Design and Processing for Lowest Warpage with IXEF® Polyarylamide-Based Compounds

Introduction

IXEF® polyarylamide compounds are highly glass fiber-filled (usually 50 or 60% by weight). The high fluidity of the base polymer ensures very good flowability, including for fairly thin applications (approximately 0.5 mm, and as low as 0.3 mm locally), as well as a very good fiber-free surface finish. The material also exhibits very high stiffness and good strength.

In parts made of IXEF resin, the glass fibers are oriented by the flow and the resulting anisotropy (difference in properties along and across the flow direction, e.g., modulus, CTE) will be evident in the part properties including in its dimensional aspects (e.g., shrinkage and warpage).

Contributions to warpage

Warpage can be described as part deformation (e.g., planarity or circularity loss) resulting from some non-uniform shrinkage effect.

Out-of-plane deformations are due to several contributions, nicely illustrated by the models underlying the Moldflow® (MF) programs:

- Differential shrinkage (difference in average shrinkage from one area to another).
- Anisotropic shrinkage (in-flow vs. cross-flow) (see Figure 1).
- Bending moments due to unsymmetrical cooling (see Figure 2).

Other more sophisticated effects, at present not included in MF simulations, could also be relevant:

- Mold deformation.
- Spring-forward effect (also referred to as "corner" or "box" effect) (see Figure 3).

These contributions all translate into residual stresses at ejection and will potentially drive parts out of plane.

Figure 1

Anisotropic Shrinkage

For filled grades the part shows higher shrinkage perpendicular to flow direction.

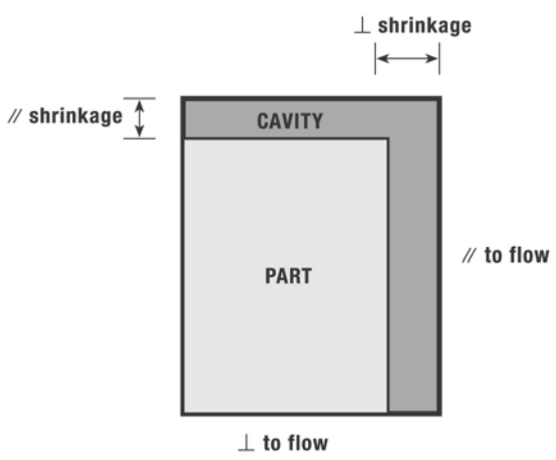


Figure 2

Bending induced by differential cooling

(One side of mold hotter than the other)

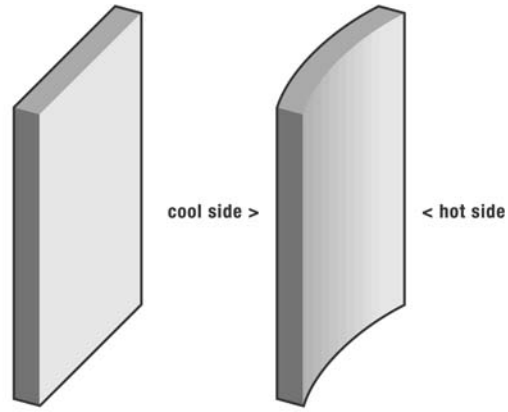
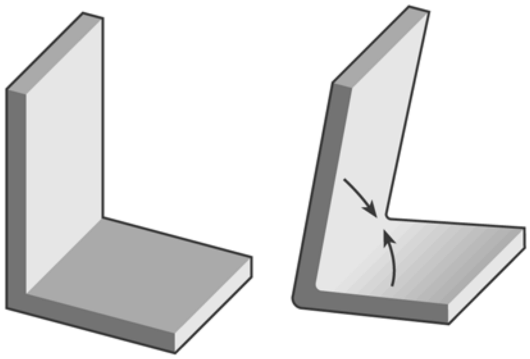


Figure 3

Angular deformation due to "corner effect"



Changes in part or gating design as well as changes in processing conditions will usually upset all of these effects at the same time. Therefore, a Finite Element approach is very valuable.

It is, however, possible to define guidelines for good design and proper processing conditions. More specifically, some molding trials can easily identify the origin of the warpage and accelerate the optimization process.

