INFLUENCE OF MOLD PROPERTIES ON THE QUALITY OF MOLDED PARTS

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O mare parte din materialele plastice sunt prelucrate prin injecţie deoarece acest procedeu permite realizarea de piese ieftin şi rapid. Prelucrarea unor piese injectate de calitate depinde de proiectul modelării, controlul procesului şi alegerea materialului. In lucrare se identifică principalele probleme în realizarea matriţelor pentru modelarea prin injecţie, precum şi progresele tehnologiei materialelor în legătură cu materialele cuiburilor de formare. Se prezintă realizările autorilor în proiectarea şi execuţia de matriţe de injecţie pentru prototipuri sau serii scurte şi rezultate ale metodelor de simulare pentru optimizarea piesei şi a matriţei înainte de fabricaţie.

An important part of all plastics materials are processed by injection molding, because it offers producing parts cheaper and quickly. The manufacturing of quality injection-molded parts depends on the part and mold design, process control, and material selection. In the paper are identified the main problems in the realization of the injection moulds and the major issues in the materials technology in connection with the materials for the forming nests. There are also presented the authors' realizations in the design and manufacturing of the injection moulds for prototypes or short series, and some results of the simulation methods for the optimization of the prototype parts or mass-produced parts and for the moulds before the manufacturing.

Keywords: rapid prototyping; rapid tooling; rapid tool inserts; injection molding simulation.

1. Introduction

The plastic injection molding process demands knowledge, expertise and, most important, experience for its successful implementation. Often, there are the molding parameters that control the efficiency of the process. Effectively controlling and optimizing these parameters during the manufacturing process can achieve consistency, which takes the form of part quality and part cost.

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Injection molding produces highly accurate products in a very short time of the cycle. It is one of the most important polymer-processing operations in plastics industry. The level of experience of the manufacturer determines how effectively the process parameters are controlled.

Prototypes are useful because design errors can be detected in the earliest possible stage of product design, cutting back the cost and time involved in the modifications.

The Rapid Prototyping technologies usually produce inadequate models to fulfill these requirements.

Rapid Tooling processes complement the Rapid Prototyping options by being able to provide higher quantities of parts in a wider variety of materials, even short-run injection molded parts in the intended production material.

2. Background

1.1. Injection Molding. Injection molding is a process by which hot polymer melt is forced into an empty, cold cavity of the desired shape and it is allowed to solidify under high pressure and controlled cooling. The conventional mold material for injection molding is usually tool steel.

Rapid tooling is the term for either indirectly utilizing a rapid prototype as a tooling pattern for the purposes of molding production materials, or directly producing a tool with a rapid prototyping system [1].

In comparison with machined molds, manufacturing of epoxy or aluminum-epoxy molds is an inexpensive way to create prototype and production tools quicker.

Epoxy resins tools present higher heat resistance because of the poor thermal conductivity, influencing the length of molding cycle.

Lifetime of the tool is a function of the thermoplastic material, fillers and part complexity. Some molds can create as few as 50 parts, while others can exceed 5.000 [1-3].

The Selective Laser Sintering (SLS) technique enables complicated molds to be built directly in metal from CAD data, without geometrical restriction associated with the manufacturing tools.

The laser-sintered parts can be post-processed to produce suitable tools for injection molding. Like all layer-manufacturing techniques, complex shapes can be built easily. One of the most important applications of this technique is to manufacture curved internal cooling channels or conform to part geometry. Depending on the type of plastic and the force and temperature of injection molding, core and cavity sets created through the SLS process can produce up to 50.000 parts [2].

1.2. Shrinkage and Warpage. Shrinkage happened due to the density difference between the melt and the final product (fig.1), and it is inherent in injection molding process.

Warp age is a distortion where the surfaces of the molded part do not follow the intended shape of the design.
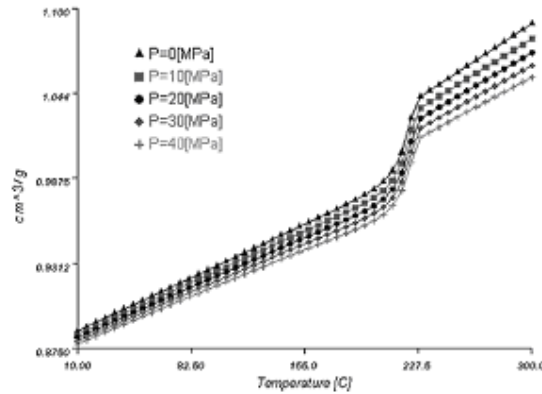

Fig. 1. The specific volume vs. temperature (pvT) curves for PA6

If the shrinkage throughout the part is uniform, the product will not deform or warp, it simply becomes smaller.

