in the holding pressure and in the maximum effective holding pressure time up to the gate sealing point. The aim should be to compensate for the contraction in volume occurring during the freezing process for as long as possible by feeding melt through the holding pressure and holding pressure time.

A high mold surface temperature affects the cooling rate of the molding and thus prolongs the possible duration of action of the holding pressure. On the other hand, the injection speed and melt temperature have only a minor influence on the course of shrinkage.

Warping in the molding is generally caused by differences in shrinkage in the direction of flow transversely to flow and also by different wall thicknesses in the component. Since the holding pressure acts for very much longer close to the sprue than far from it, the different shrinkage along the component can also give rise to warpage.

The processor has the possibility of controlling warpage of the component by means of differential temperature control on the two halves of the mold as well as by means of partial temperature control of individual parts of the mold.

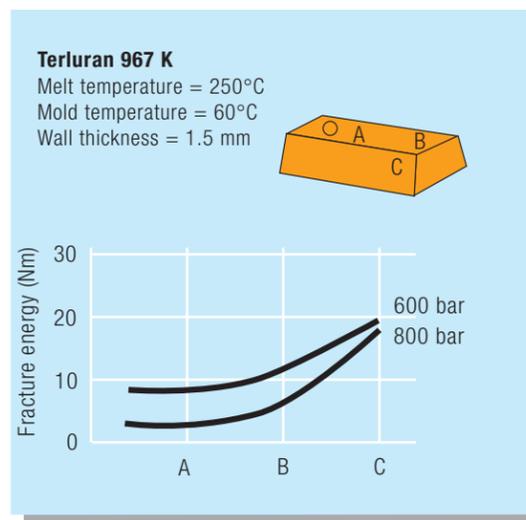


Fig. 31: Relationship between fracture energy and holding pressure

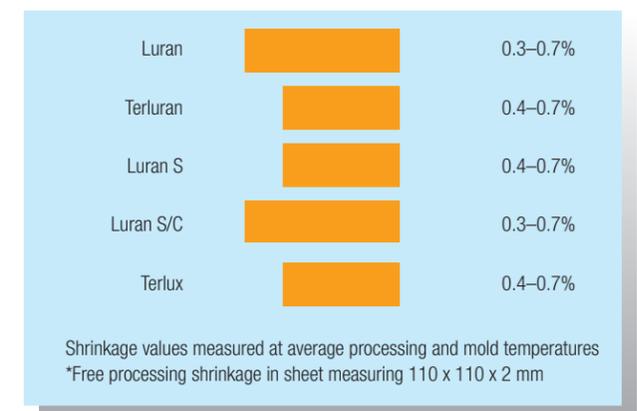
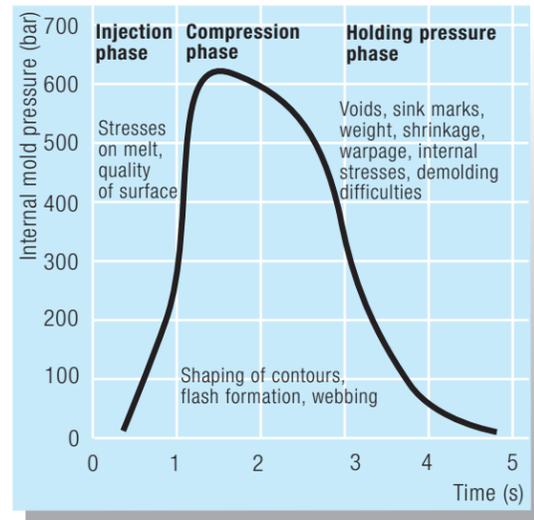