Dominant effects with IXEF resin

The high fiber content of IXEF resin usually results in warpage being largely due to anisotropic shrinkage. Differential shrinkage, mainly controlled by packing profiling, is usually the second strongest contributor.

Providing crystallization is complete (achieved with mold temperatures above 125-130°C), the contribution to warpage from differential cooling is usually quite small in IXEF resin applications.

For parts possessing corners with minimal structural constraints against angular deformation, the corner effect can be dramatic at times (5-6° closure of a 90° angle).

Controlling fiber orientation-induced warpage

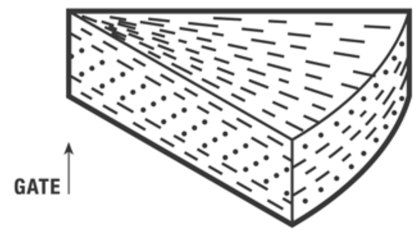
Fibers are oriented by the polymer matrix surrounding them. Both shear and elongation contribute to fiber orientation. Shear mainly orients fibers in the flow direction at the outer layers (close to the cavity walls). Elongation usually reveals itself in the central layers where shear is non-existent. The centrally-gated disc shown in Figure 4 is a typical example, with strong radial orientation in the skins and transverse fiber orientation in the core due to this divergent flow.

The combination of contradictory orientations in various layers can help reduce warpage. However, the shear effect and in-flow fiber orientation is largely dominant in most applications. The resulting differential shrinkage (about 0.1% in-flow and 0.5% cross-flow) is very often the main cause of warpage.

Figure 4

Skin-core structure in central gating

Fibers aligned along radial direction at the skins (shear flow) and perpendicular to radius in the core (elongational flow).



Injection speed does not contribute significantly to fiber orientation; nor does mold temperature or melt temperature. Cooling time has no effect upon fibers. Therefore, the most efficient way to affect fiber orientation is to change the filling pattern.

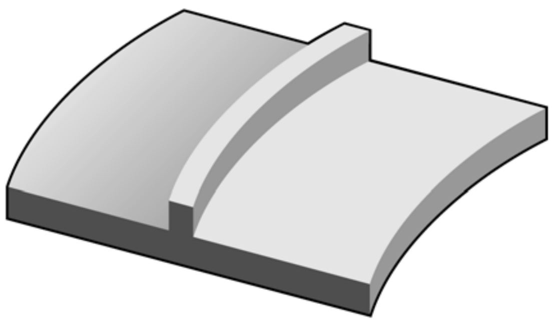
This can be achieved in a number of ways:

- Adjusting the location of gates.
- Using additional gates.
- Changing part thickness locally (flow leaders and deflectors).
- Testing adjustments to valve gate openings in multi-gate parts.
- Using a spillover to divert flow at end of fill.

Ribs significantly affect the warpage of fiber-filled compounds. The flow in the rib produces a fiber orientation which could be at an angle to the flow in the base plate, according to their relative thickness. This will create a different shrinkage along the rib compared to the base, resulting in the rib pulling or pushing the base. The most typical effect of ribbing when using IXEF polymers, however, is the production of a strongly-oriented layer of fibers along the top edge of the rib, with very little in-flow shrinkage (this is sometimes referred to as "edge effect"). The top of the rib will then push the part out of plane, with the ribs being on the outside of the curved deflection (see Figure 5).

Figure 5

Typical warpage induced by a rib when molding a fiber-filled grade



The effect of fiber orientation on warpage can also be interpreted as a differential thermal expansion problem. The part is usually quite flat at ejection (at 130°C). As the part cools to 20°C the warpage appears as a result of differential contraction in the in-flow and cross-flow directions. To reproduce this effect, place a warped part made of IXEF resin in an oven and raise the temperature to 130-140°C. The part will become perfectly flat, but will deform again and with the same magnitude upon cooling to room temperature.

Effect of the packing efficiency

Packing pressure has an interesting effect. Although the packing pressure will not change the fiber orientation, it is one of the most efficient ways of reducing warpage for fiber-filled crystalline materials.

The packing phase can be controlled with pressure profiling. The typical approach is to find the appropriate decreasing pressure profile that enables correct packing of the outer regions of the part without overpacking the gate area. This is usually obtained by trial and error or with the help of simulation. The approach is valid for all materials, but particularly important for unfilled grades.

