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SIMULATION STUDIES OF THE IMPACT OF THE GATE LOCATION ON THE DEFORMATION OF THE PA6 GF30 INJECTION MOLDED PART

The paper shows the results of computer modeling of the polymer injection molding process. The influence of the gating system design on the warpage and volumetric shrinkage of the molded part was investigated. Particular attention was paid to the location of the gate. It has been proven that the selection of the place where the material is brought to the molding cavity has a significant impact on the final shape and quality of the molded part. The degree of compliance of its shape with the assumptions and dimensional accuracy was adopted as the criteria for assessing the quality of the molded part. The specialized software package Autodesk Moldflow Insight was used for numerical calculations. The obtained modeling results were related to the design recommendations of gating systems known from the literature.

Keywords: injection molding; Moldflow; modeling; simulation; gate location

1. Introduction

Injection molding of plastics is a process widely used in many branches of modern industry. In view of this state of affairs, it becomes fully justified to conduct research aimed at an in-depth understanding of the phenomena occurring during the broadly understood processing of polymeric materials. It often happens that a mistake made by the constructor at the design stage of the molded part determines the failure when trying to implement the product into production. This work is an attempt to demonstrate the usefulness of computer simulations of the injection process to eliminate such errors.

1.1. Simulation of an injection molding process

Computer simulations of the injection process are commonly used not only at technical universities but also in design offices, tool shops (factories), and production plants. Simulation programs allow you to virtually check the correctness of the construction of molded parts and injection molds. Autodesk Simulation Moldflow Insight and Moldex3D are world leaders in this industry.

The results of computer simulations of the injection molding process are used to predict the properties of the final molding, but also to optimize the process itself. These results provide the constructor with information on the expected shrinkage [1], warpage [2], location of the weld lines [3], sink marks [4,5], the method of distribution of the material in the mold [6], air traps [7], etc. On the basis of this information, it is possible to correct the construction of the injection mold already at the design stage. The virtual injection process allows for a reduction of the costs of implementing the mold into production, shortens the implementation time, and eliminates design errors.

1.2. Gate location

A very important aspect in the design of injection molds is the appropriate choice of the gate(s) location. This location has a direct impact on the way the cavity is filled, and consequently on the properties and quality of the molded part. There are many methods to optimize the number of gates and their arrangement [9-11]. These methods are aimed at ensuring the best possible properties of the molding and improving the conditions of the injection molding process. As a result of the appropriate arrangement of the gates, it is possible to: shorten the time of filling the mold [12], improve the cooling efficiency of the mold [13], and reduce warping [14].

The location of the gate is important not only in the case of a conventional injection molding process. Many publications

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contain the results of optimization studies on multi-component injection molding [15], micro injection molding [16,17], compression injection molding [18], injection of liquid composites [19] and others.

Some industries are particularly demanding in terms of molded part quality. Examples include the pharmaceutical and automotive industries [20,21]. In the case of such demanding recipients, simulation tests are particularly useful.

In order to thoroughly understand the phenomena occurring in the injection molding process, many studies are conducted in the field of process monitoring, visualization and control [22-24]. The author of this article conducts research in the field of polymer flow visualization in the mold cavity [25].

2. Experimental

This paper presents the results obtained during the study of the polyamide-glass fiber composite. The EMS-Grivory polyamide 6 (PA 6) with the trade name Grilon BG-30 was used. The polymer contained 30 wt.% glass fibers. As part of the simulation studies, a series of numerical analyzes were performed to computer model the composite injection molding process. For this purpose, the professional computer program Autodesk Simulation Moldflow Insight version 2017 was used. For the correct conduct of the analysis, it was necessary to enter material data. For this purpose, a database was used, which is an integral part of the simulation program. Figs. 1 and 2 show selected properties (flow curves and pvT diagram) of the material used for testing.

