The fundamentals of shrinkage in thermoplastics

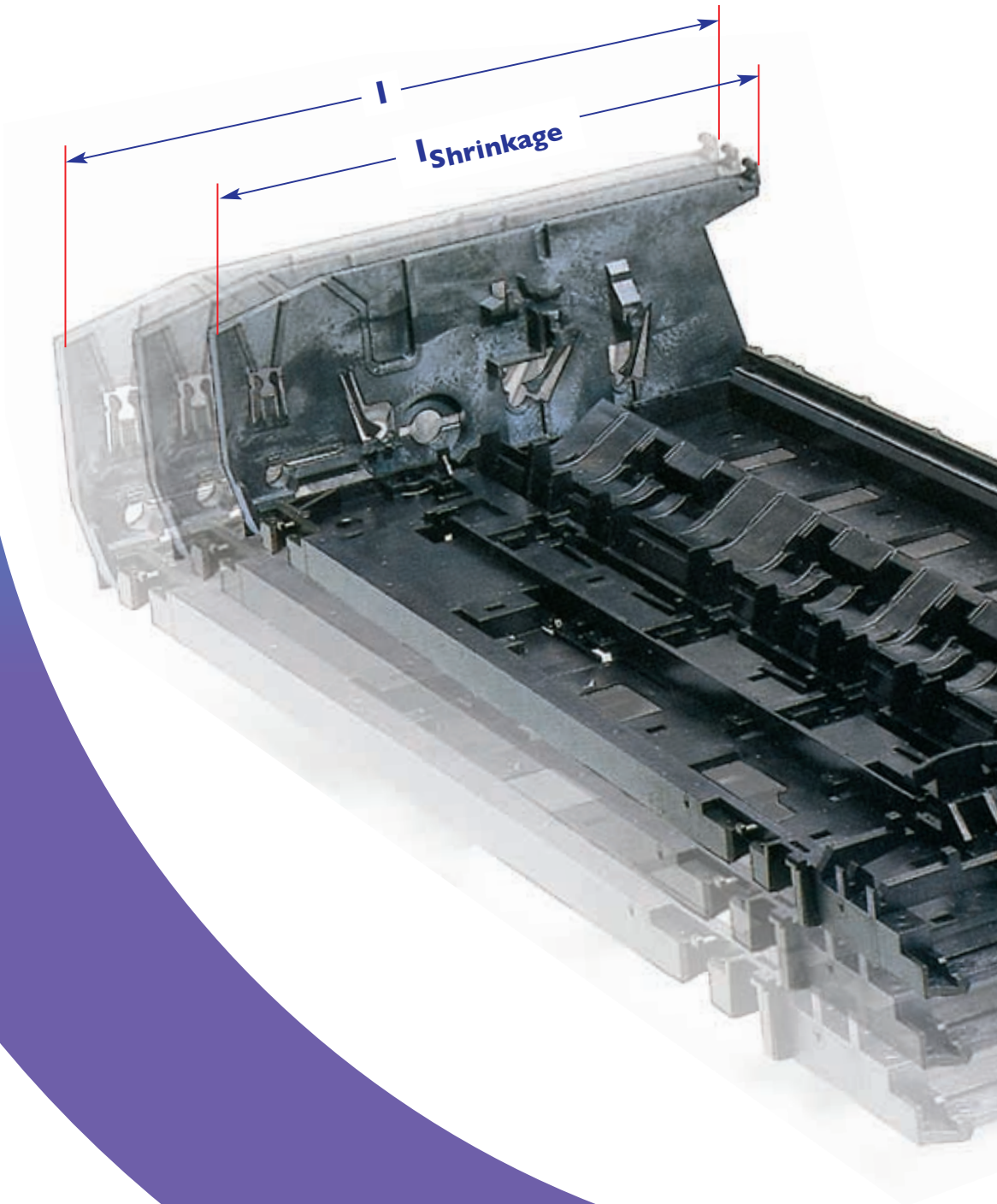


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1 The concept of “shrinkage”

When thermoplastics are processed by injection molding, the dimensions of the molded part change as the part cools. Often, these changes are referred to as either “shrinkage” or “warpage”.

Strictly speaking, **shrinkage** is due to the **compressibility** and thermal expansion of plastics. When thermoplastics **shrink,** they undergo a **volume change.** With **warpage,** by contrast, the shape changes while the overall **volume** remains constant.

For this reason, the mold builder has to predict the difference, due to shrinkage, between the dimensions of the mold cavity and those of the molded part. In many cases, this is not an easy task, since shrinkage is influenced by a large number of parameters.

Apart from process control (temperatures, pressures) and the properties of the material (e. g. its pvT behavior, filler content, and its amorphous or semi-crystalline nature), the stiffness and wall thicknesses of the molded part also have an effect on shrinkage.

Although shrinkage is based on thermal contraction, the effective reduction in dimensions after demolding is less than would be expected for pure thermal contraction.

Additional mechanisms are involved in shrinkage that lead to a lower level of thermal contraction than would otherwise result. The chief mechanisms involved here are:

– inherent stresses, influenced by
  • the temperature profile during cooling
  • the cavity surface temperature

– crystallization in the case of semi-crystalline thermoplastics, influenced by
  • cavity surface temperature
  • cooling profile

– mechanical obstruction of shrinkage, influenced by
  • mold constraint

Apart from this, thermal contraction is influenced by the thermodynamic process sequence in injection molding, and particularly through

- the pressure profile during cooling
- the action of pressure and the stressing of the melt due to the design and position of the gate
- the melt temperature and other processing conditions

The influence of the thermodynamic process profile on shrinkage behavior is presented in a very clear fashion on a pressure (p), volume (v) and temperature (T) diagram – known simply as the pvT diagram – which characterizes:

- **compressibility**
  change in volume with a change in pressure

and

- **thermal behavior**
  change in volume with a change in temperature

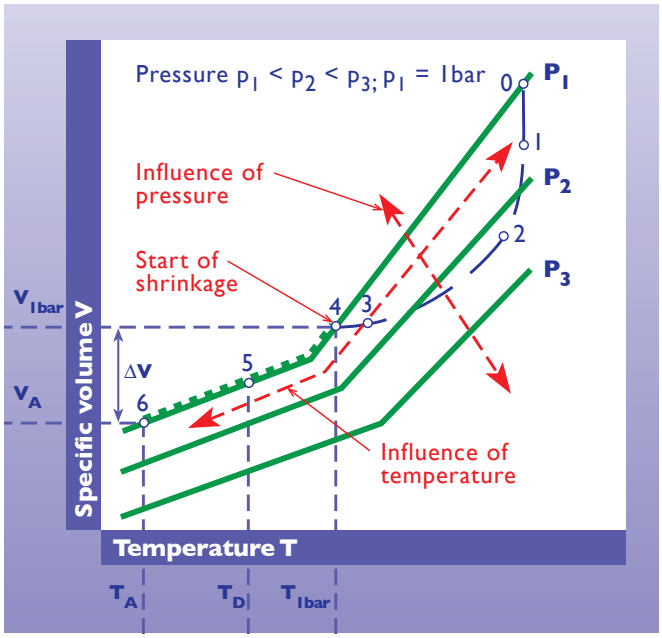


Fig. 1: Schematic pressure (p), volume (v) and temperature (T) diagram

0 → 1 volumetric filling
1 → 2 compression
2 → 3 action of holding pressure
3 → 4 pressure reduction to ambient pressure
4 → 5 cooling to demolding temperature (T_D)
5 → 6 cooling to ambient temperature (T_A)

The pvT diagrams supply information on the volume shrinkage, S_V, from ($\Delta V = V_{1bar} - V_A$) and show shrinkage potentials. Volume shrinkage is defined below:

$$S_V = \frac{V_C - V_P}{V_C}$$

V_C = volume of cold cavity
V_P = molded part volume

$$S_V = 1 - (1 - S_L)(1 - S_W)(1 - S_S)$$

S_L = longitudinal shrinkage
S_W = shrinkage in width
S_S = shrinkage in thickness

When it comes to the practical design of injection molds, however, it is the linear shrinkage that is more important.

$$S_l = \frac{l_W - l_F}{l_W}$$

S_l = linear shrinkage
l_W = dimension of cold cavity
l_F = dimension of molded part

Shrinkage is a relative value and is given in the form of a percentage.

A real-life part cannot shrink uniformly in all three directions (over its length, width and thickness). Only over the thickness of the part does virtually unimpeded shrinkage take place. Most of the volume shrinkage, therefore, is "used up" in the shrinkage of the wall thickness of the molded part. Even if the mold does not impede shrinkage in any way, the fact that the layers of the molding freeze from the outside towards the inside means that shrinkage is obstructed over the length and width of the part.

The following shrinkage situation generally results from shrinkage that is due to the mold and internally obstructed shrinkage.

- **Shrinkage over thickness**
  $S_S = 0.9 - 0.95 * S_V$
- **Shrinkage over length or width**
  $S_{L/W} = 0.1 - 0.05 * S_V$

S_V = volume shrinkage
S_S = shrinkage over thickness
$S_{L/W}$ = shrinkage over length or width

Shrinkage SL/W does not make allowance for any anisotropic shrinkage that may occur on account of fillers and reinforcing materials.

