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Simulation of polymer melt flow in the mold cavity

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Abstract: Moldflow analysis provides to the user insight into the cavity mold during its filling. After the analysis, it is possible to determine whether are problematic area on the injection mold part, because it is possible to influence to the parameters which can make changes inside the mold cavity. With this approach, possible errors of the finished product are significantly reduced, as well as the time and costs. In the paper, a simulation of melt flow for polymer material - polypropylene (PP) for a chosen test sample with two mold cavities, was performed. Fill, Cool, Pack and Warp analysis were carried out and the conclusions of the analysis were drawn.

Keywords: injection mold, simulation, Moldflow analysis, polymer, polypropylene.

Introduction

Injection molding (IM) is widely used in the production of products made of polymer materials. The process is cost-effective for large-scale and mass production, given that the price of making the mold represents a relatively large expense. The quality of the finished product obtained by IM is affected by a number of parameters, and various errors in the product are possible. In order to minimize errors and cycle time, it is recommended to use software to simulate the polymer melt flow inside the mold cavity, which helps to optimize the polymer product and mold design, and reduces possible product defects and improves the molding process. By changing the design of the product, it is possible to avoid possible defects that affect the quality of the finished product. In this paper, the simulation of polymer melt flow was performed in Autodesk Moldfow Insight software for a chosen part (test specimen for tensile test conduction), designed according to the EN ISO 527-2 standard. Fill, Cool, Pack and Warp analyzes were carried out by computer simulation, as well as an analysis for the optimal gate placement on the molded part.

Related Work

A simulation of the polymer melt flow provides to see changes inside the mold cavity during the mold filling. That also enables to predict and eliminate potential errors and thus reduce costs and material waste, and because of uts complexity this topic is the subject of many research studies 1. Borkar, S. (2021), Chandrashekhar, N. S., Shinde, S. S. (2019), Bahanan, W., Fatimah, S., Song, H., Lee, E. H., Kim, D.-J., Yang, H. W., Woo, C. H., Ryu, J., Widiantara, I. P., Ko, Y. G. (2023), Li, Y., Zhong, C., Li, C., Jiang, R., Lu, J., Sun, R. (2022), Zeng, Y.-J., Hwang, S.-J., Liu, Y.-D., Huang, C.-S. (2021), Dadhich, K., Tiwari, A. N. (2019), Shashank, S., Sudeep, I., Nagaraja, R. (2023), Weimin, Y. (2021), Weimin, Y. (2023). In the paper Li, Y., and Zhou, W. (2023), the optimization of the gate location was performed on two models with different geometries. Moldflow software was used to balance the flow of the polymer melt and the DOE experimental design method was used to optimize the runner system. By optimizing the runner system, the time balance rate was reduced to 0.6% and the pressure was also reduced. The authors in their analysis considered the parameters: material melting temperature, mold temperature and filling time. Achieved results with the Extended Adaptive Weighted Summation Method for optimization shows that the shrinkage was reduced by 15.75% and the warpage by 3.847 mm regarding to injection molding process (Hiyane-Nashiro, G., et al., 2022).

Research Results

Injection molding is a cyclical production process in which melt is injected under pressure into a closed mold, which represents the first phase (volume filling). This is followed by a compression phase and a subsequent pressure phase during which the molded part hardens and separates from the mold wall. The reduction in volume can be compensated for by injecting additional melt material into the mold cavity. This is followed by an isochoric pressure decrease, as a result of which the completely melted material and gate, so additional injection of the melt material is no longer possible. After the reaching a pressure of 1 bar in the cavity mold, further decreasing of the pressure is not possible, and the cooling of the molded part takes place under isobaric conditions. The molded part is then removed from the mold cavity and continues cooling outside the mold until it reaches environment temperature. A simulation was conducted with a thermoplast material with a crystalline structure, which properties are visible in Table 1. In the designing mold process, the subsequent shrinkage of the material due to the subsequent crystallization of the thermoplast should be taken into account. All the mentioned changes can be followed in the pvT diagram [Figure 1 a]. Also, the filling of the mold cavity is significantly affected by the viscosity of the material, since it represents the resistance to the flow of the material. The fluidity of high-viscosity materials, among other things, can be improved by increasing the melting temperature in recommended range values for each material. The viscosity diagram of the selected polypropylene (PP) material in relation to the shear rate is shown in Figure 1 b).