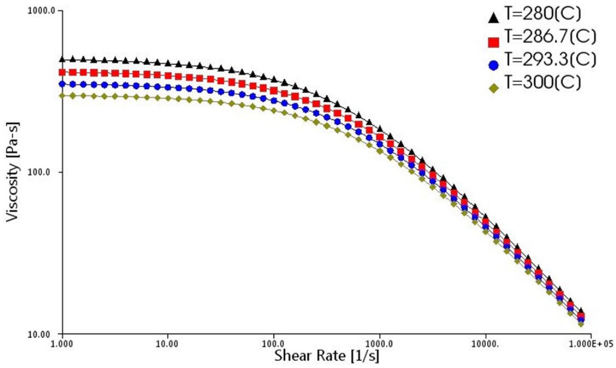

Fig. 1. Viscosity plots for composite Grilon BG-30

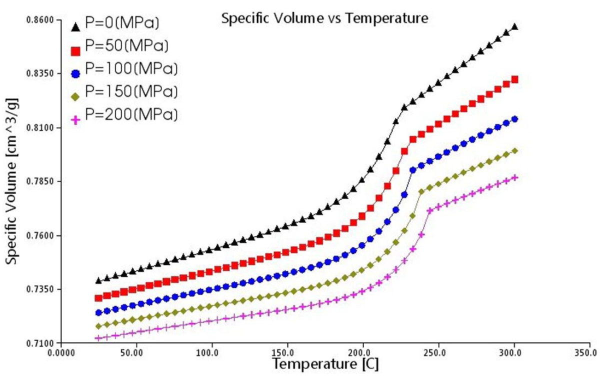

Fig. 2. PvT plot for composite Grilon BG-30

The shape shown in Fig. 3 was used for the tests. The molding part, according to the designer's intentions, should be characterized by a 90-degree angle between the "arms". Unfortunately, this angle is much smaller. The location of the gate is marked in red.

Fig. 4 shows the 3D CAD model of the molded part, and Fig. 5 shows the FEM model of the molded part and cooling system. The simulation required the use of a model that met specific requirements (the number of finite elements per part wall thickness could not be less than six). In addition, it was forced to take into account the effects of inertia and gravity in numerical calculations.

Fig. 3. Injection molding part with marked gate

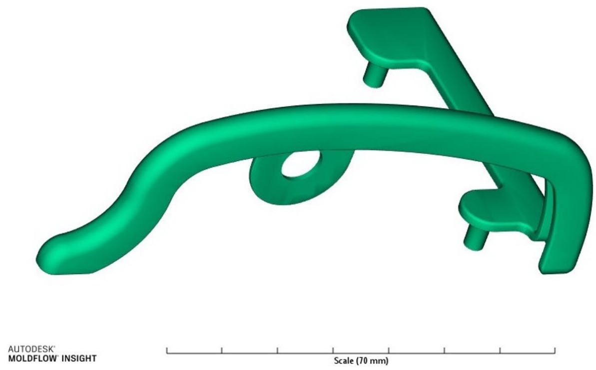

Fig. 4. 3D CAD model of the molded part

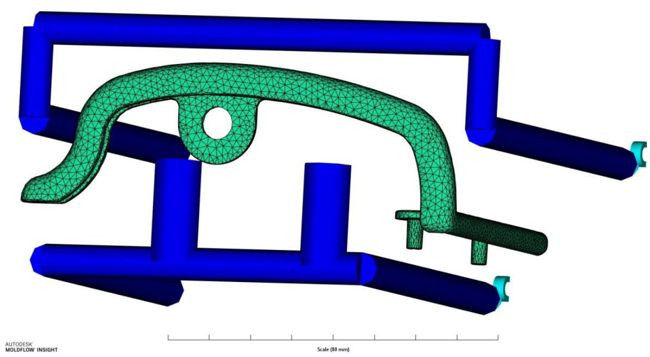

Fig. 5. FEM model of the molded part with cooling system

Fig. 6 shows the FEM model of the molding part with the default location of the gate, while Fig. 7 shows the FEM model of the molding part with the modified location of the gate. The reason for modifying the location of the gate is explained in Chapter 3.