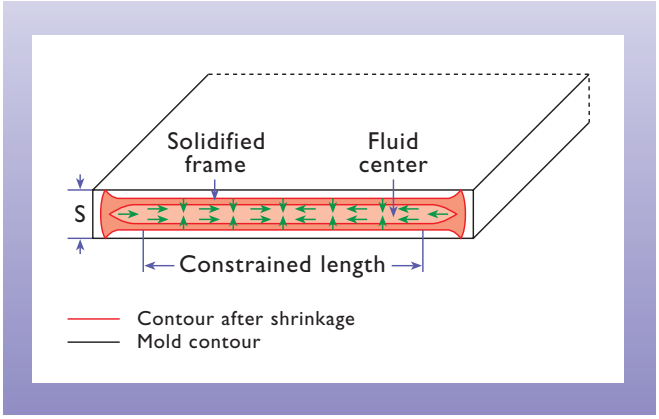


Fig. 2: Internal obstruction of shrinkage in a cooling plastic panel [4]

Since shrinkage is a time-dependent parameter, the point in time after demolding at which the shrinkage is measured must be specified in order to achieve a precise definition.

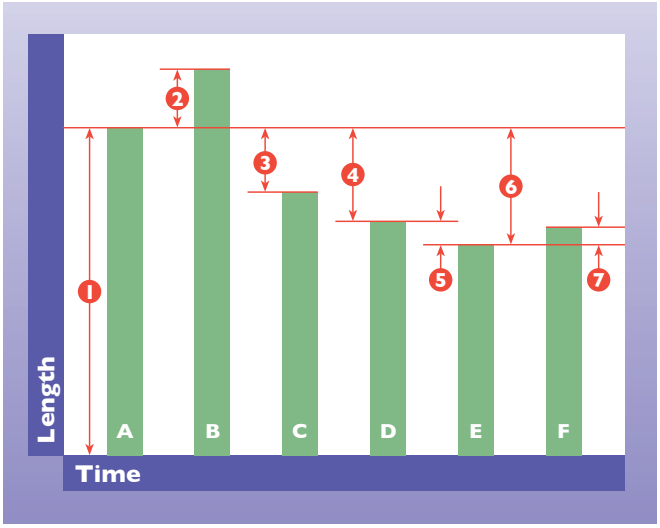


Fig. 3: Change in a molded part dimension over time through shrinkage

1 = Mold dimension
2 = Thermal expansion of mold
3 = Demolding shrinkage SE
4 = Molding shrinkage SM
5 = Post-shrinkage SP
6 = Overall shrinkage Stotal
7 = Potential length increase through conditioning, e. g. for polyamides

A = Cold mold
B = Hot mold
C = Molded part after demolding
D = Molded part after 24h in standard atmosphere
E = Molded part after a prolonged period or after storage in heat
F = Molded part after water absorption, e. g. polyamides

A distinction is drawn between demolding shrinkage SD, which is measured immediately after the injection molded part has been ejected, molding shrinkage SM and post-shrinkage SP.

According to DIN 16901, the molding shrinkage (SM) of engineering plastics in injection molding is specified as the difference between the dimensions of the cold mold and those of the molded part after 16 hours' storage in a standard climate [3]. With continued storage at high temperatures, a further change in dimensions can occur, which is then known as post-shrinkage (SP).

Molding shrinkage S_M

$$S_M = \frac{l_W - l_{F1}}{l_W}$$

Post shrinkage S_N

$$S_P = \frac{l_{F1} - l_{F2}}{l_W}$$

l_{F1} = molded part dimension before S_N
l_{F2} = molded part dimension after S_N
l_w = dimension of cold mold

The reasons for post-shrinkage are the relaxation of inherent stresses, together with re-orientation processes and, in the case of semi-crystalline materials, potential post-crystallization [1].

With a number of thermoplastics, conditioning (water absorption) can also take place, in addition to post shrinkage. This effect is seen particularly with polyamides.

The level of post-shrinkage can be quite considerable if the processing is not correctly tailored to the material.

The term "overall shrinkage" is defined as follows:

Overall shrinkage
= molding shrinkage + post-shrinkage

2 Factors that influence shrinkage



Fig. 4: Factors influencing shrinkage [2]

The interplay between the different influencing factors is highly complex. There are factors which mutually influence one another and which are dependent on one another. Hence, a poorly dimensioned gate (molded part) can have a direct negative influence on the effect of the holding pressure (processing).

The interaction between the different influencing factors is not covered in what follows. Instead, the basic way in which shrinkage is influenced is explained on the basis of these factors.

The decisive point in this observation is that the correlation between the influencing factors and the shrinkage is always viewed in terms of the mechanisms listed at the outset:

- thermodynamic state profile, inherent stresses and crystallization.

This makes it possible to explain the dependence of shrinkage on the influencing factors in a clear manner.

2.1 Material

2.1.1 Amorphous and semi-crystalline thermoplastics

The dissimilar shrinkage behavior of the two material types can be presented particularly clearly on the pvT diagram.

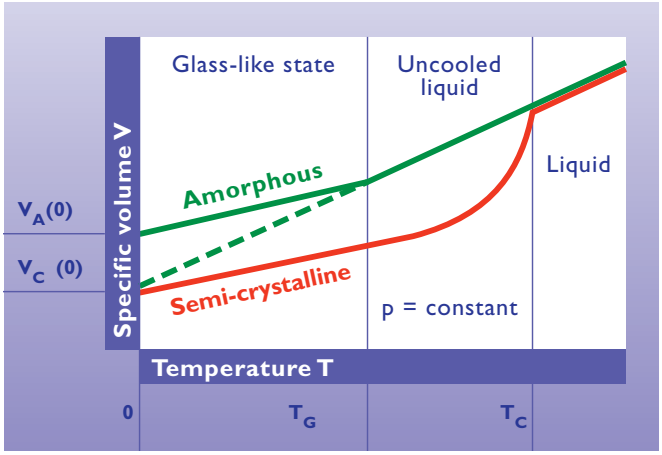
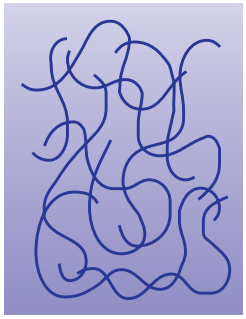


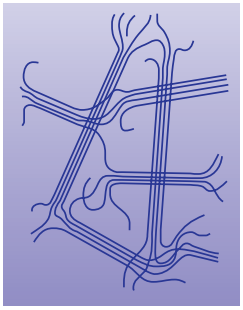
Fig. 5: Qualitative pressure, specific volume and temperature diagram (pvT diagram) for an amorphous and a semi-crystalline thermoplastic

Amorphous materials



The green curve in Fig. 5 shows the dependence of the specific volume on the temperature of an amorphous thermoplastic (e. g. ABS, PC). Undercooling of the melt is evident here as the temperature falls. Below the glass transition point TG, the volume undergoes a less pronounced reduction (lower gradient), and the material is in a glass-like state – "undercooled liquid". The free volume remains virtually constant during this phase [5].

Semi-crystalline materials



The red curve in Fig. 5 shows the path of the specific volume as a function of temperature for a semi-crystalline polymer (e. g. PA, PBT).

In the case of semi-crystalline thermoplastics, crystallization takes place during cooling. If the plastic falls below the crystallization temperature, TC, then linear, or only slightly branched, chains with easily alignable repeat units will reconfigure themselves into an ordered (crystalline) state with a lower free enthalpy. The polymer chains lie parallel to one another, tightly packed in some cases, forming fine crystallites in which almost complete order prevails, with the exception of a few defect points. Contrary to the case with purely crystalline materials, there is no single point of crystallization here but a transition range instead [5].

The superposition of advancing crystallization and thermal contraction leads to the parallel-shaped curve profile in the semi-crystalline range. Higher shrinkage values are seen than with purely amorphous materials.

The influence of the pressure that prevails during cooling on the specific volume is shown in Fig. 6.

