How to cite this article:

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Title of article: "Simulations of thick-wall injection molding using the Moldex3D program"

Mechanik, No. 4 (2019)

DOI: <https://doi.org/10.17814/mechanik.2019.4.30>

Simulations of thick-wall injection molding part using the Moldex3D program

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Simulation of thick-walled part produced by standard injection molding (IM), gas-assisted injection molding (GAIM) and microcellular injection molding (MuCell) for two plastic types: ABS and POM using Moldex3D R15 software. It was found high reducing mass and reducing cooling times and decreasing sink mark, volumetric shrinkage and warpage deformations of parts analyzed by GAIM and MuCell compared to IM.

KEYWORDS: *thermoplastic injection molding, gas assisted injection molding, microcellular injection molding, computer simulation, Moldex3D*

Introduction

The versatility and universality of polymer materials injection technology have determined its rapid development. Over the past years, many modifications and improvements have been made to both the technology itself and the machines used in it. In addition to standard injection molding technique, different variants have been developed and implemented, which has been comprehensively described by Bociaga [1, 2]. The most important are:

- multi-component injection molding (MIM),
- injection molding (ICM),
- gas-assisted injection molding (GAIM),
- water-steam assisted injection molding (WAIM),
- microcellular injection molding (MuCell),
- injection with labeling molding (IML) or varnishing (IMP) in the mold.

Development of injection techniques entails the progress in commercial programs for computer simulation of manufacturing processes. Specialized computer systems include:

- Autodesk Moldflow Insight,
- Cadmould,
- Moldex3D,
- Sigmasoft.

These programs facilitate optimization of molded parts and tools (injection molds) and injection parameters, which contributes to shortening the time of introducing new products and helps to avoid errors in the design of fittings and molds, the improvement of which is a costly component of implementations [3]. An unquestionable advantage resulting from the use of injection simulation is the ability to trace the impact of various process parameters on basic features of molded parts without the need for many technological tests.

The paper compares results of the injection simulation of a thick-walled sleeve with a flange, obtained in the Moldex3D program (version R15) [4, 5]. Dimensions of the analyzed sleeve are shown in fig. 1. The following techniques were selected for the simulation: standard injection molding (IM), gas-assisted injection molding (GAIM) and microcellular injection molding (MuCell). It was expected that these analyses would enrich knowledge on the selection of process parameters and benefits (such as shortening the cycle time and material savings) that could be achieved using modern GAIM or MuCell techniques [6–9].

Fig. 1. View of thick-walled sleeve designed for injection simulation

The FEM model of the analyzed molding piece together with the cooling channel system, designed in the Moldex3D Designer R15 program and consisting of various types of three-dimensional elements, are shown in fig. 2 [4, 5]. Polymer materials for planned simulations were selected from the Moldex3D R15 database:

- from the group of amorphous materials: acrylonitrile-butadiene-styrene terpolymer, Cycolac GHT 4320 type from Sabic (ABS),
- from the group of partially crystalline materials: polyoxymethylene type Delrin 500 CL NC-10 from DuPont (POM).

Fig. 2. FEM model of the sleeve with inlets and designed cooling channels designed for simulation in the Moldex3D program

In the injection simulation, the following modified Cross models were used as viscosity models of the analyzed materials:

- for ABS:

$$\eta = \frac{\eta_0}{1 + \left(\frac{\eta_0 \cdot \gamma}{\tau^*} \right)^{1-n}}$$

$$\eta_0 = D_1 \exp \left(\frac{-A_1(T - T_c)}{A_2 + (T - T_c)} \right) \quad (1)$$

$$T_c = D_2 + D_3 p$$

$$A_2 = A_{2b} + D_3 p$$

where: η – apparent viscosity, η_0 – lower Newtonian viscosity, γ – shear rate, T – temperature, p – pressure, and the material constants have the values: $n = 0.2638$, $\tau^* = 106 \text{ dyna/cm}^2$, $D_1 = 8.66 \cdot 10^{14} \text{ g/cm} \cdot \text{s}$, $D_2 = 375.24 \text{ K}$, $D_3 = 0 \text{ cm}^2 \text{K/dyna}$, $A_1 = 33.728$, $A_{2b} = 51.6 \text{ K}$;

- in the case of POM:

$$\eta = \frac{\eta_0}{1 + \left(\frac{\eta_0 \cdot \gamma}{\tau^*}\right)^{1-n}} \quad (2)$$

$$\eta_0 = B \exp\left(\frac{T_b}{T} + Dp\right)$$

where material constants are equal to: $n = 0.2922$, $\tau^* = 2.5872 \cdot 10^6$ dyna/cm², $B = 0.0007933$ g/cm·s, $T_b = 7534$ K, $D = 0$ cm²/dyna.