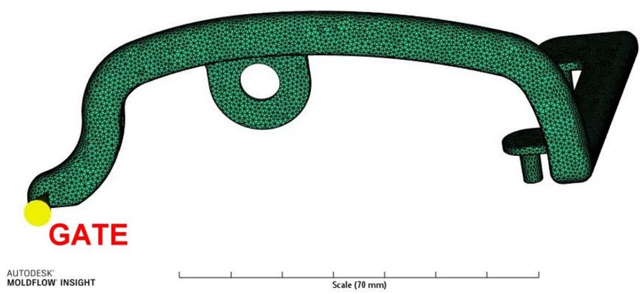

Fig. 6. FEM model of the molding part with the default location of the gate

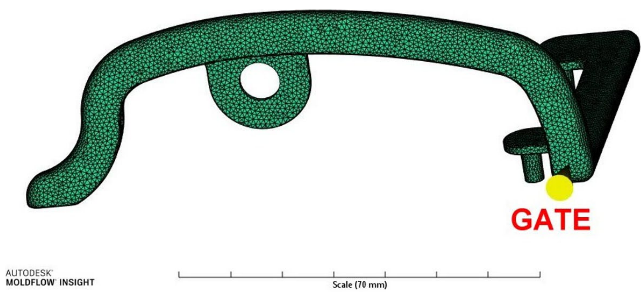

Fig. 7. FEM model of the molding part with the modified location of the gate

The conditions of the injection process were identical for both FEM models (Figs. 6 and 7):

- Clamping force 800 kN
- Injection temperature 275°C
- Mold temperature 75°C
- Injection time 1.2 s
- Flow rate 25 cm^3/s
- Packing time 7 s
- Cooling time 15 s

The results of the simulation for FEM model of the molding part with the default location of the gate were compared with the real molding part. After analyzing the simulation results, the location of the gate was corrected and the calculations were performed again.

A cylindrical gate automatically generated by the Moldflow program was used. The effective surface area of the gate node is calculated as one third of the sum of the tetrahedral surface facets surrounding the node. On this basis, the gate diameter is determined. In the considered case, the diameter of the gate is 1.6 mm.

3. Results and discussion

Selected results of the injection molding process simulation for the part with the default location of the gate are shown in Figs. 8 and 9. Results for warpage and average volumetric shrinkage are presented. These are the most important results due to the dimensional accuracy of the injected part.

Considerable differences in the value of the average volumetric shrinkage in individual regions of the part were observed. This is the result of the long flow path of the material in the mold. In the areas farthest from the gate, the effect of the holding pressure is negligible, which increases the value of processing shrinkage.

The simulation results were compared with the real part. The nature of the distortions (deformations) was found to be consistent. Warpage of the actual part was slightly greater due to post-processing shrinkage.

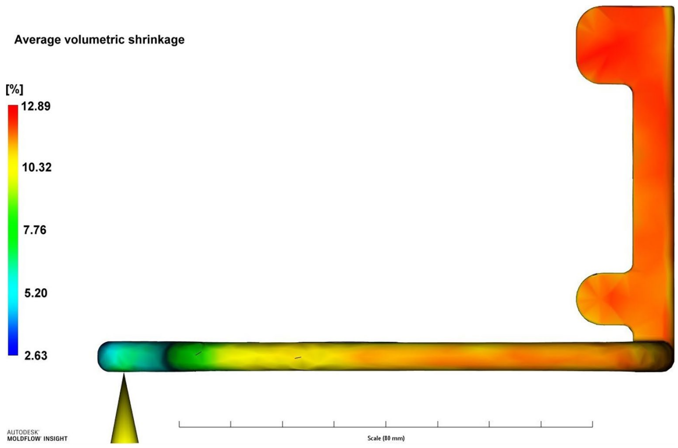

Fig. 8. Average volumetric shrinkage for of the molding part with the default location of the gate

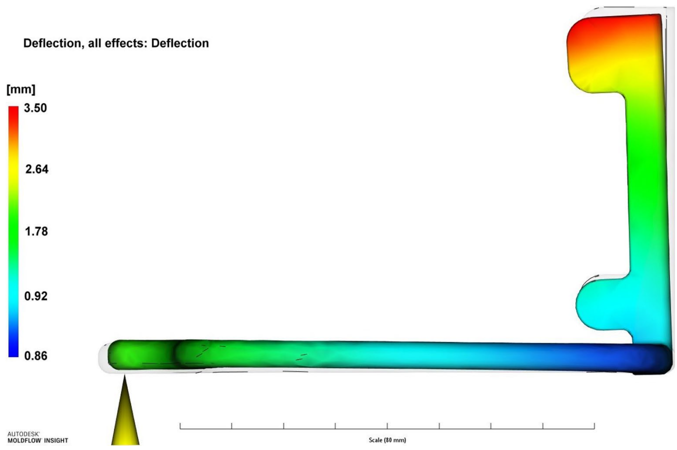

Fig. 9. Warpage for of the molding part with the default location of the gate

The predicted warpage value disqualifies the molded part from its intended use.