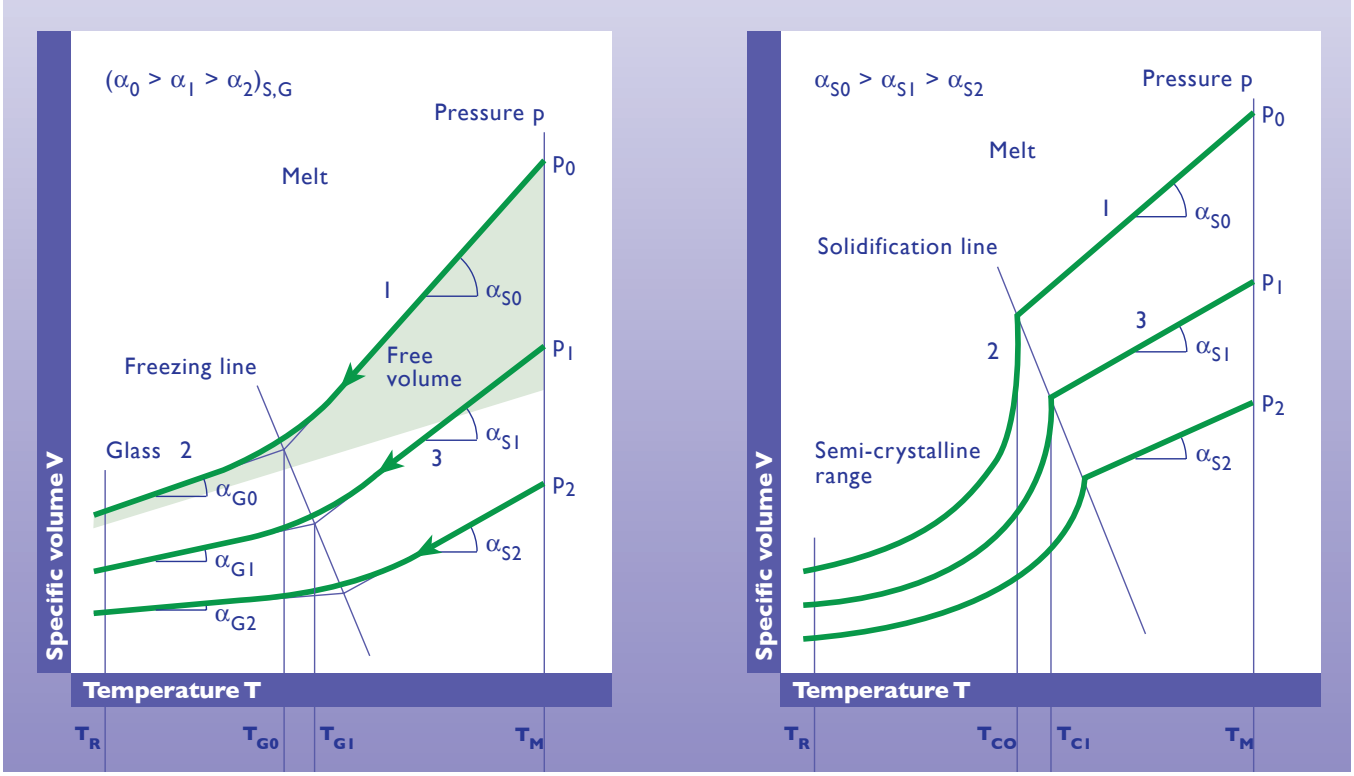


Fig. 6: pvT diagram of an amorphous (left) and semi-crystalline (right) plastic during slow cooling under different pressures p0, p1, p2

Figure 6 shows that the higher "packing density" that results with rising pressure causes an upward shift in the glass transition point TG for amorphous plastics and in the crystallization temperature TC for semi-crystalline plastics [5]. The specific volume achieved at room temperature under a high pressure is lower than the specific volume at atmospheric pressure. When the pressure is removed, the plastic attempts to achieve the specific volume at a normal pressure of 1 bar.

Figure 7 shows linear shrinkage ranges for a number of amorphous and semi-crystalline thermoplastics. These shrinkage ranges result from the influence of processing, the process, the mold and the molded part (e. g. the wall thickness) and the fillers or reinforcing materials. The shrinkage of the non-reinforced amorphous polymers (Bayblend®, Makrolon®, Apec®) is less than 1 %, while that of the non-reinforced semi-crystalline polymers thermoplastics is more than 1 %. With the reinforced materials (GF), an increased anisotropy (directional dependence) is observed in the shrinkage.

Amorphous thermoplastics

S < 1 %

Relatively isotropic shrinkage values, hence only a slight tendency to warp

Semi-crystalline and reinforced thermoplastics

S > 1 %

Shrinkage as a function of fiber and molecule orientation, hence a pronounced tendency to warp

Established on shrinkage measurement plaques (150 x 90 x 3 mm) under the recommended processing conditions. Holding pressure approx. 500 bar.

Shrinkage values relate to the product class and not to individual grades and cannot be used for the precise design of a mold.

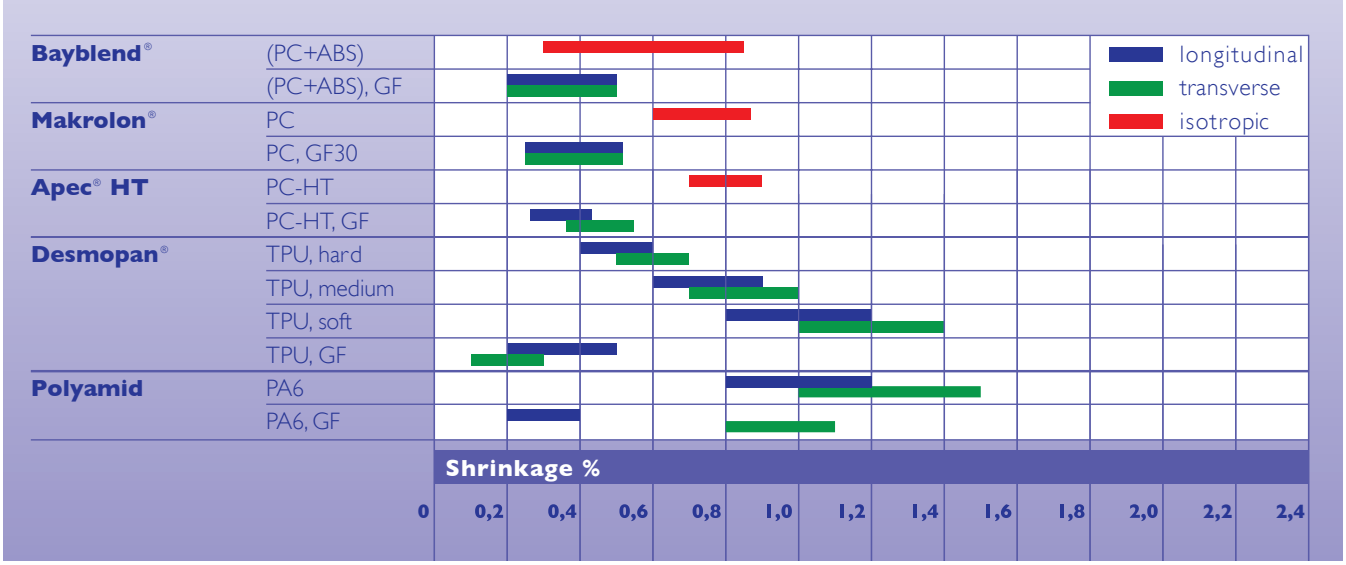


Fig. 7: Shrinkage ranges for amorphous and semi-crystalline thermoplastics [2]

2.1.2 Crystallization behavior

In the case of semi-crystalline thermoplastics, crystallization occurs during cooling. This crystallization process is time- and temperature-dependent. The cooling rate has a major influence on nucleation and nucleus growth and hence on the structure that develops.

The more slowly cooling takes place (through high cavity surface temperatures), the higher the degree of crystallization – and the greater the level of shrinkage.

If the temperature falls too rapidly, then it is possible for nucleation and nucleus growth to be suppressed. This will give rise to a structure with a low degree of crystallization and hence to a low molding shrinkage. This can then lead to more pronounced post-crystallization and hence to undesirable post-shrinkage.

2.1.3 Fillers and reinforcing materials

Fillers of a **spherical shape** lead to reduced shrinkage on account of their lower CLTE when compared with plastics [1].

Glass fibers have an even more pronounced effect on shrinkage than spherically-shaped fillers [6]. The glass fibers constitute an additional internal restraint, which impedes thermal contraction in the direction of the glass fibers and thus leads to lower shrinkage values. Perpendicular to the direction of orientation, the fibers act in the same way as the fillers referred to above and similarly reduce shrinkage, albeit to a lesser extent [4].

Table 1 shows that, in polyamide 6, it is possible to influence shrinkage to a large extent through the filler content and filler type.

Filler	Shrinkage longitudinal / transverse
non-reinforced	1.0 / 1.2
mineral	1.2 / 1.2
30 % glass fibers	0.2 / 0.8
15 % spheres / 25 % glass fibers	0.3 / 0,9

Table 1: Influence of fillers on the shrinkage behavior of polyamide PA6 (holding pressure: 500 bar)

Through the use of glass fibers, it is possible to reduce shrinkage by 50 to 80 % in the longitudinal fiber direction. Adding more than 20 to 25 % glass fiber has no further effect on the shrinkage behavior of semi-crystalline thermoplastics [2].

This is illustrated in Figure 8, which shows how the shrinkage changes with varying glass fiber content and progresses towards a limit in semi-crystalline polyamide resin.

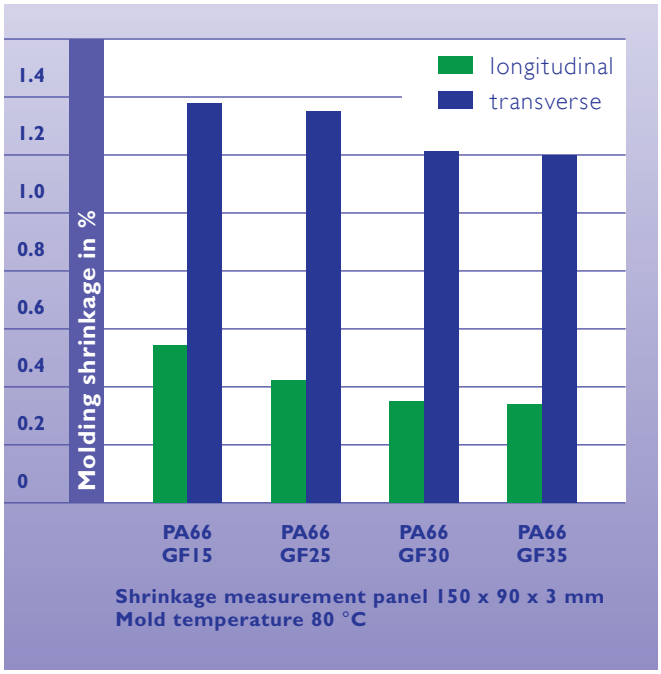


Fig. 8: Influence of glass fiber content on shrinkage for semi-crystalline polyamide AKV (PA66, GF)

2.2 Processing

The qualitative correlations between the individual process parameters and the molding shrinkage are displayed in Fig. 9. The correlations between molding shrinkage and process parameters are explained in more detail below.