For IXEF resin, the benefit of the packing pressure is due to an entirely different effect. As mentioned above, anisotropic shrinkage is the main force driving warpage of parts made of IXEF resin. Anisotropic shrinkage originates in the constraint applied by the fibers to the surrounding polymer. More simply put, the polymer would like to shrink along the flow direction as much as across, but fibers will constrain in-flow shrinkage to a much lower value. Increasing the packing pressure will reduce the overall shrinkage of the base resin. If the shrinkage of the polymer matrix is low, the fiber constraints will be lower. In fact, if the polymer shrinkage was lowered to zero (which is theoretically possible at high pack pressure) the shrinkage anisotropy would entirely disappear, and with it the warpage.

Therefore, increasing the packing efficiency (pressure and time, gate diameter or valve-gate timing) will greatly reduce the warpage. We have consistently seen that an extra 200 bar of packing pressure can improve flatness in mobile phone parts by about 0.1 mm. For this reason, we recommend a high quality mold (e.g., parting line, steel hardness, etc.) that will accept higher pressure without flash or long-term fatigue damage.

Ejection issues

If a part made of IXEF resin been strongly packed to reduce warpage, it may be difficult to eject, especially in the presence of intricate ribbing or an insufficient draft angle. The polishing of the mold is also very important and an appropriate coating can improve ejectability. Because of crystallinity issues, the mold temperature for IXEF resin molding must be well above the glass transition of the base polymer (recommended mold temperature is 130°C). At this temperature the amorphous fraction of the polymer base in IXEF resin compounds is likely to creep very easily. This is why warpage can be strongly influenced by ejection forces. Perform a rapid check by ejecting a few parts with the help of a release spray and comparing the warpage to parts made without it. Any change is likely to be due to the reduction of ejection problems. When ejection is causing warpage the actual capability (reproducibility) of the part will be lower, showing more dimensional fluctuations.

Effect of cooling time

When ejection is not an issue, an extended cooling time will not be very effective in decreasing the warpage. Of course a very short cooling time (very high part-temperature at ejection), will increase the warpage. But once an acceptable cooling time is set, extending the residence time in the mold will not improve part flatness significantly since the driving force (fiber orientation) is not a stress that can be thermally relaxed.

Shop-floor tips

- Ensure the mold is at 130°C minimum. Temperatures below 115°C will result in lower shrinkage and warpage, but will not be acceptable because of poor crystallization, the potential for post-shrinkage, and lower stiffness.
- Look at shortshots and try to determine if flow is creating a peculiar fiber orientation. Look for recesses where slow-down of the flow upsets fiber orientation. Repeat this process for flow-leaders.
- Make almost full parts without packing pressure to gauge how much warpage comes from the fiber orientation rather than differential shrinkage due to packing.
- Apply packing and inspect for any changes in shape. Appropriate packing should reduce the warpage but not change the shape of the warpage. If this happens (i.e., you see a new dome near the gate) packing pressure profiling is the appropriate solution.
- Ensure ejection is always smooth and not deforming the part. Look for whitening, surface scratches or ejector marks indicating ejection problems.
- Remember that warpage of IXEF resin should be minimized as much as possible at the design stage with the help of Finite Elements analysis, by optimizing part itself and with gating location(s).

Summary

In technical-part applications based on glass-filled grades, dimensional quality of the part is usually very important. Therefore, it is important to understand the various contributions to warpage and to be able to relate them to the specific thermo-mechanical properties of the material in use. In this short bulletin we have presented the characteristic behavior of our IXEF polymers, attempting to identify and rate the various contributions to part dimensional quality issues.

Some of the statements are quite general and would apply to most fiber-filled materials; some are quite specific to our material due to its unique rheological and thermo-mechanical properties. Some tips for optimum processing have been included as a conclusion. Our customer support team is of course available to help with more specific or difficult issues.

About the Author

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Dr. Vito Leo pursued scientific tuition at the Brussels University where he obtained a degree and subsequently a Ph. D. in Physics in 1983. Within the same year, he joined Solvay Research Lab in Brussels where he still works today as a Principal Scientist in charge of Rheology and Injection Molding. Dr. Leo has been involved in Flow Analysis (finite elements) for many years and has utilized this expertise extensively for customer support in the last two decades. He is also currently teaching and has a long record in training activities at academic and industrial levels.

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