Achieving low and uniform shrinkage is a complicated task due to the presence and interaction of many factors such as molecular and/or fiber orientations, mold cooling, part and mold designs and process conditions.
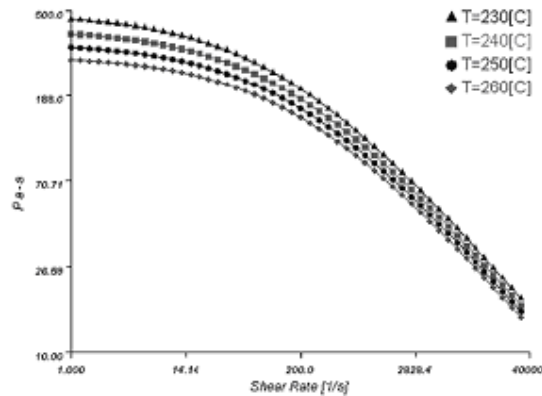

Fig. 2. Viscosity vs. shear rate function for PA6

Using the rapid tool inserts may cause warp age of the part because of the different thermal conductivity and other properties compared with conventional injection molds.

Non-uniform cooling in the part can also induce different shrinkage [3-5].

1.3. Injection Molding Simulation. The injection molding programs are used for analyzing the equations of continuity, momentum and energy. The shear viscosity is the most important material property in numerical simulation of the filling stage (fig. 2).

Shear viscosity depends on the shear rate and the polymer temperature. The shear behavior of the viscosity is characterized either by the Power-law polymer viscosity equation or by the Cross-WLF (Cross-Williams-Landel-Ferry) equation [6].

The Power-law polymer viscosity model characterizes the flow behavior of the material but it works only when shear rates are relatively high. This model does not account the effect of pressure and it might lead to inaccuracies. The Power-law equation, utilized by the Moldflow programs is:

$$\eta(T,\dot{\gamma}) = A \cdot \exp\left(\frac{T_a}{T}\right) \cdot \dot{\gamma}^{(n-1)} \tag{1}$$

where T is the actual temperature, Ta is the ambient temperature, $\dot{\gamma}$ is the shear rate, n and A are constants.

The Cross-WLF model is more appropriate for injection molding simulations as temperature and pressure sensitivities of the zero-shear viscosity are better represented.

The shear thinning behavior of the viscosity is characterized by the Cross-WLF equation [6]:

$$\eta(T,\dot{\gamma},p) = \frac{\eta_0(T,p)}{1 + \left[\frac{\eta_0(T) \cdot \dot{\gamma}}{\tau^*}\right]^{(1-n)}} \tag{2}$$

where $\dot{\gamma}$ is the shear rate, p is the pressure, T is the temperature, τ^* is constant and η_0 is the zero-shear viscosity which can be represented by the WLF form as follows:

$$T > T_{trans} \rightarrow \eta_0(T,p) = B \cdot \exp\left(\frac{T_b}{T}\right) \cdot \exp(\beta \cdot p) \tag{3}$$

$$T < T_{trans} \rightarrow \eta_0(T,p) = \infty \tag{4}$$

where T_{trans} is a reference temperature and it is typically taken as the glass transition temperature of the material, B, T_b and β are constants.

The pvT data reflect the transitions as the material undergoes a phase change from a physical state to another (from melt to solid).

The kink of the curve of pvT data of crystalline thermoplastics at atmospheric pressure is the crystallization temperature of the material (T_g), which depends on pressure.

The slopes of the specific volume vs. temperature curves in the melt and solid states represent the bulk thermal expansion coefficients in the given states.

Modified Tait polymer density equation describes the variation of density (specific volume) with temperature and pressure in the melt and the solid states, between room and processing temperature over a wide pressure range:

$$\rho(T,p) = \left\{ v_0(T) \cdot \left[1 - C \cdot \ln\left(1 + \frac{p}{B(T)} \right) \right] + v_1(T,p) \right\}^{-1} \tag{5}$$

where ρ is the polymer density, C is a universal constant equal to 0.0894, $v_0(T)$ is a temperature dependant specific volume, $v_1(T, p)$ is a temperature and pressure dependant specific volume. Above the transition temperature $v_1(T, p)$ is equal to zero.

To solve the coupled equations of continuity finite element methods, momentum and energy are used.