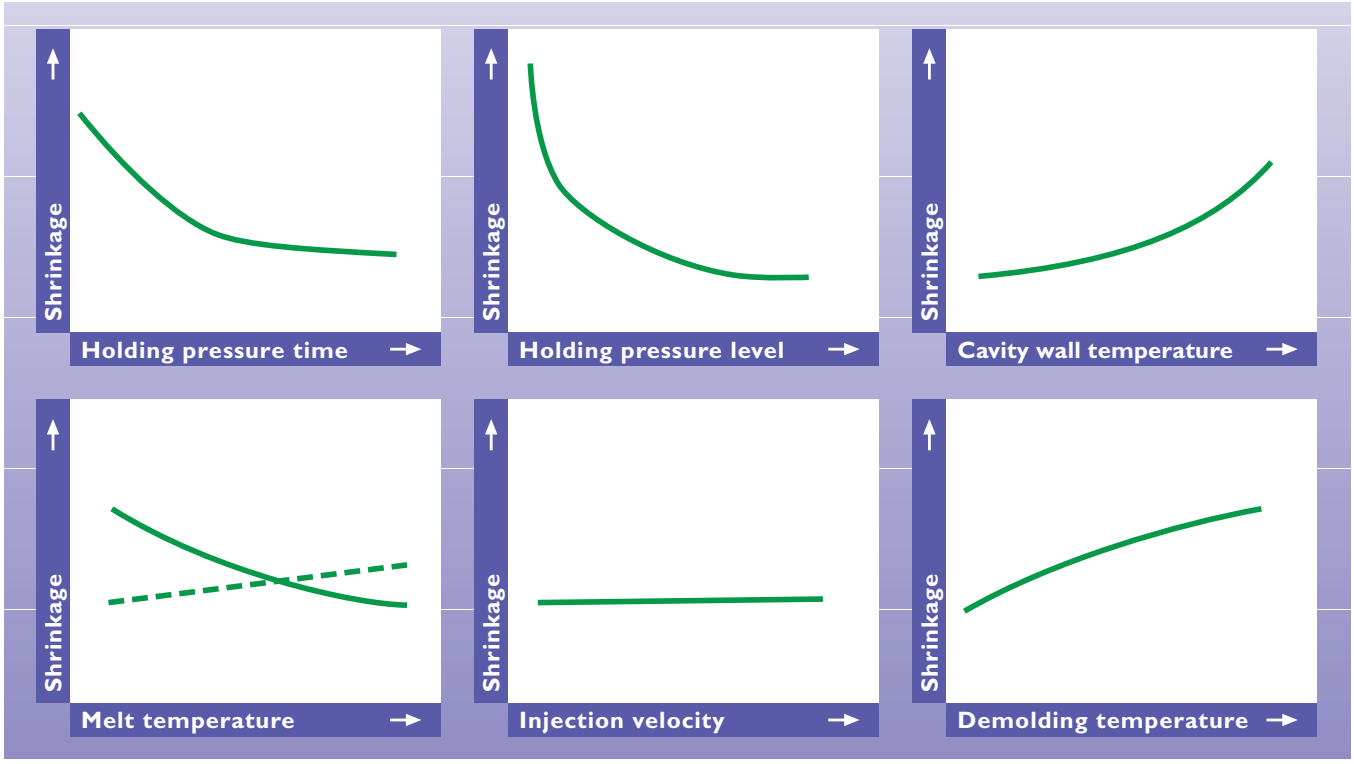
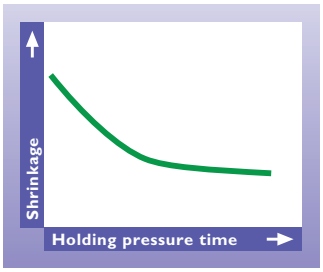


Fig. 9: Influence of processing parameters on shrinkage behavior [2]

2.2.1 Holding pressure time

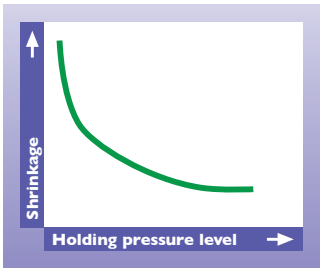


The purpose of the holding pressure is to offset material shrinkage by conveying more melt into the cavity. Under the action of the holding pressure, the material in the cavity is compressed and volumetric contraction due to the cooling process is offset. The holding pressure time thus has a major influence on the amount of extra melt injected and on the shrinkage compensation. The longer the hold time, the lower the shrinkage.

With amorphous materials, the holding pressure time has slightly less influence than with semi-crystalline materials due to the reduced additional volume conveyed into the cavity [1].

Using large gates with generous cross-sections dramatically increases the time over which holding pressure can act. Always position gates where wall sections are thickest.

2.2.2 Holding pressure level



With both amorphous and semi-crystalline thermoplastics, the level of holding pressure has a decisive influence on the degree of shrinkage. The higher the holding pressure, the lower the mold shrinkage.

The extent to which shrinkage can be influenced by holding pressure is regressive, however. In other words, as the holding pressure increases, the reduction in shrinkage becomes less pronounced.

With an optimally designed gate system and molded part, it is possible to reduce shrinkage by up to 0.5 % in semi-crystalline thermoplastics by increasing the holding pressure. With amorphous materials, values of no more than 0.2 % are achieved on account of the lower shrinkage potential [1].

Figure 10 shows how dissimilar shrinkage occurs due to the dissimilar action of the holding pressure close to and remote from the gate.

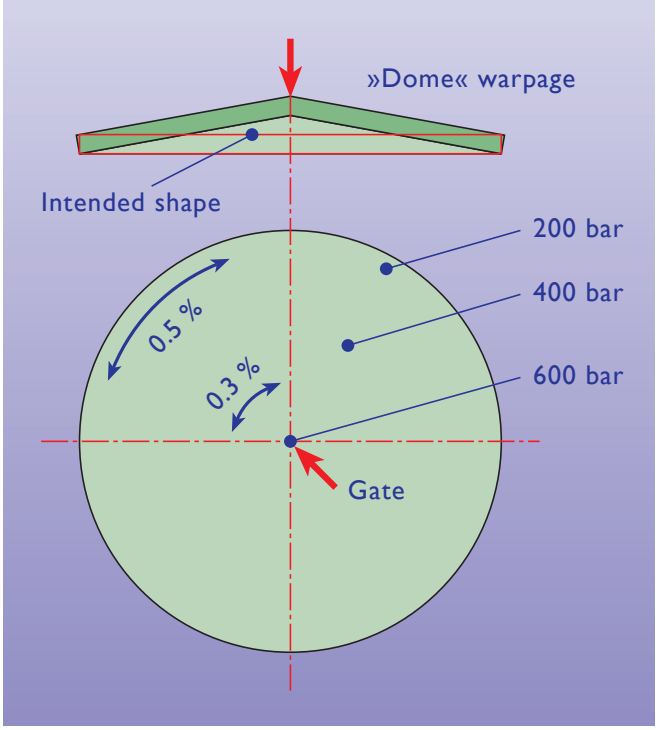
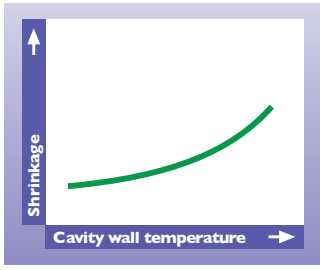


Fig. 10: Dissimilar action of holding pressure close to and remote from the gate with a centrally-gated circular disk in a non-reinforced thermoplastic [2]

2.2.3 Cavity wall temperature

The molding shrinkage increases with the cavity wall temperature. Due to the influence of cavity wall temperature, various different factors are superimposed which affect the flow process (holding pressure phase), the crystallization and the inherent stress profile. This holds true for semi-crystalline materials in particular.



Apart from enhancing or impairing the action of the holding pressure, the mold wall temperature also has a strong influence on the cooling rate (Fig. 11).

A low mold temperature TW (40 °C) leads to high cooling rates and hence to a low level of crystallization in the polyamide, as shown in Fig. 11. This leads to low molding shrinkage followed by high post-shrinkage.