For analysis in Moldex3D, 3D Solid Model Solver was chosen, designed especially for simulation of injection molding of thick-walled parts and simulation of special injection techniques [4, 5]. In tab I, the basic process parameters selected in accordance with the recommendations of the producers of the tested materials and on the basis of own processing experience, were presented.

TABLE I. Basic process parameters used in the injection analysis of individual materials

Injection technique	Processing parameter	Material	
		ABS	POM
IM GAIM uCell	Injection temperature [°C]	260	220
	Mold temperature [°C]	65	90
	Maximum molding temperature at ejection [°C]	90	120
	Injection time [s]	2.5	2.5
	Injection time phase [%]	0/10/15/90/100	0/5/10/90/100
	Injection rate [%]	50/50/100/100/40	40/40/100/100/50
GAIM	Gas pressure [MPa]	10	10
	Start of gas injection [%of seat filling]	70	70
	Gas injection delay [s]	0.1	0.1
	Gas injection time [s]	5	5
MuCell	Foaming start [%of seat filling]	85	85
	Initial gas content [mass %]	0.5	0.5

TABLE II. Comparison of virtual results of parts obtained with the analyzed techniques

Feature	Material type	Analyzed injection technique		
		IM	GAIM	MuCell
Internal injection pressure [MPa]	ABS	0.4	0.2	0.1
	POM	0.2	0.2	0.1
Maximum melt temperature [°C]	ABS	260.0	265.4	260.1
	POM	220.0	216.7	211.9
Time to reach ejection temperature [s]	ABS	729	209	246
	POM	932	550	286
The weight of the part [g]	ABS	516	374	324
	POM	624	446	440
Warping, maximum deflection [mm]	ABS	1.06	0.48	0.53
	POM	1.80	1.30	1.57
Sink marks [mm]	ABS	0.73	-	0.15
	POM	0.85	-	0.61
Maximum volumetric shrinkage [%]	ABS	11.5	10.6	3.4
	POM	12.0	11.6	11.5

Moldings made using the standard injection technique have a greater mass than moldings produced by other analyzed methods (tab. II). In the case of ABS material, the molding obtained by the IM method reaches a mass of 516 g, and in the case of POM – 624 g (which results from higher density of this material). Injection techniques with gas and microporous injection allow for a significant reduction in weight of the molding – by approximately

30%. The weight of the ABS material part is 374 g (GAIM) and 324 g (MuCell), respectively, and the weight of POM fittings – 446 g (GAIM) and 440 g (MuCell).

It is similar with another parameter important from the point of view of production profitability, which is the minimum cooling time (tab. II). GAIM and MuCell techniques bring beneficial shortening of cooling time, which for thick-walled parts is the main factor influencing the length of the forming cycle. This is due to the fact that the wall thickness of the material, from which heat is received by the walls of the socket, and then by the coolant, is reduced. It should be noted that the minimum cooling time for semi-crystalline POM moldings is clearly longer than the cooling time for amorphous ABS moldings for each of the injection molding techniques analyzed. This is probably due to the need to collect the solidification heat of POM from the cooled molding – this thermal effect does not occur in the case of amorphous polymers.

Values of parameters related to dimensional accuracy of the fittings also speak in favor of modified injection techniques. In the moldings obtained using the GAIM technique, no sink marks occurred, and in the moldings obtained using the MuCell method, their number was clearly reduced. The use of GAIM and MuCell techniques also reduces the warpage and volumetric shrinkage of the fittings, although this effect is not so pronounced.

In the case of the analyzed fittings, no significant differences were found in the values of injection pressure and temperature of the flowing alloy. This is due to the considerable wall thickness of the molding, so that filling the seat with liquid polymer does not create much resistance.

Computer simulations of GAIM and MuCell processes have confirmed the beneficial effect of these techniques on the likely improvement in the economic efficiency of producing the thick-walled moldings, and also facilitated the selection of optimal process parameters. However, it should be noted that in both these methods, there is some weakening of the fitting, resulting from the reduction of its active cross-section – this must be taken into account at the stage of construction and design works [10, 11]. In addition, the MuCell technique causes increasing of the molded surface defects, therefore it is currently used along with fast heating and cooling of the mold cavity, the so-called RHCM (rapid heat cycle molding) [11–13].

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