Fig. 32: Processing shrinkage\* of styrene copolymers

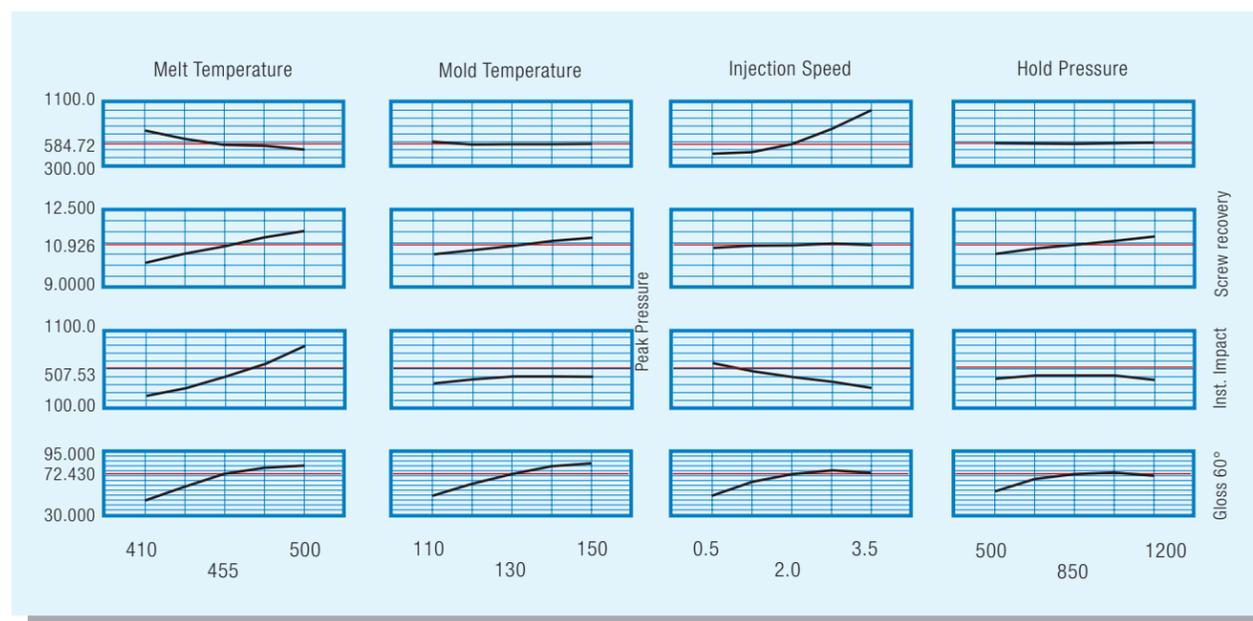
#### 4.11 Optimization of the injection molding process

Properties of a molding are frequently affected by changes in individual machine and mold as well as the process parameter adjustments due to the machine/mold changes. By way of example **Figure 33** shows in which phases of the injection molding process the key properties of a molding can be changed. **Figure 34** illustrates the magnitude of these interactions on part properties and process responses.

Here the key process and mold parameters are the melt temperature, the mold surface temperature, the injection speed and the pressure in the mold cavity. Measurement of these variables during the injection process simplifies not only the adjustment process but also shows potential problems in production at an early stage.



**Fig. 33:** Modification of the properties of the molding in the injection molding process



**Fig. 34:** Effects of Injection Molding Parameters on BASF HIPS and the molding process.

## 5. Special processes

#### 5.1 Multicomponent injection molding with styrene and styrene copolymers

The multicomponent injection molding technique makes it possible to selectively combine different products having their own specific properties in a molding. Styrene copolymers in combination with different thermoplastics and thermoplastic elastomers are also highly suitable for this special process in injection molding technology.

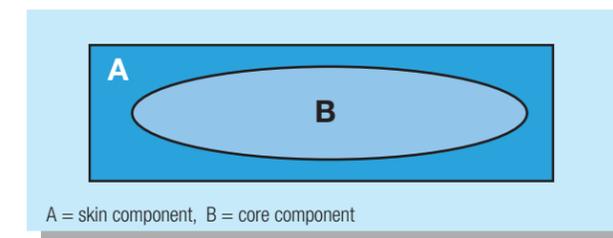
The processes combined under the generic heading of multicomponent injection molding include injection molding. Here, two plastic melts are prepared in different units and injected one after the other through a gate into the mold cavity. The result is a skin, or outer component (first injected component) and a core component (material which flows after the first component). A molding with a sandwich-like structure is produced (**Fig. 35**).

This three-layer structure has the advantage that the core component is usually completely enclosed by the skin component. In this way it is possible to produce moldings having specific properties matched to the application in question. For example, these can exhibit on the one hand a very good surface quality and on the other hand possess a reinforced or expanded core. Typical applications of the process are thick-walled articles, such as handles, and housings.