With a high cavity temperature TW (120 °C), a greater proportion of molding shrinkage takes place right away (high degree of crystallization). The post-shrinkage potential is drastically reduced. Overall shrinkage is more or less identical at both processing temperatures (Fig. 13).

$$T_W \uparrow \quad V_{CR} \downarrow \quad \Rightarrow \quad S_M$$
$$T_W \downarrow \quad V_{CR} \uparrow \quad \Rightarrow \quad S_M$$

T_W = mold temperature
V_{CR} = cooling rate
S_M = molding shrinkage

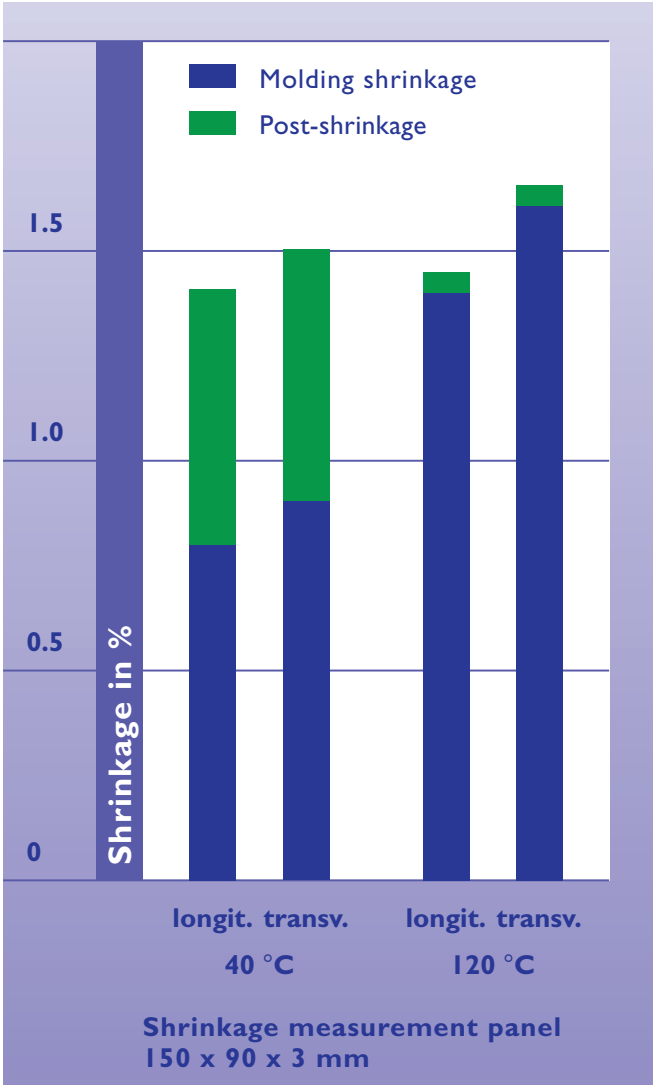
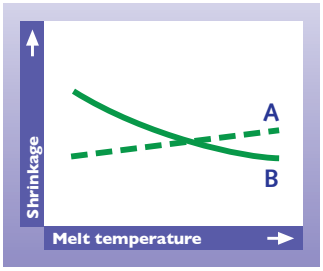


Fig.11: Shrinkage as a function of the cavity surface temperature for non-reinforced polyamide PA6

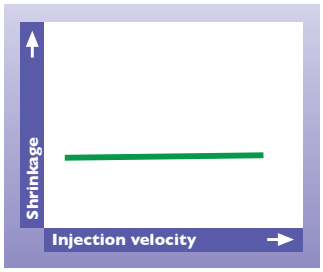
2.2.4 Melt temperature



The melt temperature also has an influence on shrinkage behavior. Two counteracting effects are involved here. Firstly an elevated melt temperature increases the potential for thermal contraction in the resin (increased shrinkage, A) and, secondly, it leads to a reduction in the melt viscosity and hence to better packing and, ultimately, to a reduction in shrinkage (B). As a general rule, curve profile B is measured and observed. The improved packing predominates over the contraction potential. If, however, an unfavorable wall thickness situation and poor packing conditions exist, then raising the melt temperature can actually increase shrinkage (sink marks, curve profile A) [1].

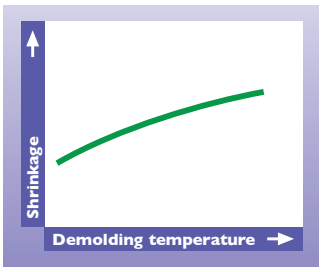
When optimizing other process parameters, it is often helpful to maintain a constant melt temperature.

2.2.5 Injection velocity



The injection velocity has almost no influence on overall shrinkage. Apparently, counter effects such as orientation vs. re-orientation and shear heating vs. pressure distribution cancel each other out.

2.2.6 Ejection temperature (longer cooling time, increased mold restraint)



The longer the part remains in the mold, the longer the cooling time and the lower the ejection temperature will be. At the same time, the part will see increased mold restraint. Particularly with semi-crystalline thermoplastics, lower ejection temperatures typically cause less mold shrinkage.

With higher ejection temperatures (shorter cooling times), a more pronounced temperature increase occurs in the outer layers of the molded part. A kind of virtual “heat storage” takes place. This relieves surface stresses and increases shrinkage [6].

2.3 Molded part geometry

2.3.1 Wall thicknesses

When the thickness of the molded part is varied, this leads to a quantitative change in all the other variables that affect shrinkage (such as the action of holding pressure or the cooling rate).

Given identical melt and mold temperatures, a thinner molded part will cool more rapidly than a thick one. All the different thermally-conditioned processes (such as crystallization and internal stresses due to cooling) thus have less time in which to act. Because the boundary conditions change with wall thickness it is very difficult to make a general statement on the influence of thickness [4].

Despite this, it is still possible to point to basic correlations between the shrinkage and the thickness of the molded part.

Figures 12 and 13 show the correlation between shrinkage and wall thickness for semi-crystalline and amorphous thermoplastics. Especially in the case of non-reinforced semi-crystalline thermoplastics (Fig. 12 left), the wall thickness is seen to have a major influence on shrinkage. The thicker walls lead to slower cooling, and thus give rise to more favorable crystallization conditions. The degree of crystallization is higher, increasing the level of shrinkage.

These figures show that there can be large shrinkage differentials if there are different wall thicknesses in a plastic molded part. If dissimilar shrinkage occurs, then warpage can result. This is more pronounced with semi-crystalline thermoplastics than with amorphous thermoplastics (Fig.13).

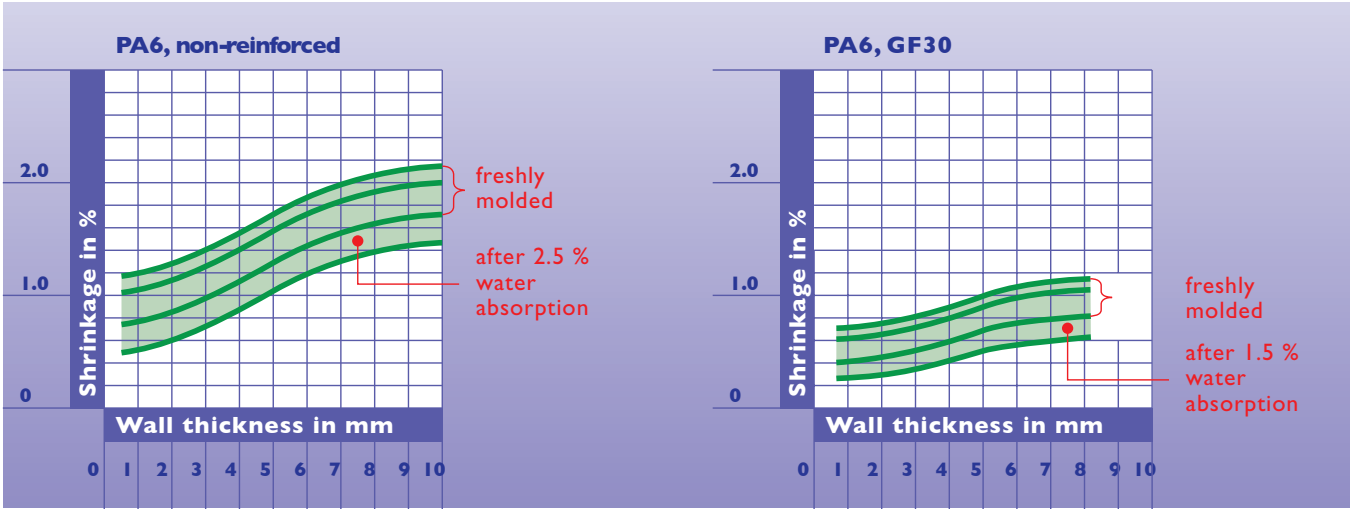


Fig. 12: Correlation between shrinkage and wall thickness for semi-crystalline thermoplastics

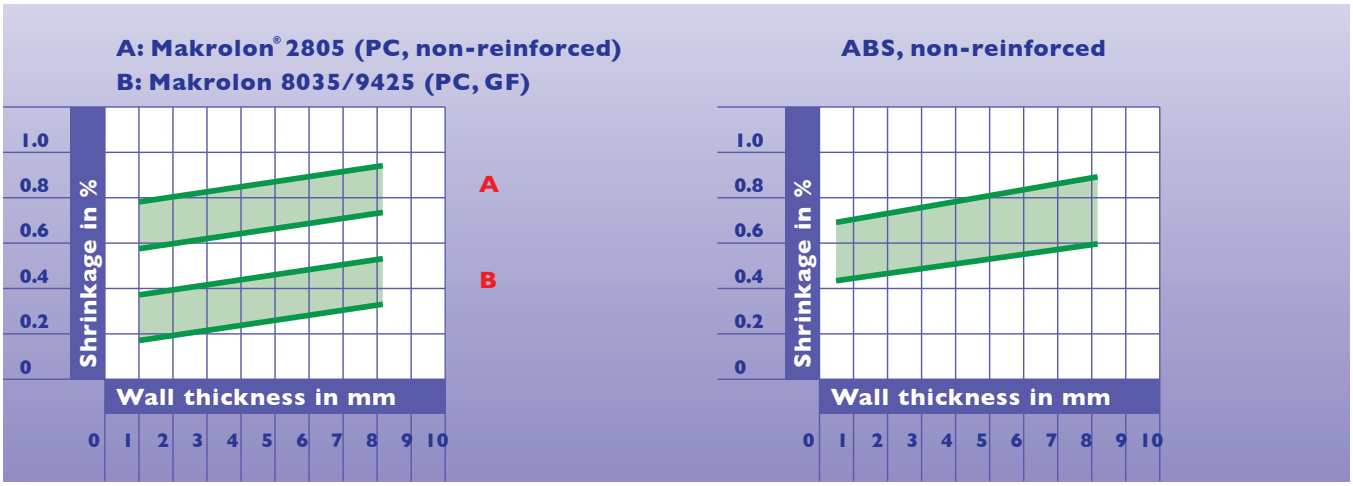


Fig. 13: Correlation between shrinkage and wall thickness for amorphous thermoplastics

2.3.2 Reduced wall thickness at the end of the flow path

As Fig. 14 shows, the holding pressure has less of an effect farther from the gate than close to the gate. This leads to higher shrinkage at points far from the gate, which means that it is useful to reduce the wall thickness at these points (at the end of the flow path). The wall thickness reduction means that there is a lower "shrinkage potential" in these areas, so that the shrinkage differential compared with the region close to the gate is no longer so pronounced.

