Construction of Pre-Deformed Shapes for Rapid Tooling in Injection Molding

József Gábor Kovács

Summary: The major issues in the development of injection molding technology include the progress in CAE and the developments in tool design methodology such as rapid tooling. The applicability of rapid tooling in injection molding was examined using unbalanced cooling to analyze the warpage and shrinkage. Moldflow Plastics Insight simulation software was used for the deformation calculations with different mold thermal conductivities. It can be concluded that the decreasing mold thermal conductivity will dramatically increase the volumetric shrinkage and the warpage as well. Because of these effects, it is of fundamental importance to compensate for the shrinkage and warpage, so in the paper a new design methodology is suggested for rapid tooling, which is based on the pre-deformed model.

Keywords: CAE; injection molding; moldflow; rapid tooling; RT; shrinkage; simulation; warpage

1. Introduction

Injection molding is one of the most powerful, highly productive and versatile, rapidly developing methods of polymer processing. In injection molding dimensionally very precise, complex 3D shaped parts can be produced in one step from the raw material. It is the most common way of processing of polymer products and the basis of the economical production of injection-molded parts is the fast and expedient design cycle of tool development [1–2]. It is very common that the engineer uses empirical methods to develop tools, because it is the fastest way to achieve his aim. Usually designers are experienced in tool designing and they make use of the previous practice.

During the past two decades, tool design has changed greatly. Traditionally tool designers used empirical methods to develop tools, but they were not able to consider the complex process of polymeric behavior that caused inaccuracy in the shape and dimensions of the product. A great step forward was achieved by the application of computers in the design process, mainly by the appearance of efficient simulation programs. These programs simulate the filling and post-filling stage of injection molding and can be used to estimate the shrinkage and warpage of the product [3]. In spite of these results, the tool design still relies on empirical methods; the engineer applies intuitive corrections, which can be justified by simulation results. A considerable progress in the automation of the design process would be the direct use of the output of the simulation.

There are many different types of defects, which occur in molded thermoplastic parts. The causes of these defects can be found in the molding machine, in the mold, or in the material. However, the specific defect must be identified before a solution can be suggested and the molding parameters changed to relieve the problem.

Shrinkage is inherent in the injection molding process. Shrinkage occurs because the density of polymer varies as the part cools down from the processing temperature to the ambient temperature .[4]

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Warpage is a distortion where the surfaces of the molded part do not follow the intended shape of the design. If the shrinkage is uniform throughout the part, the molding will not deform or warp, it simply becomes smaller. However, achieving low and uniform shrinkage is a complicated task, due to the presence and interaction of many factors such as molecular and fiber orientations, mold cooling, part and mold designs, and process conditions.

There are many rapid prototyping techniques, which can produce either visualization models or functional parts. Some of these techniques can also be used for the manufacturing of prototype and production tools. Short prototype runs require the same material and process conditions to be utilized as would be during mass production to ensure comparable quality standards and mechanical properties are obtained. There are many different types of Rapid Tooling processes and the number of them increases year by year. The classification of them is not an easy and exact task because the borders between the groups are not well defined and there are some overlaps.[5] Using the rapid tool inserts may cause warpage of the part because of the different mold thermal conductivity and other irregular properties as compared with conventional injection molding tools. Non-uniform cooling in the part and asymmetric cooling across the part thickness from the mold wall to the core can also induce differential shrinkage.[6–8]

2. Methodology

The dimensions and the potential for the warpage of a plastic part will be influenced by a variety of material properties, part geometry, tooling, and processing related factors. Most of the plastic materials exhibit relatively large mold shrinkage values and unfortunately mold shrinkage is usually not isotropic in nature. If a desired part does exhibit anisotropic shrinkage behavior, designing the cavity is no longer a simple method and in addition, it will lead to a degree of warpage or internal stress. There are various methods to reduce this unwanted behavior, such as the optimization with simulation software or filling the material with special additives or setting up the injection molding machine differently (Figure 1).

Using the simulation programs during rapid tooling development the parts and the technologies can be optimized to achieve the same or even better result than using the conventional molds. Moreover, it is possible to produce special waved surfaces in the rapid mold inserts using the layer-by-layer technology, which is unimaginable with conventional molding. Hence, it is possible to produce a special pre-deformed shape to eliminate the majority of the warpage in advance. Originally, when a cavity is produced (Figure 2 – a), after the injection the deformations will appear (Figure 2 – b). On the other hand, if the pre-deformed shape is produced (Figure 2 – c) — the deformations are applied in the reverse direction into the cavity — the part will deform to the desired shape after injection (Figure 2 – d).

