LyondellBasell Technical Tip

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Warpage

INTRODUCTION

Part warpage, either soon after molding or at some time in-service, is a problem frequently experienced by injection molders and, at times, also by extruders. Similar to mold shrinkage, the causes and control of warpage are closely related to inherent material characteristics and the laws of heat transfer. In this Technical Tip, we explain the causes and general guidelines to minimize warpage.

It should be noted that warpage, like mold shrinkage, is a very complex mechanism and many factors, other than those mentioned here, have an effect on warpage. In some cases, a specific variable may have a different effect depending on other factors present.

WHAT CAUSES WARPAGE?

Warpage of thermoplastic parts can be caused by two mechanisms: the contraction of the polymer during cooling and the tendency of high-molecular-weight molecules to "relax' if they are under stress. The first is easy to understand, as it is a common property of all solids. The second may be compared to stretching a rubber band. As the stress is reduced, the band returns to its original size at a speed related to the rate of stress reduction. However, if the band is “frozen” while stretched, it retains its shape until the temperature increases sufficiently to allow it to “relax” and return to its normal state.

As a polymer melt is injected into a mold or extruded through a die, a rapid cooling must take place in order to achieve economic cycles or throughput rates. All polymers have low heat transfer coefficients, so the rate of heat transfer is relatively slow. This is further complicated during injection molding by the shrinkage that occurs allowing the part to retract from the mold surface, losing effective cooling. In the semi-crystalline polymers such as polypropylene and polyethylene, it is necessary to remove the heat of crystallization, in addition to the heat to reduce the temperature of the mass.

There is additional concern with semi-crystalline polymers that internal stresses are developed during cooling due to the differential shrinkage between the crystalline and amorphous regions.

Thicker part sections have limited cooling available and cool more slowly than their thinner or better cooled counterparts. Ribs, bosses, corners, differential mold temperatures, etc., all contribute to variations in cooling time and rate of cooling. In the mold, a part develops a differential temperature profile. When the part is ejected, the thicker sections are still cooling while thinner sections may have reached their final temperature. As the part cools further the thicker areas, which are no longer restrained, contract and possibly cause warpage.

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The second source of warpage is related to the molecular structure of the polymer. Polymers are made up of very long molecules which, when molten, resist flow because of their high viscosity. Forcing these long molecules through constricted geometries at very high velocities such as die lands, runners, gates, thin pan sections, etc., subjects the molecules to high strains (similar to a rubber band being stretched). If the stress is removed and the polymer does not cool, the molecules rearrange themselves into a lower stress condition (analogous, in respects, to the annealing of metals). However, in injection molding, the cooling of the part does not allow this to happen and parts generally have some level of "molded-in stress" after they have been ejected. If sections of the part are still hot, relaxation continues, incrementally contributing to warpage beyond that which may occur due to thermal contraction.

Differential stresses may also occur due to non-uniform filling profiles. A classic example of this is a bottom, center-gated, rectangular shallow box. Unless flow directors are used, filling the edges is not simultaneous. Relaxation begins in the edge, which fills first, i.e., the near edge. Even though the time frame is very small, there is enough differential in relaxation compared to the far edge, that non-uniform stress relief can occur after the part is ejected.

It is also possible that after complete cooling a residual degree of molded-in stress may still exist in the part which, due to the geometry or rigidity of the part, does not cause any warpage. However, if at some point in its application, the part is exposed for a sufficient time to an elevated temperature, it is possible the part will lose some of its stiffness and allow these stresses to relax, causing warpage.

■ CONTROL OF WARPAGE

As noted, there are certain polymer material characteristics such as high molecular weight, low heat transfer coefficients, crystallinity, contraction during cooling, etc., which are inherent and cannot be changed.

The primary keys to achieving low or minimal warpage are in the design of the part and mold. A thorough review of the factors that cause warpage, conducted at the design stage, can circumvent many problems after the mold has been constructed.

■ SOME FACTORS TO BE CONSIDERED:

1. Maintain as uniform a part thickness as possible for uniform heat transfer.
2. Avoid abrupt and/or large changes in part thickness.
3. Intentional changes in part thickness may be used to control warpage caused by other factors.

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4. Utilize ribs and gussets to impart stiffness, rather than increased wall thickness.
5. Give special consideration to ribs, bosses, comers, etc., which inherently contain a larger mass of material. Consider coring out ribs to reduce the amount of material mass.
6. Consider differential or zone cooling to control heat transfer and compensate for the natural contraction of the part.
7. Consider the use of special inserts to promote (or retard) heat transfer in critical areas.
8. Try to achieve uniform fill patterns on all parts and balanced flow in multicavity molds.
9. Consider the design of cams and lifters carefully because of the inherent mechanical restrictions often encountered in providing adequate cooling channels.
10. Ensure the effectiveness of your cooling system by periodically cleaning and flushing lines (to remove fouling) and maintaining high coolant velocities for maximum heat transfer rates.
11. Do not use a material with a melt temperature higher than necessary. Materials with higher-than-needed melt temperatures not only waste energy and require longer cooling times, but create more potential for warpage if the cycle remains the same.
12. On the other hand, molding at too low a melt temperature may result in more molded-in stress and subsequent warpage in use,
13. Mold filling should be done as rapidly as possible.
14. Establish the location of cooling channels for effectiveness, not just for convenience.

■ SUMMARY

There are no easy solutions to eliminate warpage, but with careful consideration of the factors contributing to warpage, many potential pitfalls may be avoided.

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