Three-noded triangular elements are used to describe the cavity and two-noded tube elements for the runners, connectors and channels.

The melt front advancements are calculated by the control volume method, while the pressure, temperature and velocity field can be obtained in each time step. These results constitute the basis of the stress and deformation analysis [7-8].

3. Experiments

For the simulation of the injection molding process a lot of simulation packages such as the Moldflow Plastics Insight and C-Mold are commercially available [7].

The basic idea is to create a model of the geometry or the mold to be analyzed.

The conventional injection mold was compared to the Rapid Tooling. There are significant differences between these two techniques such as the mold materials, which cause different cycle times, shrinkage and warpage.

The durability of the rapid tool inserts are worse compared to the conventional molds, but it is worth to use to produce a couple of thousand parts.

In practice, rapid tooling mold material can be added to the simulation program (material database).

In our experiment, as a mold material, we will investigate a type of epoxy resin filled with metal powder (as Weidling C – epoxy resin aluminum filled produced by Weicon company) to increase stiffness and heat conductivity.

Epoxy resin is a thermo set plastic that can be cast to shape before cured. This special grade epoxy resin is aluminum powder filled for strength, stiffness and thermal conductivity improvement.

The epoxy resin has a heat conductivity of 0,2 W/mK, the metal has 75–90 W/mK, while the metal powder has 6–10 W/mK depending on the porosity.

The heat conduction is dramatically grooving up to above the limit of 90% metal filler, but in practice the possible ratio is around 60% to the metal powder, so heat conductivity is usually less than 0.5 W/mK as fig. 3 shows.
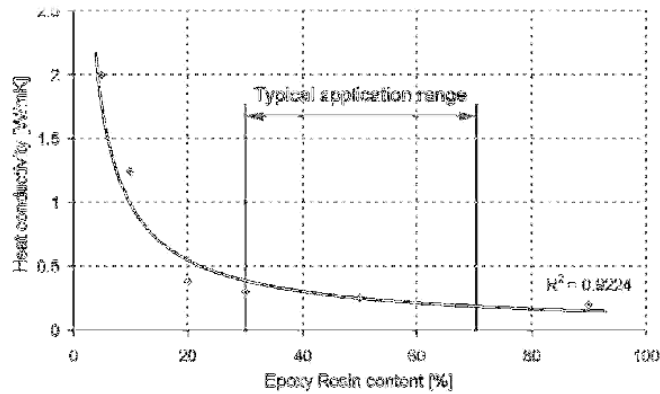

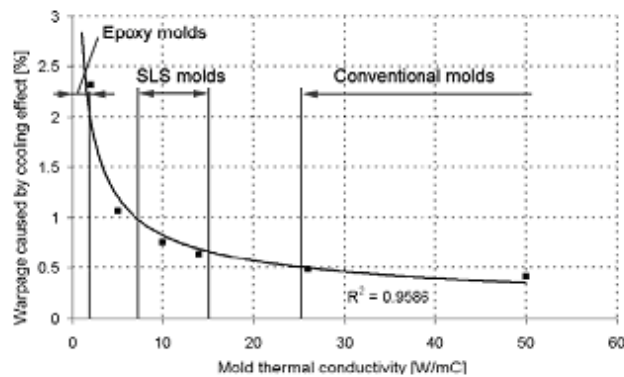Fig. 3. Heat conductivity of metal powder filled epoxy

Fig. 4. The influence of the mold thermal conductivity on warpage

The influence of the mold thermal conductivity on the warpage of the mold was examined, and in fig. 4 it is presented that the part warpage, which is caused by the differential cooling, is function of the mold thermal conductivity.

The typical mold thermal conductivity is between 25 and 80 [W/mC] if conventional tool steel are used. The deformation dependence between these values is near constant, but using rapid tool inserts it could vary much more.

The SLS tool insert's thermal conductivity is less than 15 [W/mC] while the unfilled epoxy resins' thermal conductivity is around 0.5 [W/mC], which causes warpage of the part.

4. Conclusion

Mould that is made of plastics is built from casting some special grade epoxy resins directly onto the master model. This mould making method does not require high precision machine tools as with conventional metal mould production.

This technology of the direct transfer from the master model allows large reduction in mould production costs and time.

Rapid tool inserts are useful in the injection molding technology although the warpage of the part could be more significant. Injection molding simulation programs can analyse the cooling, and can optimize or minimize the warpage using special cooling channel forms.

The mass-production with these Rapid Tooling technologies is already available, but the prototyping methods could be improved to produce more accurate tools with better surface finish.

R E F E R E N C E S

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