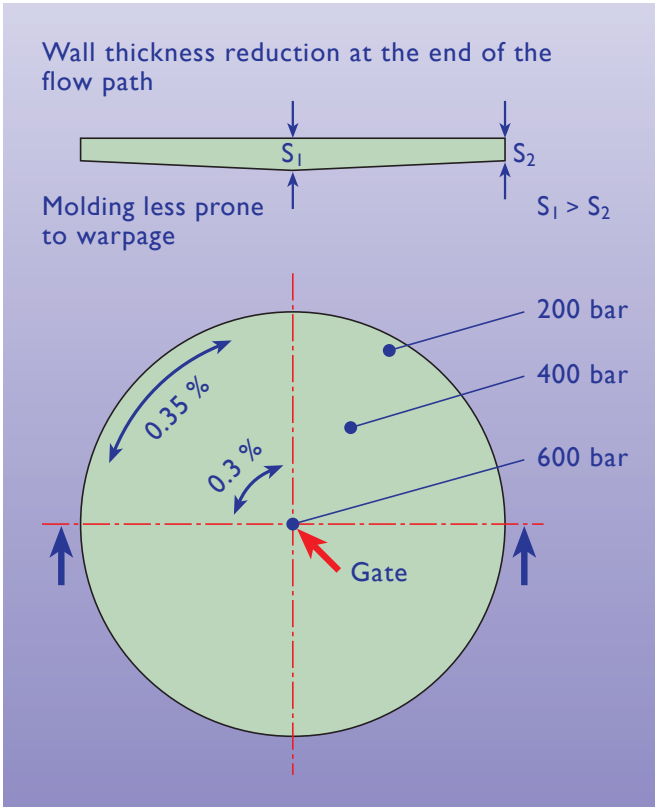


Fig. 14: Lower tendency to warp through a reduced wall thickness at the end of the flow path on a centrally injected circular disk in a non-reinforced thermoplastic

2.3.3 Ribs

Ribs can have a pronounced influence on molded part shrinkage and, in particular, on the uniformity of shrinkage. Ribs should be made thinner than the wall to which they are attached, observing a specific rib wall thickness to nominal wall thickness ratio. The correlations between shrinkage and wall thickness referred to above mean that the ribs generally shrink less (i. e. they "remain longer") than the other molded part dimensions. The result can be a warped part.

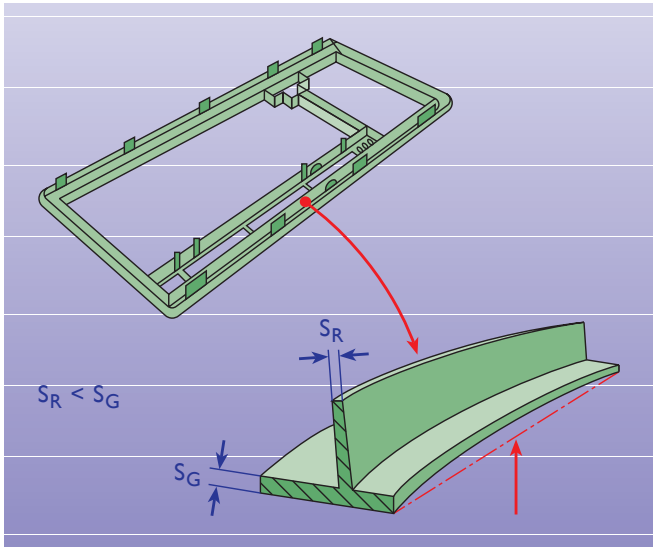


Fig. 15: Warpage due to differences in the rib wall thickness and nominal wall thickness [2]

2.4 Mold

2.4.1 Heating/cooling

Different levels of heating and cooling in different areas of the molded part produce dissimilar shrinkage and hence dissimilar molded part properties (Fig. 16).

When a different mold temperature exists on the inside and outside of the molded part, the plastic on the hotter side will undergo more pronounced shrinkage. During this uneven cooling, there will be a shift in the temperature profile in the solidifying melt, and hence dissimilar shrinkage potentials and cooling stresses will result. This type of differential shrinkage is similar to the effect that dissimilar metals experience when coupled together as in a bi-metallic structure and then are exposed to a certain temperature range (as in a thermostat gage). Differing degrees of thermal expansion and contraction occur within each metal.

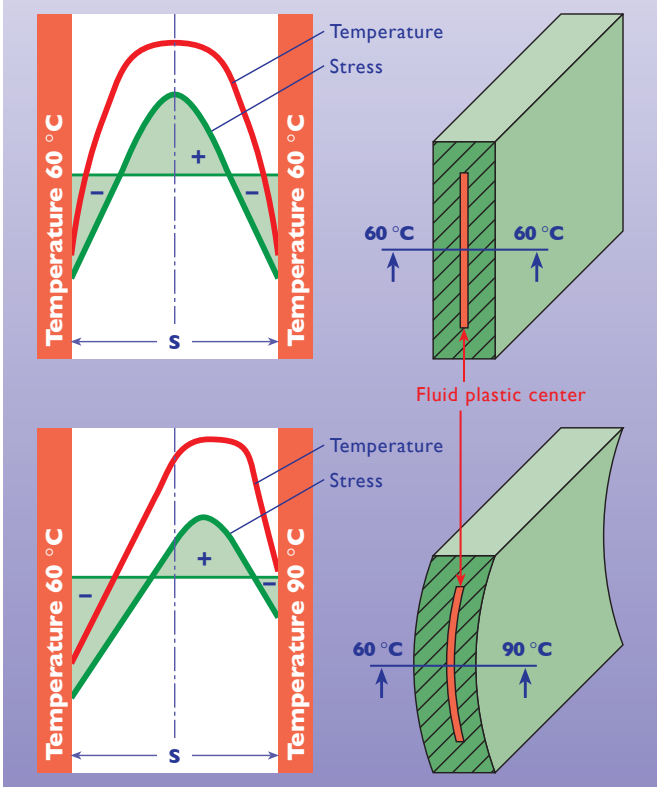


Fig. 16: Warpage as a result of heating/cooling differentials in the mold

Warpage can occur in the molded part as a result of the asymmetrical stress distribution that develops (see lower part of Fig. 16).

Therefore, take care to ensure a uniform mold wall temperature in the injection mold. The influence of heating/cooling in the mold is considerably greater with non-reinforced thermoplastics than with glass fiber reinforced thermoplastics, for example.

In the case of glass fiber reinforced thermoplastics, it is the influence of the fibers on the shrinkage that predominates (Chapter 2.1.3).

2.4.2 Gate type

Different molded part geometries frequently call for different types of gating.

Design gates to allow good packing regardless of gate type (e. g. film, pin-point or tunnel gate, etc.). Then, the holding or packing pressure is much more effective at minimizing shrinkage.

The modified tunnel gate depicted in Fig. 17 will only provide optimum conditions for an effective holding pressure phase (in terms of the influence on shrinkage) if it is of the optimum design in terms of the plastic and the molded part.

The version with an unfavorable design not only reduces the effect of the holding pressure but also imposes greater thermal and mechanical stressing on the melt during injection.

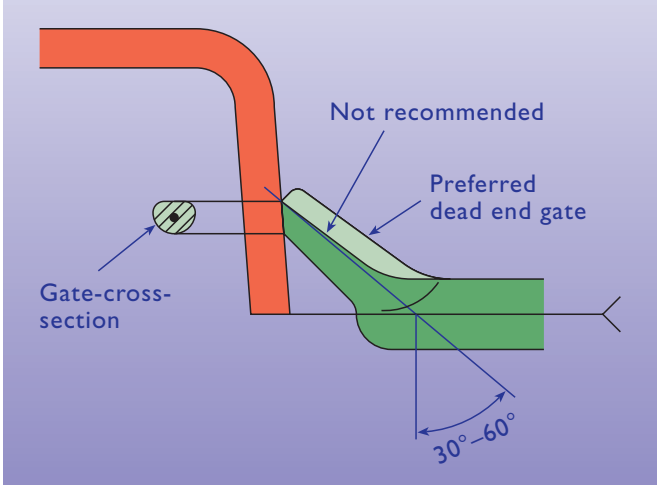


Fig. 17: Recommended design for a modified tunnel gate [2]

2.4.3 Gate position

Position the gate in the thickest area of the part, when possible. This allows shrinkage differentials to be minimized through wall thickness adjustment, if neccessary.