3. Results and Discussion

The influence of cooling in the rapid tools was analyzed to compare its efficiency to the conventional mold cooling. To compare the influence of the mold thermal conductivity a special mold was designed with a changeable insert. In the mold there are 3 independent cooling channels; one is in the stationary mold half and the other two are in the moving mold half (Figure 3), and both halves can be changed easily to replace the mold itself.

Homo-polypropylene was used as a raw material for the investigation with the melt temperature of 200 °C. During the simulations in the 3rd cooling line the coolant temperature was fixed to 15 °C, while that of the first two lines was varied between 10 and 90 °C to analyze the sensitivity to the unbalanced cooling using different mold

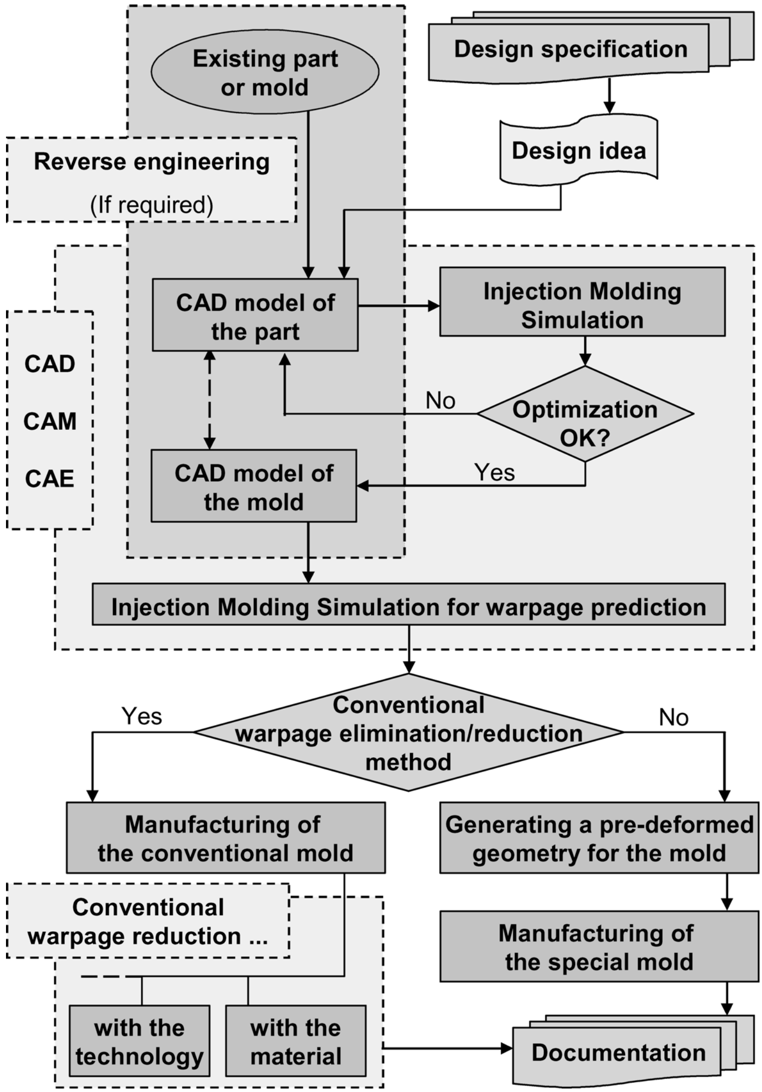

Figure 1.
Ways of warpage elimination.

materials. To analyze the sensitivity to the unbalanced cooling the warpage of the part was calculated with Moldflow Plastics Insight simulation program. If the temperature difference between the two sides was low – as in most cases in the real life — the warpage was twice as big on the part made by epoxy mold than that of the part made by conventional mold (Figure 4).

Although the unbalanced cooling has a minor effect on the volumetric shrinkage (Figure 5) the mold material has a huge influence on that (Figure 6).

