Residual stress within injection process.

Abstract: The article describes searching of reasons of the rotor cracking via thermal and mechanical analyses and it shows the solution. The solution was done by replacement of composite steel insert-in a polypropylene matrix with composite containing 50% glass fibers in polypropylene matrix. There is also described the flow and warpage analysis of the injection process of the new composite.

Key words: residual stress, injection molding, stress analysis, thermal analysis, polypropylene, glass fibre, warpage

1. INTRODUCTION

The situation on the dynamically changing market requires faster development and design of the injection molded parts and molds which are necessary for their production. Injection molds manufacturing is very precise, demanding and high-priced. Then any changes of the molding shape or mold design after trial operation have to be paid by production costs and time loss of the new product introduction to the market.

One of the very carefully watched parameters of the injected plastic parts is warpage. Warpage is part deflection and deformation after ejection of the part from the mold cavity. It leads to shape and dimension changes which can be out of toleration field borders and instabilities are also created in the part walls. The special case of injection molding is the metal inserts overmolding.

2. RESIDUAL STRESS

Warpage is primarily caused by residual stresses generated during the injection cycle. We distinguish two kinds of residual stresses. Injection inducted residual stress generated during the filling and packing stage and thermal inducted residual stress rising during the packing and cooling stage. The injected part is constrained by the cores and cavity in the mold and the stresses can not deflect the part. After ejection of the part from the mold the stresses have to reach the balanced state and deflect the injected part.

2.1 Flow-induced Residual Stress

Unstressed, long-chain polymer molecules tend to conform to a random-coil state of equilibrium at temperatures higher than the melt temperature (i.e., in a molten state). During processing the molecules orient in the direction of flow, as the polymer is sheared and elongated. If solidification occurs before the polymer molecules are fully relaxed to their state of equilibrium, molecular orientation is locked within the molded part. This type of frozen-in stressed state is often referred to as flow-induced residual stress. Because of the stretched molecular orientation in the direction of flow, it introduces anisotropic, non-uniform shrinkage and mechanical properties in the directions parallel and perpendicular to the direction of flow.

Due to a combination of high shear stress and a high cooling rate adjacent to the mold wall, there is a highly oriented layer frozen immediately below the part surface. Subsequent exposure of a part with high residual flow stresses (or frozen-in orientation) to high temperature may allow some of the stresses to relieve. This typically results in part shrinkage and warpage. Due to the thermal insulating effect of the frozen layers, polymer melt in the hot core is able to relax to a higher degree, leading to a low molecular orientation zone.

2. 2 Thermal-induced Residual Stress

Material shrinkage during injection molding can be conveniently demonstrated with a free quenching example, in which a part of uniform temperature is suddenly sandwiched by cold mold walls. During early cooling stages, when the external surface layers cool and start to shrink, the bulk of the polymer at the hot core is still molten and free to contract. However, as the internal core cools, local thermal contraction is constrained by the already-rigid external layers. This results in a typical state of stress distribution with tension in the core balanced by compression in the outer layers.

3. OVERMOLDING OF METAL INSERTS

If there is encapsulated the metal insert reinforcing the plastic part then the insert restrains warpage and deflection after the part demolding and it causes creating of the stresses influencing the part stiffness. The stress peaks can cause the cracks in the plastic shell covering the metal insert. If the part, which is in our case a pump rotor, is exposed to chemical agents, the metal insert is stained due to the cracks in the plastic shell.

4. INJECTION MOLDING OF IMPELLER

On the impeller there occur cracks not only in work load but also in long term storage. The impeller is made by process of injecting polypropylene filled with 30% CaC[O.sub.3]. A steel insert is encapsulated to the impeller to increase stiffness (Fig. 1). Cracks occur due to different coefficient of thermal expansion of steel 1,1.[10.sup.-5] 1/K and polypropylene 9,5. [10.sup.-5] 1/K. The injected part of the impeller is ejected from the injection mold in temperature about 120[degrees]C. As polypropylene has ten times higher coefficient of thermal expansion than steel, there are generated residual stresses due to higher shrinkage in polypropylene matrix during a storage period. These residual stresses exceed strength limit of polypropylene and cracks occur.

[FIGURE 1 OMITTED]

[FIGURE 2 OMITTED]

4. 1 Thermal analysis

Thermal analysis shows changes of temperature of the polypropylene matrix and the steel insert during the cooling time. The analysis was done for cooling time of 20 minutes, in 1 minute step. As we can see in figure 3 the color spectrum indicates temperature in impeller section in 10th minute after ejection of the part from the mold cavity. Thermal induced residual stresses in the polypropylene matrix are then generated due to temperature differences.

[FIGURE 3 OMITTED]

4. 2 Stress analysis

The analysis of thermal induced residual stresses was done for temperature gradient in 10th minute after ejection of the part from the mold cavity. As we can see from the color spectrum (Fig. 3) stress peaks occur in the impeller hub. Comparative Von Mises stress reaches the peak value of 80 MPa. This value exceeds 2,5 times the value of strength limit of polypropylene filled with 30% CaC[O.sub.3] which is 30 MPa. As the steel core restrains volumetric shrinkage of the polypropylene matrix, the high values of residual stresses are generated. The cracks could occur during the whole storage period.

To prevent from crack occurrence a new solution of the impeller design was proposed. As the impeller is used to pump strong acids, polypropylene must be used. The steel insert will not be used and filling with 50% short glass fibers will be used instead of 30% CaC[O.sub.3]. The fibers must be processed chemically to make bonds between the polypropylene matrix and the filler.

The thread to fix the impeller on the shaft will be injected in the mold. To prevent from occurrence of stress concentration a non-standard thread with rounded edges must be used. The impeller has to perform operation temperature 0-110[degrees]C. Although Young's modulus of polypropylene filled with 50% glass fiber is 10 000 MPa, we must take into account operation temperature and polypropylene creep that decreases five times the modulus' value.

[FIGURE 4 OMITTED]

5. CONCLUSIONS

The thermal and stress analysis confirmed that the cracks occurred as a result of different coefficient of thermal expansion of polypropylene matrix and the steel insert. As the steel core restrains volumetric shrinkage of the polypropylene matrix, the high values of the residual stresses are generated. Polypropylene filled with 50% glass fibers Niplene F50 AGR has been chosen for injection molding of the impeller without the steel insert. Upon the analysis of the impeller deflection in operation loading the impeller can be tested during operation. If the impeller deflection does not meet the test requirements, two-component injection must be used. The core components should be polymer with high stiffness and high temperature resistance and the skin component should be injected of polypropylene. Polyphenylenesulfide filled with 50% carbon fibers can be used due to high temperature and chemical resistance and high stiffness.

6. ACKNOWLEDGEMENT

The research has been performed thanks to support of the Ministry of Education and Youth of the Czech Republic under grant MSM 7088352102.

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Article Details

Printer friendly Cite/link Email Feedback

Author:	Halaska, P.; Manas, M.
Publication:	Annals of DAAAM & Proceedings
Article Type:	Technical report
Geographic Code:	4EUAU
Date:	Jan 1, 2005
Words:	1433
Previous Article:	Analysis of influence of variation of cutting forces direction on accuracy of curvature representation by profile milling operation.
Next Article:	Bending under conditions of plane stress.
Topics:	Glass fibers Mechanical properties

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Methods
Polypropylene
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