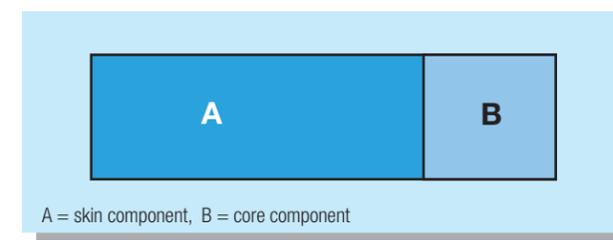
The distribution of the core component in the molded part usually has a direct effect on the quality of the finished part. It is controlled by the flowability of the products, the processing parameters, the positioning and design of the sprue and by the shape of the molding. In order to ensure adequate utility of the moldings, the components must be compatible with one another.

If, for example, they do not adhere adequately to one another, delamination of the layers can result in a reduction of functionality or serviceability. On the basis of experience, styrene copolymers undergo comparably good bonding to one another. On the other hand, a materials combination involving styrene copolymers with polypropylene for example is not recommended.

An increasing number of new applications are produced by a further multicomponent injection molding process, sandwich injection molding or over-molding. In this process, pre-moldings produced out of the first component are first manufactured. On completion of the setting time, these are covered in part with at least one further product (**Figs. 36 and 37**).



**Fig. 35:** Co-injection molding



**Fig. 36:** Composite injection molding



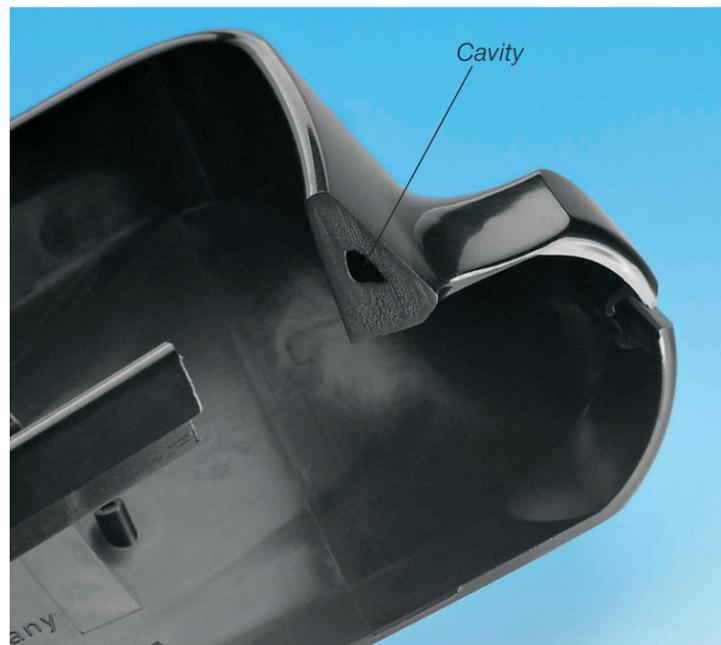
**Fig. 37:** Lid for a mixing cup made from Luran 388 S (transparent) and Luran S 778 T (white ring)

The multicomponent injection molding machines usually used are fitted with a number of units corresponding to the number of components. These special multicomponent injection molds, depending on the part to be produced, can have a very complex structural design because premoldings and finished moldings are produced in one mold. Tried and tested mold concepts for this are rotary and sliding split molds. In some cases, the premoldings are positioned in what is known as the final injection station with the aid of a handling device. Composite injection molding is also possible, however, using conventional molds and machines. In this case, the premolding is placed in a second mold and co-molded. The type of mold and machine employed depends on the part geometry, the piece numbers and the planned combination of materials.

The good bonding of the participating components required in most cases is ensured when styrene copolymers are used both in composite injection molding as well as in sandwich injection molding (usually as rigid/rigid components). In rigid/flexible applications, thermoplastic polyurethanes (TPE-U), for example, which undergo good bonding to Terluran and Luran, are suitable for the flexible component. Known applications are housings having a direct mold-on seal or handles which have injected over their surface a flexible component to improve their feel.

Since the bonding strength is affected by many factors and is difficult to predict, preliminary trials with test molds and prototype molds is frequently recommended to determine suitable combinations of materials or geometries of the bonding surfaces.