Figs. 10 and 11 show the results of the part injection simulation with the modified gate location. These are the same results as for the part with the default gate location. Thanks to this, it was possible to directly compare the results of both simulations.

A significant improvement in the uniformity of the average volumetric shrinkage throughout the volume of the part was observed.

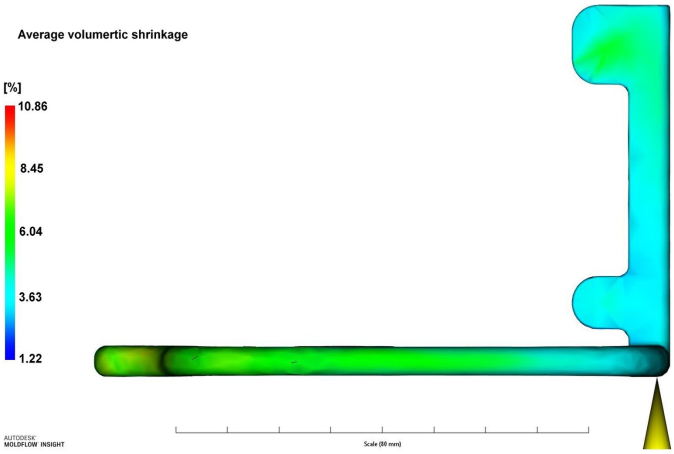

Fig. 10. Average volumetric shrinkage for of the molding part with the modified location of the gate

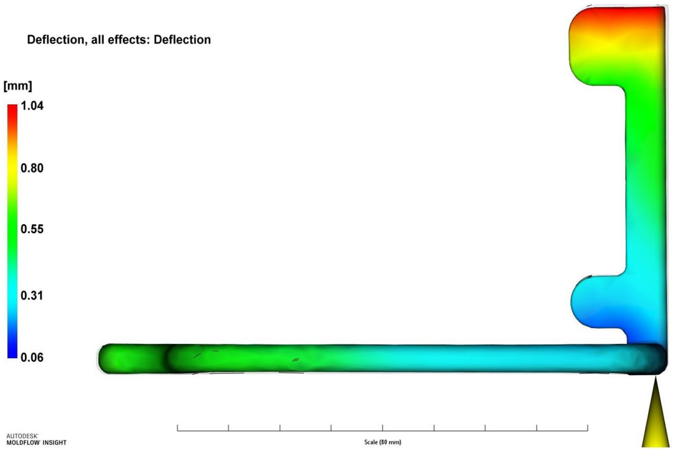

Fig. 11. Warpage for of the molding part with the modified location of the gate

Changing the location of the gate significantly reduced the warping of the part. This is the result of shortening the flow path of the material in the mold and improving the effectiveness of the packing phase. The maximum warpage for the first simulation was approx. 3.5 mm. After changing the location of the gate, this warpage at the level of 1 mm was observed. This value is acceptable from the point of view of the purpose of the part. The presented simulation results take into account all the factors that affect the final shape of the molded part. The method of presenting the deflections is global, with no divisions into individual reasons for their creation. An additional reduction in the warpage size is possible due to changing the injection conditions or by using an amorphous material.

4. Conclusions

After research and analysis of the results, the following conclusions were drawn:

– performed simulations of the injection molding process confirmed that the location of the gate(s) has a significant impact on the properties of the injected part. The arrangement of the gates determines the method of filling the mold cavity. The even packing of the mold cavity ensures uniform shrinkage and warpage throughout the part volume.
– the conducted tests showed the possibility of a more than three times reduction in the size of warping as a result of changing the location of the gate.
– the location of the gate should ensure the shortest possible flow path in the mold cavity. Unfortunately, this is not always possible due to the geometric shape of the part, construction conditions of the injection mold, etc.
– the credibility of the results of computer simulations of the injection process was confirmed. The simulation results were consistent with the real processing results.
– it is advisable to repeat the simulation calculations for the amorphous material (ABS, polycarbonate) to confirm the further reduction of part warping.

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