Table 1

Material properties for polypropylenes (PP)

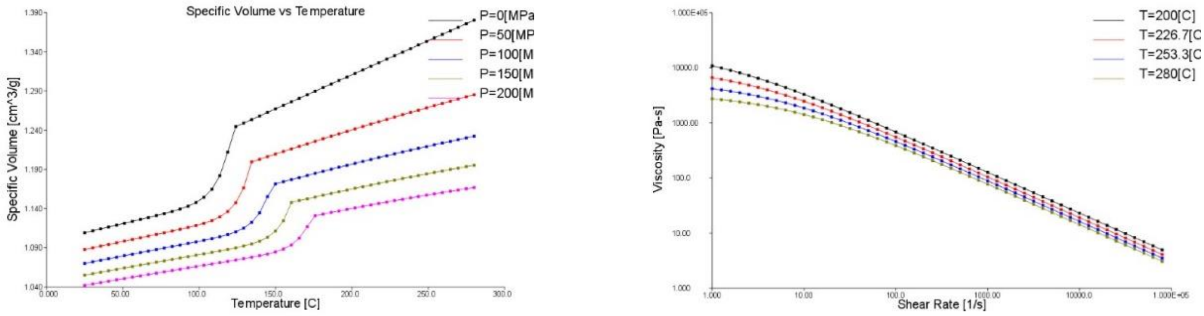
Material properties for polypropylenes (PP) – Propathene GS 16 – INEOS Acrylics

Mold surface temperature	50 °C	Viscosity	0.2578 Pa·s
Melt temperature	230 °C	Elastic modulus	1340 MPa
Mold temperature range	20-80 °C	Poissons ratio	0.392
Ejection temperature	93 °C	Shear modulus	481.3 MPa
Maximum shear stress	0.26 MPa	Average nominal shrinkage	1.016 %
Maximum shear rate	24000 1/s	Melt density	0.74802 g/cm^3

Source: Autodesk Moldflow Insight software

Figure 1

pvT graph representation and viscosity of polypropylene (PP)



a) pvT graph representation b) Viscosity of PP

Source: Autodesk Moldflow Insight software

Moldflow analysis was performed for the selected molded part with two mold cavities and a designed cold runner system. The analysis gave an insight into the quality of the molded parts. The selected material filled the mold cavity 100% in a time of 0.9083 s [Figure 2a]. The melting temperature used is 230°C and mold surface temperature is 50 °C. The filling time, and thus the cycle time, can be reduced, among other things, by optimizing the runner system. Symmetrically placed runners with a diameter of Ø4 mm were chosen, however, if the flow of the melt went through runners with larger diameters, the filling of the mold would be faster, but also the material consumption would be higher (the runner system represents a material waste). It is also necessary to take into account the length of the runner channels, i.e. the flow path depending on the structure of the thermoplast (crystalline or amorphous).

The result of the actual injection pressure shows the value of the maximum injection pressure before the velocity/pressure switchover occurs during the filling phase. At the beginning of filling, the pressure is 0 bar throughout the entire mold. The highest injection pressure for the selected material is 14.67 MPa, which is also shown in Figure 2b. The recommended pressure is in the range of 70 - 90 MPa.

Figure 2c shows changes in temperature at flow front during filling in the range of 229.9 to 230 °C which is optimal, as it is recommended that the temperature drop should not be more than 2 - 5 °C. In areas where the temperature rises by a few degrees, degradation of the surface may occur, and if the temperature is too low, non-filling mold cavity may occur.

Figure 2d shows the cooling time of the molded parts required to reach ejection temperature (in this case 43.66 s), before ejection from the mold, which is measured from the start of filling. The places that reach the ejection temperature the fastest are shown in blue, and the places that cool the slowest are shown in red. It would be ideal if the molded parts were cooled equally.