In the lower mold thermal conductivity zone (Figure – I.) the higher melt temperature produces a much larger shrink rate than that of the lower melt temperature resulting in greatly increased warpage. All the epoxy and iron powder filled epoxy molds (soft tooling) are located in this zone. The next zone (Figure 6 – II.) is a typical region for direct metal inserts (hard tool-

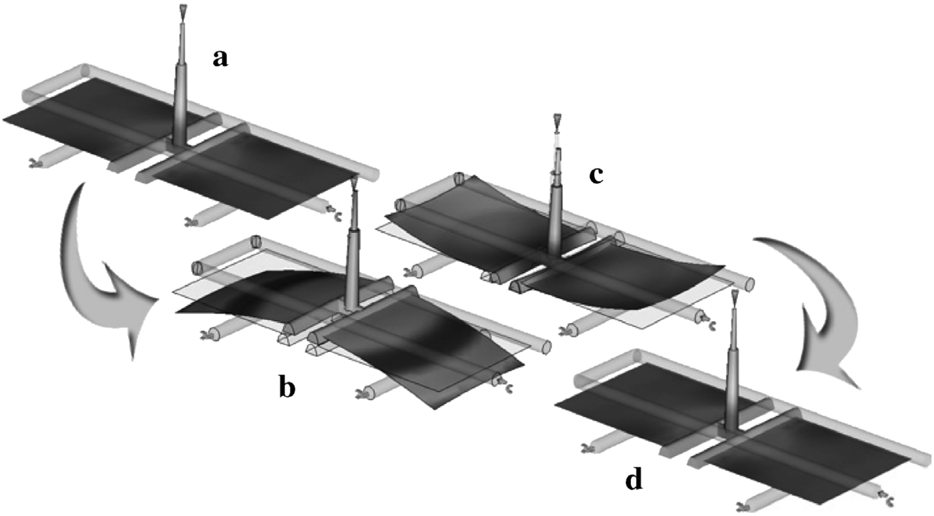

Figure 2.
Deformation chains.

ing), which are a little bit worse for the volumetric shrinkage than the conventional mold region (Figure 6 – III.).

Using epoxy molds, the solidification time dramatically increases if the mold temperature and/or the melt temperature increase (Figure 7).

Using conventional tool steel the mold thermal conductivity is higher than 20 W/(mK), where the solidification time dependence is nearly constant, but the epoxy tool insert's thermal conductivity is usually less than 1 W/(mK) (Figure 8), which causes the increased solidification time of the part (Figure 7). Using epoxy molds the solidification time could vary much more as a function of the mold and melt temperature.

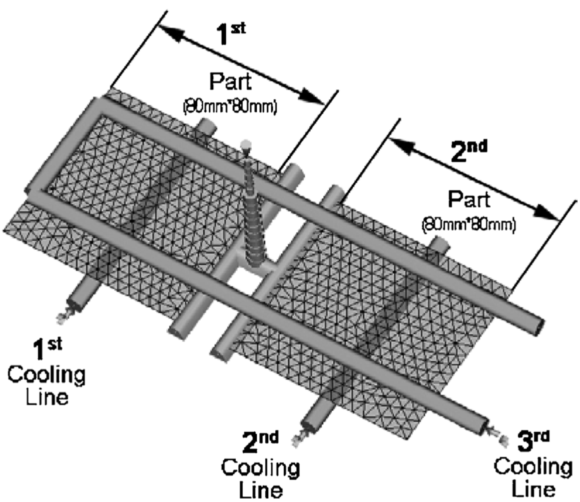

Figure 3.
Part and cooling lines geometry (Moldflow model).

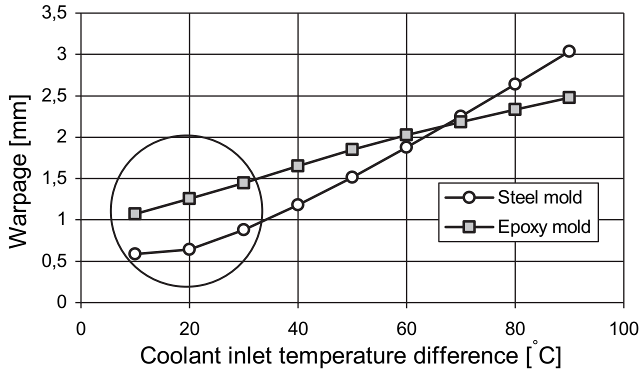

Figure 4.
Unbalanced cooling effect on warpage.

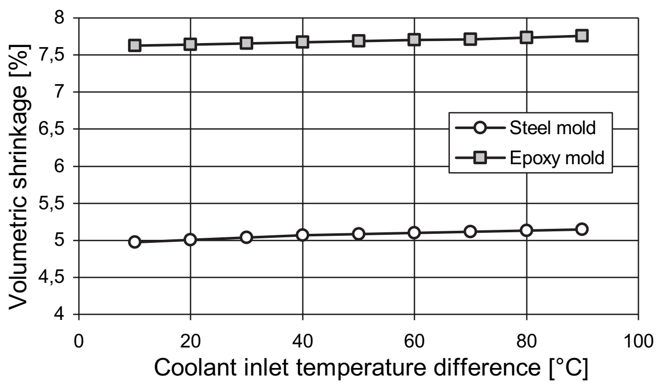

Figure 5.
Unbalanced cooling effect on volumetric shrinkage.