3 Phenomena of relevance to shrinkage

Due to the large number of influencing parameters a large number of shrinkage effects occur, as shown in Fig. 18.

A number of these phenomena are explained in greater detail in the following pages.

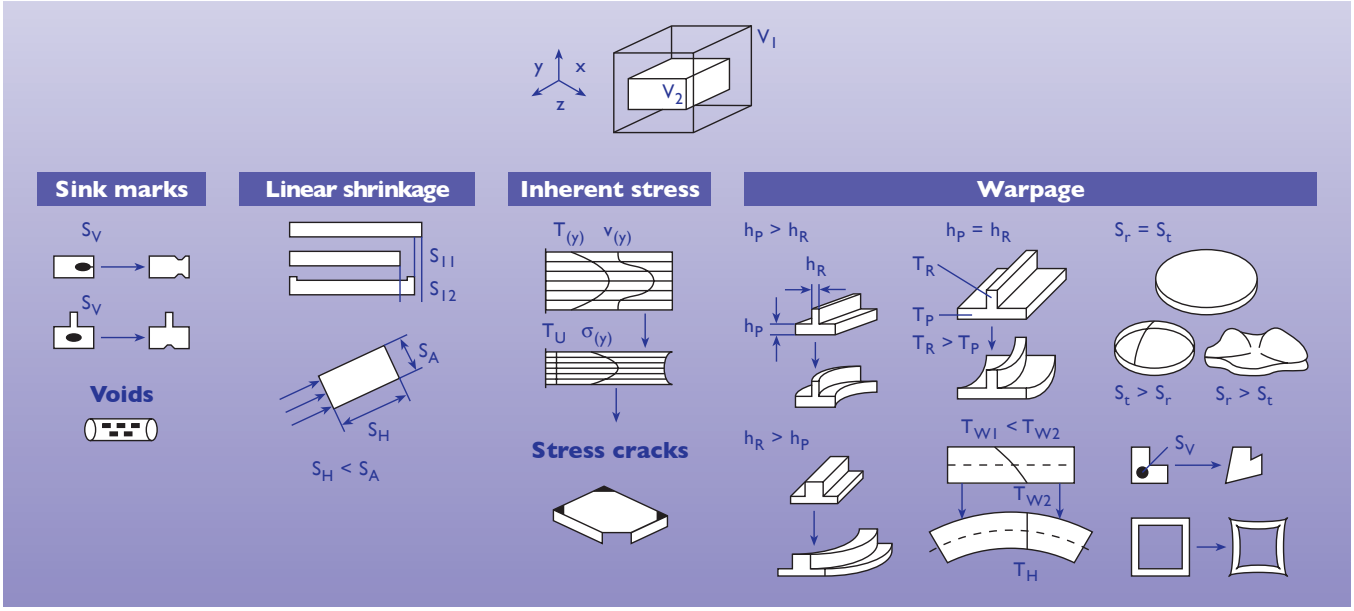


Fig. 18: Shrinkage and warpage phenomena [1]

3.1 Warpage

Warpage always results from differing degrees of shrinkage. This can take the form of

- a shrinkage differential in the direction of flow and at right angles to this direction for glass fiber reinforced materials
- shrinkage differentials due to dissimilar molded part wall thicknesses
- shrinkage differentials due to locally dissimilar mold temperatures
- shrinkage differentials due to locally dissimilar holding pressure action

The high shrinkage potential of semi-crystalline plastics means that these materials generally suffer greater warpage than amorphous plastics (Chapter 2.1.1). Fig. 19 shows a molded part made of three different plastics:

It is clear from Fig. 19 that greater warpage occurs in semi-crystalline materials than in the amorphous PC with 30 % GF.

The reason for this is that the shrinkage potential and the difference in directionally-dependent shrinkage behavior is greater in the semi-crystalline PA and PBT and thus gives rise to more pronounced warpage.

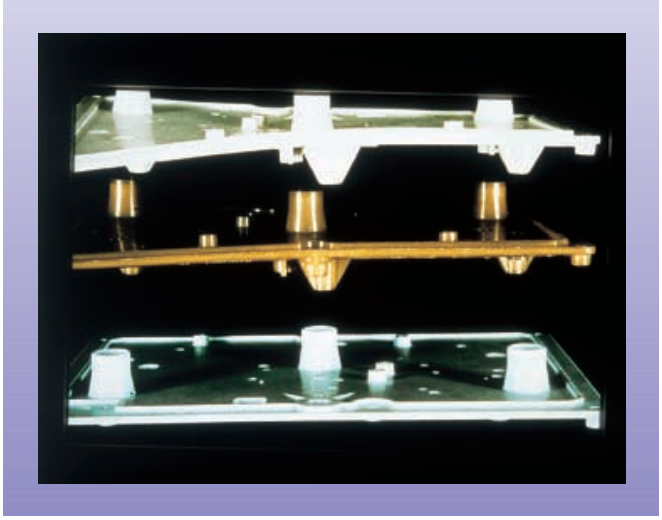


Fig. 19: Warpage of a support plate in different thermoplastics [2]
– PBT, 30 GF (top)
– PA6, 30 GF (center)
– PC, 30 GF (bottom)

Fig. 20 shows the basic warpage of a circular plate in glass fiber reinforced thermoplastic. The different warpage variants that can occur are evident here.

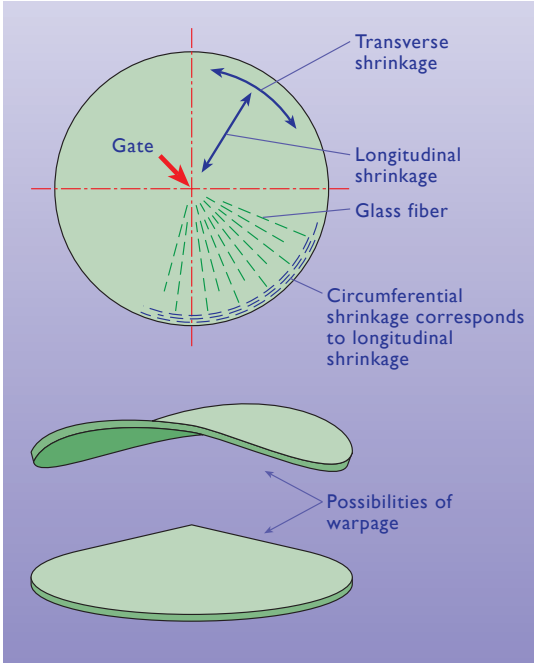


Figure 20: Warpage of a circular plate in glass fiber thermoplastic [2]

Fig. 21 shows that it is possible for different warpage behavior to result in reinforced and non-reinforced materials when identical geometries and gate types are employed.

In glass fiber reinforced plastics, shrinkage is caused less through the correlation with wall thickness and more by the orientation.

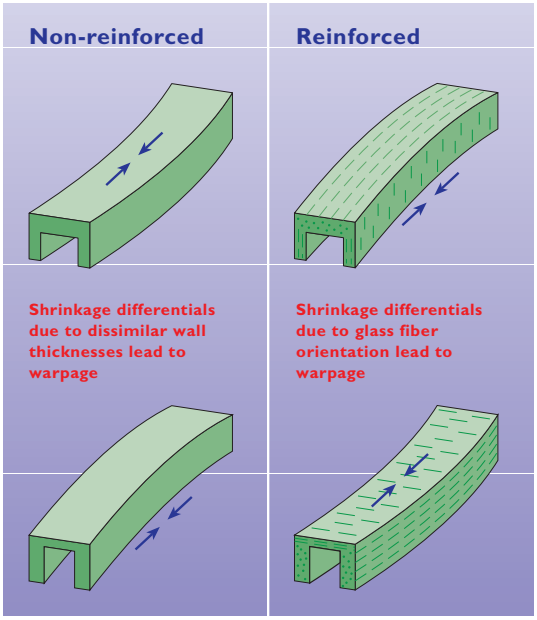


Fig. 21: Dissimilar shrinkage behavior in non-reinforced and reinforced thermoplastics [2]

Even when the glass fibers display a uniform orientation, warpage can still occur in flat panels (Fig. 22). This is due to the glass fibers turning around at the end of the flow path, which leads to shrinkage differentials between the center section of the panel and the area at the end of the panel. If the inherent rigidity of the panel is too low (wall thickness), then warpage will result. This warpage can be reduced by making changes to the geometry (Fig. 23).

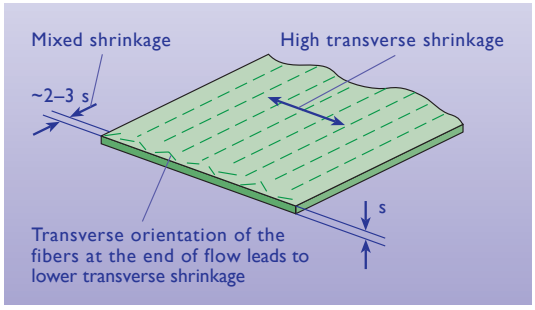


Fig. 22: Glass fiber orientation at the end of the flow path [2]

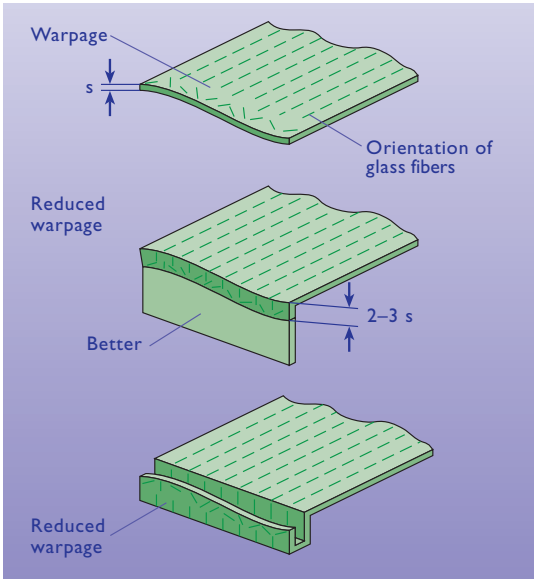


Fig. 23: Eliminating warpage on flat panels [2]

Fig. 24 and 25 show how the relocation of the gate changed the glass fiber orientation and reduced the amount of warpage of a waffle-iron in PBT 35 GF.