If the processed components do not adhere sufficiently well to one another, what are known as clamping mechanisms can also increase bonding strength. In this case, the undercuts or openings provided in the premolding are permeated during the subsequent overmolding by the melt of the second component and mechanically coupled. The disadvantage is the higher effort in mold engineering by comparison with bonding achieved by adhesion.



**Fig. 38:** External automobile mirror made from Luran S 778 T

## 5.2 Internal gas pressure process

The internal gas pressure method (IGP), also known as gas assist, was developed in the middle of the seventies. It has been used on a large scale only since the middle of the eighties.

The principle of the IGP method is the selective production of cavities at points in the molding having great wall thicknesses by the injection of inert gas – nitrogen as a rule – into the cavity partially or completely filled with plastic melt. The gas can be introduced by injection needles both via the machine nozzle as well as via a gas nozzle installed directly in the mold. In principle, all thermoplastics used in conventional injection molding, i.e. including styrene polymers and copolymers, can be processed by IGP. **Figure 38** shows an example of this.

Depending on the type of plastic molding to be produced, a choice can be made between the inflation method and the blowing out method.

The decision whether to use IGP or conventional injection molding is substantially determined by the mold geometry. In order to make optimum use of the advantages of the IGP method, it is necessary to start thinking differently as early as the design of the component and the mold. The factors affected are: position and layout of the sprue, design of wall thicknesses, use of ribs and diversion points for the melt.

The following advantages relative to conventional injection molding come to the forefront when the IGP method is used.

- Greater design freedom in the development of the molding.
- Simpler, more suitable injection molds.
- A great level of integration, i.e. the production of one part instead of two or more individual parts which subsequently have to be assembled.
- Prevention or minimization of sink marks.
- More uniform shrinkage, lower internal stresses and less warpage on account of the uniform distribution of gas pressure in the molding.
- Optimization of weight or material consumption while the rigidity of the molding is relatively high.
- Reduction of cycle times.
- Use of machines having a lower clamping force.

On the other hand, the following disadvantages can occur.

- Gas spreading and the hollow space formed is not predictable. Appropriate computer simulations, such as FEM programs for example, can provide indications.
- The gas spreading, size of the hollow space and the resultant residual wall thickness can only be affected within certain limits by the process parameters such as melt temperature, mold surface temperature, gas pressure and gas delay time.
- Additional resources are needed to carry out the process. These include gas pressure generator and pressure control modules, process gas and injection nozzles.
- Patent situation (license fees).
- Injection molds must be made with great precision and be perfectly balanced – this applies especially to multicavity molds – in order to ensure uniform spreading of the gas.

All injection molding machines commonly available on the market are suitable for the IGP method.

The manufacturers of gas systems supply different systems, such as Airmould, Airpress, Cinpress, Gain, etc. Some systems or variants of the process are protected by patents. For that reason, the processor should obtain comprehensive information about the patent position before starting technical utilization.

## Plastics Line of the BASF Corporation

### Products of BASF Corporation

<b>Terluran®</b>	Acrylonitrile/butadiene/styrene copolymer	ABS
<b>Luran® S</b>	Acrylonitrile/styrene/acrylate copolymer	ASA, (ASA + PC)
<b>Luran®</b>	Styrene/acrylonitrile copolymer	SAN
<b>Terlux®*</b>	Methyl methacrylate/acrylonitrile/butadiene/styrene copolymer	MABS
<b>Crystal PS</b>	Polystyrene	PS
<b>Avantra®*, high-impact PS</b>	Styrene/butadiene polymer	HIPS
<b>Styoblend®</b>	Blend based on styrene/butadiene polymer	HIPS blend
<b>Styrolux®</b>	Styrene/butadiene block copolymer	S/B/S
<b>Ultradur®</b>	Polybutylene terephthalate	PBT, (PBT + ASA)
<b>Ultraform®</b>	Polyoxymethylene	POM
<b>Ultramid®</b>	Polyamides	PA 6, 66, 6/66, 6/6T
<b>Ultrason® E</b>	Polyethersulfone	PES
<b>Ultrason® S</b>	Polysulfone	PSU
<b>Styropor®</b>	Expandable polystyrene	EPS
<b>Neopor® P</b>	Expandable polystyrene	EPP
<b>Neopor® E</b>	Extruded rigid polystyrene foam	EPE

® = registered trademark of BASF Aktiengesellschaft  
 ®\* = registered trademark of BASF Corporation

### Note

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