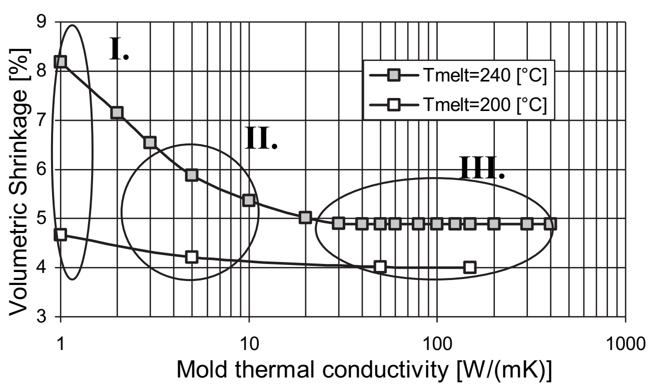

Figure 6.
Mold material influence on volumetric shrinkage (I. – Soft tooling; II. – Hard tooling; III. – Conventional molds).

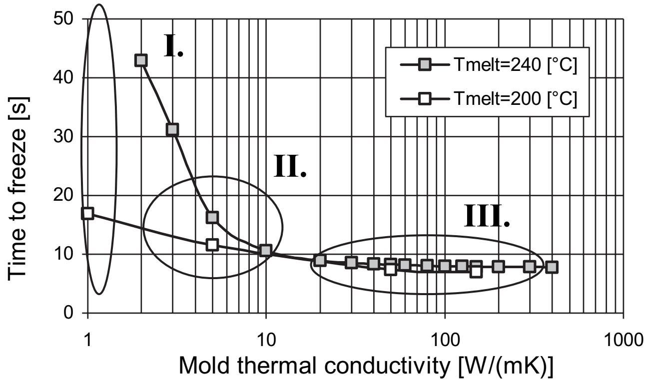

Figure 7.
Mold material influence on cycle time (I. – Soft tooling; II. – Hard tooling; III. – Conventional molds).

The metal powder has no radical influence on the heat conductivity, that of the epoxy resin is 0,2 W/(mK), while that of the metal powder filled epoxy resin is 0,2 – 1 W/(mK) (Figure 8).

4. Conclusions

The pre-deformed shape for the rapid tooling can be applied, but a careful simulation has to precede the manufacturing of the mold insert. Using special mold materials with lower heat conductivity it is important to analyze the injection molding because the decreasing mold thermal conductivity will dramatically increase the volumetric shrinkage and the warpage as well.

Injecting the material into the cavity with higher melt temperature the increment in the volumetric shrinkage can exceed 60% while using lower melt temperature it is no more than 20%. While the unbalanced cooling has a minor effect on the volumetric shrinkage, it has a major effect on the warpage.

Because of these effects, it is of fundamental importance to compensate for the shrinkage and warpage, so in the paper a new design methodology was suggested for the rapid tooling that is based on the pre-deformed model. By starting the injection molding process with the pre-deformed shape, deformations in the final product can be eliminated. The pre-deformed model is a real 3D CAD model, which is developed from the simulation results. It can be

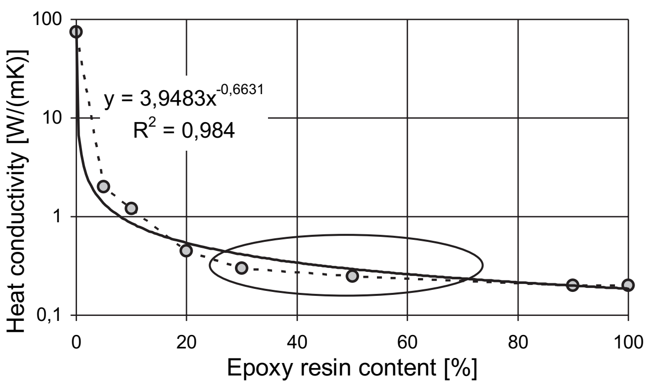

Figure 8.
Measured heat conductivity of the epoxy mold inserts.

directly used to create the rapid tool insert for further manufacturing.

The main advantages of the rapid tool inserts are the shorter time to market and the cost effectiveness in short production runs. Other advantage is the special curved internal cooling channels that could decrease the warpage of the part and the waved surface — pre-deformed shape – of the mold that can dramatically reduce the warpage. Disadvantages of these rapid tooling technologies are the abrasion of the surfaces and the longer cycle times because of the low heat conductivity.

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