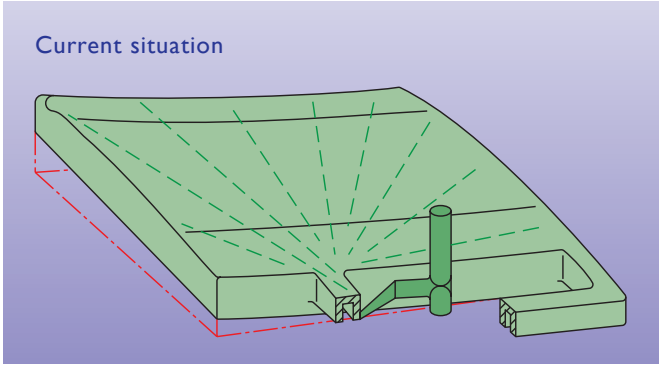


Fig. 24: Warpage due to unfavorable orientation of the glass fibers

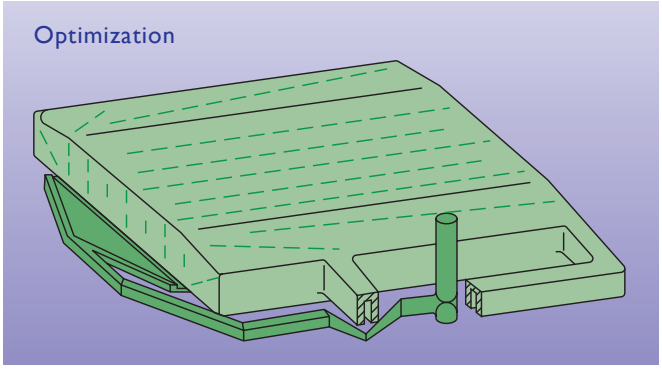


Fig. 25: Reduced warpage through longitudinal orientation of glass fibers [2]

3.2 Internal stresses

Positive interlocking with the mold can prevent certain dimensional changes in the molded part while it is still in the mold. When forces act on the molded part from the outside they are known as **external** contraction restraints. **Internal** contraction restraint can also exist.

The solidification model according to STITZ /4/ can be used to explain the phenomena that prevail with an internal restraint.

Fig. 26 shows the molded part wall thickness divided up into layers. As a result of the temperature profile over the wall thickness (A), the individual layers have a different shrinkage potential. If the layers are viewed in the uncoupled state, then they can slide over one another and thus contract to differing extents (B).

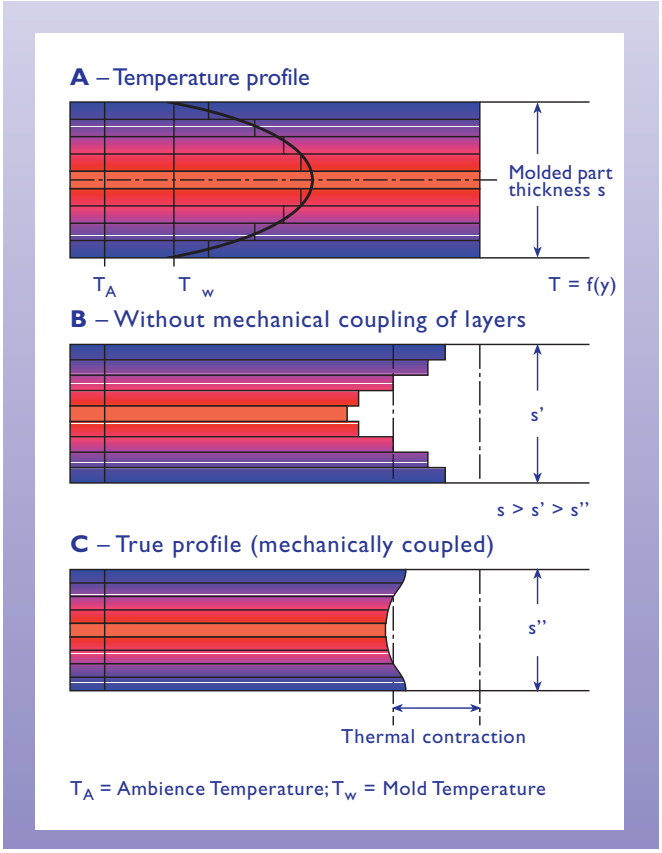


Fig. 26: Thermal contraction in the layer model [4]

Since the layers are coupled to one another, however, they are prevented from sliding over. The inside layers are extended and the outer layers compressed (C).

This coupling makes it difficult for the inside sections to undergo thermal contraction in the longitudinal and transverse directions. Since there is no resistance to deformation over the thickness of the part, the volume reduction is achieved primarily through a reduction in the thickness.

All forms of obstruction to thermal contraction produce internal stresses in the molded part, which, in turn, affect the level of shrinkage.

3.3 Sink marks/voids

In the case of sink marks, volume contraction leads to local depressions on the molded part surface, since the solidified edge layer is not yet stable enough to absorb the internal contraction forces.

Sink marks occur primarily at points where a hot melt core and a thin edge are present at the same time. The forces of contraction will be all the greater the bigger the melt core is by comparison to the overall cross-section. This is particularly true with ribs, since heat elimination is less efficient on the side facing the rib (Fig. 27, top).

Voids are air cavities inside the molded part cross-section. They occur when the solidified edge layer withstands the contraction forces and the inside layers become detached from the outer layers with further cooling (Fig. 27, bottom).

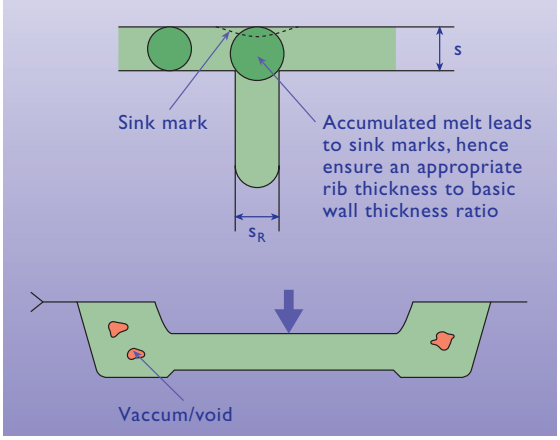


Fig. 27: Voids and sink marks as shrinkage phenomena

3.4 Corner warpage

The phenomenon of corner warpage is similarly attributable to shrinkage. The uneven cooling behavior in the corners causes the inside of the corner to shrink to a greater extent (Fig. 28). This then leads to stresses and forces which produce corner warpage.

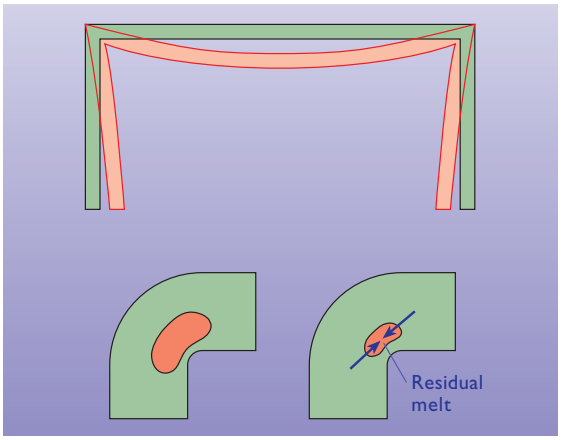


Fig. 28: Corner warpage due to uneven thermal behavior

4 References

[1] Pötsch, H. G.: Prozesssimulation zur Abschätzung von-Schwindung und Verzug Thermoplastischer Spritzgussteile. Dissertation RWTH Aachen, 1991

[2] Covestro Deutschland AG – Leverkusen

[3] N. N.: DIN 50014, Normklimate – Klimate und ihre technische Anwendung. Juli 1985

[4] Stitz, S.: Analyse der Formteilbildung beim Spritzgießen von Plastomeren als Grundlage für die Prozesssteuerung Dissertation RWTH Aachen, 1973

[5] Zöllner, O.: "Prozessgrößen beim Spritzgießen von Thermoplasten als Produktionskostenfaktor" paper presented at the SKZ Würzburg, Bayer AG, 1993

[6] Hoven-Nievelstein, W. B.: Die Verarbeitungsschwindung thermoplastischer Formmassen. Dissertation RWTH Aachen, 1984

Typical value
These values are typical values only. Unless explicitly agreed in written form, they do not constitute a binding material specification or warranted values. Values may be affected by the design of the mold/die, the processing conditions and coloring/pigmentation of the product. Unless specified to the contrary, the property values given have been established on standardized test specimens at room temperature.

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