The weld lines [Figure 2e] shows the alignment angle of the two melt flows. Weld lines show places of lower strength and mechanical properties compared to the rest of the molded part. These lines are undesirable, but impossible to avoid if the melt front separates and rejoins around a hole or if the molded part has a multiple gates. The weld lines do not appear on this molded part.

Volumetric shrinkage at ejection [Figure 2f] from the mold represents a decrease in the volume of the molded part, which begins when the ejection temperature is reached and continues until the molded part is cooled to environment temperature. The obtained results are presented as a percentage of the nominal volume of the molded part. It is recommended that the shrinkage be uniform throughout the entire molded part, and in order to avoid torsion of the part, it is desirable that the volume shrinkage be as small as possible.

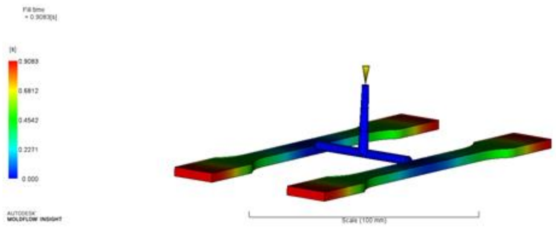
The simulation of orientation at skin [Figure 2g] represents the direction of the skin orientation of polymer flow inside the mold cavity. Proper selection of the gate location is important for the proper orientation at skin. The direction of the skin orientation must be followed, which means that the flow is uniform inside the mold.

Air traps [Figure 2h] are formed in places where the material melt traps and compresses a bubble of air or gas between two or more melt fronts or between the melt front and the mold cavity. If they exist, air traps are shown as small holes on the surface of the molded parts. Air traps were determined at the edges of the molded part by this analysis.

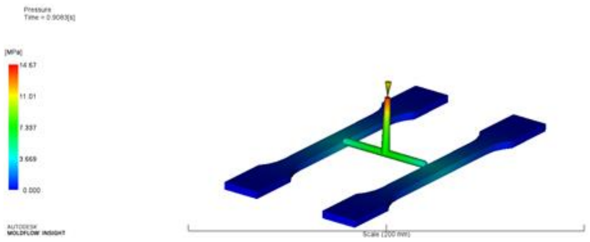
Figure 2i show the circuit coolant temperature which is 25.37 °C and also a temperature of part [Figure 2j] in the amount of 41.06 °C for Cool analysis conducted in Moldflow for the designed cooling system.

Figure 2

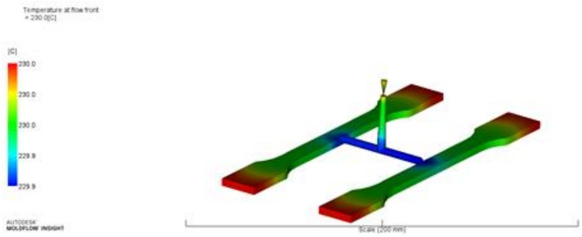
Moldflow analysis results



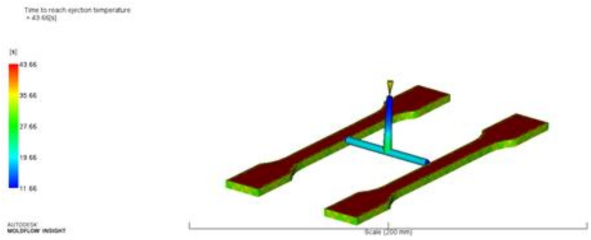
a) Fill time (0.9083 s)



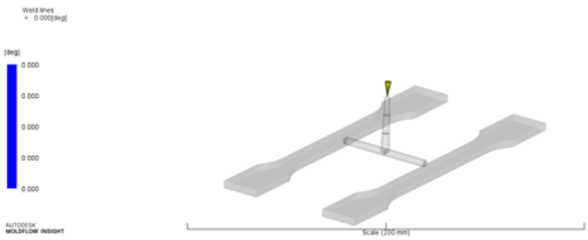
b) Pressure (14.67 MPa)



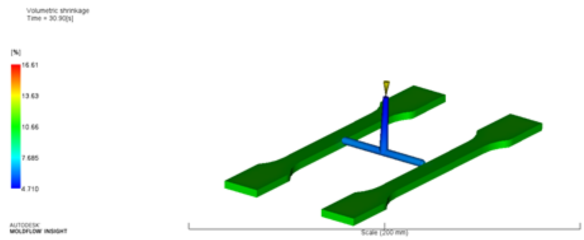
c) Temperature at flow front (230 °C)



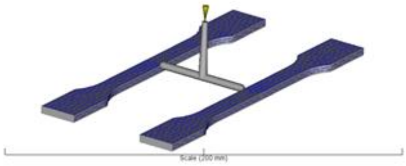
d) Time to reach ejection temperature (43.66 s)



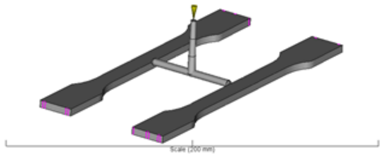
e) Weld lines



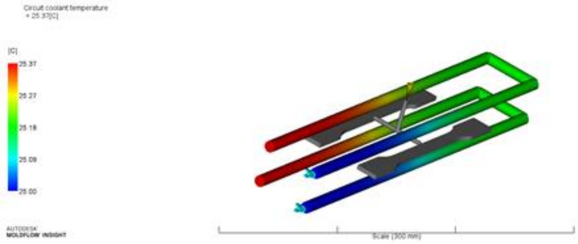
f) Volumetric shrinkage



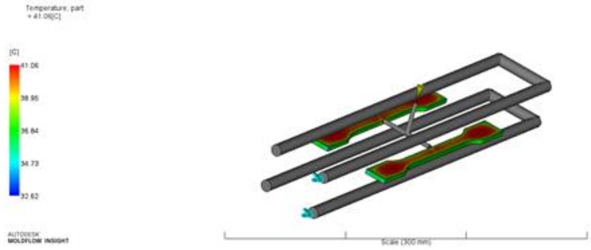
g) Orientation at skins



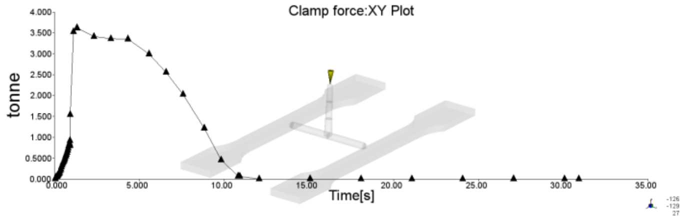
h) Air traps

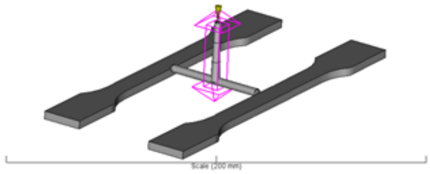


i) Circuit coolant temperature (25.37 °C)



j) Temperature part (41.06 °C)





k) Clamp force

Source: Autodesk Moldflow Insight software

Figure 2k represents the clamp force graph based on the force applied in tones (y-axis) with respect to the time (x-axis) taken as shown in the graph. The maximum required mold holding force is approximately 3.5 tones. The higher is pressure, the higher are forces required to hold the mold closed. Also a Warp analysis was conducted. Deflection in X and Y directions belongs to the natural shrinkage, while deflection in Z direction is uniform.

Conclusions

The results of the Moldflow analysis showed that a significant number of parameters affect to the quality of the finished product. Using the recommended parameters of the Moldflow software also reduces the cycle time. The software provides the possibility of choosing the most suitable place for gate location, which significantly affects to the final results. Due to the designed a balanced runner system, relatively low values of the required injection pressure were achieved, which enables less force required to keep the mold closed. The mold cavity is completely filled, but the filling process can be accelerated by optimizing the runner system, increasing the melting temperature or using another material with a lower viscosity. For molded parts with more complex and/or different geometries and with a larger number of mold cavities, runner system balancing can be challenging, and future research might be in that direction.

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