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ANALYSIS OF TEMPERATURE INFLUENCE ON INJECTION MOLDING PROCESS

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Abstract: *This article deals with possibilities of modern advanced simulation methods for determining quality of mechanical systems. For temperature studies injection molding process was chosen. It is influenced by many parameters such as temperatures and pressures. This article is focused on influencing by temperature. The main aim is to determine optimal temperatures of injected plastic material, mold and coolant. For each plastic material temperature range of mentioned parameters is given. Using modern plastics flow simulation it is identified the exact influence of each parameter on final properties of product. As main parameters for evaluation the followings are chosen: level of mold filling, number of weld lines and total production times. As a reference state it is chosen the process with mean values of all injection parameters. Simulations are verified by comparing with an experiment on real injection molding machine.*

Key words: *injection molding, temperature, quality, molding simulation.*

1. INTRODUCTION

Injection molding of plastics is worldwide one of most commonly used production methods. Nowadays, there are plastic parts used in almost all kinds of products and in all industrial fields. Quality is now with costs the main indicator, which will determine success on global rapidly changing market.

Our research is focused on improvement of technological process of injection molding using new methods of advanced simulations (CAE). In the past, adjustments of all injection parameters were tested using real experiments. It means that production was stopped and until setting up all parameters properly it was not producing any parts.

One of advanced methods for experiment is using virtual simulation with finite element method. Using this, it is possible to predict influence of all parameters on target product. This article is focused only on influence of temperature. Changes in second main parameter, which is pressure, will be under inspection in future work and research.

The quality of the final product and the productivity of the injection molding process depend on several parameters. The manufacturing parameters, material characteristics and mold design have direct influence on the product. Determination of the optimum parameters for the process is mandatory for ensuring the product quality and to decrease production costs.

Therefore, the main purpose of this work is to determine the optimum manufacturing parameters for injection molding of an existing part in order to decrease cycle time. To do so, both CAD (NX 10 software) and CAE (Moldex 3D software) tools are used to reproduce the part and the process and then, after the simulations, to validate the results by experimental molding injection.

An important thing is that all manufacturing parameters of injection mold are highly interdependent. At this point, a suitable method to conduct the simulations is required to avoid unnecessary time spending and computational costs and to organize the results.

2. INFLUENCE OF TEMPERATURE

Temperature can influence quality of final product. All main parts of injection molding press have different temperature during injection molding. The parameters considered here are injection temperature, mold temperature and coolant temperature.

2.1. Injection temperature

Injection (melting) temperature is the temperature of plastic material in time of entering gate into cavity of mold. All plastic materials have ranges for melt temperature. For general kinds of plastic materials the ranges of injection temperatures are shown in Table 1.

Table 1

Melt temperatures of typical materials

Material	**Injection (Melting) temperature [°C]**
HDPE	190–240
LDPE	170–270
PP	180–280
PA 6	240–280
ABS	190–270
PS	170–270
PMMA	200–260
PVC	190–220
PC	270–320

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Table 2

Mold temperatures of typical materials

Material	Mold temperature [°C]
HDPE	30–60
LDPE	20–60
PP	20–90
PA 6	40–100
ABS	50–80
PS	20–80
PMMA	30–80
PVC	20–70
PC	85–120

Table 3

Properties of Liten MB/ML 71 HDPE according to producer

Property	Value
Melt flow rate	8 g/10 min
Density	963 kg/m^3
Yield stress	25 MPa

2.2. Mold temperature

During production process, temperature of mold is stabilized on almost constant value. This value is in direct relation with coolant temperature and parameters (Table 2).

2.3. Coolant temperature

As coolant, in most cases it was used water supplied from an external cooling system. Sometimes air, oil or other materials are used.

2.3. Properties experimental material

As a reference material was used High-Density Polyethylene produced by Unipetrol with technical name Liten MB/ML 71 HDPE. It is a thermoplastic material with following properties.

According previous table (Table 3) is visible that temperatures for setting up molding machine are not provided by producers. In this case is necessary to use value from general range. For HDPE is injection temperature from 190°C to 240°C. Generally there is a problem with ranges in injection molding, because all parameter are not pre-determined accurately [1, 2, 3].

3. SIMULATION OF PARAMETERS VARIATON

Modern approach is in minimizing of delays in production process. For this it is suitable the usage of virtual simulation and testing [8].

3.1. Simulation using Moldex 3D

Moldex 3D is one of commonly used software for injection plastic simulation. It is based upon finite element method and has comprehensive library of materials, which is suitable for virtual testing.

First step is creating a model in CAD software Siemens NX 10. Testing model is visible on following picture. It is four pieces of shaft bearing´s halves. Visible are also runners and sprue (Fig. 1).

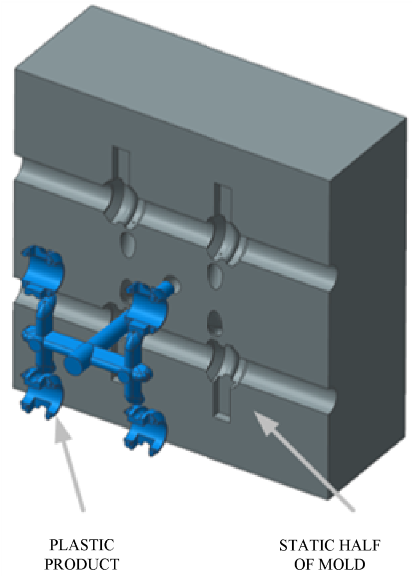


Fig. 1. 3D CAD model of plastic product and static half of mold.

Input factors were varied in range according to Table 4. For parameters, such as pressures or time were considered as default values. The first simulation was done with all default parameters. Then, for the following simulation, temperatures were varied from minimum to maximum with maintaining other parameters on default values.

By using this approach simulations are able to show how each change of temperature is influencing the whole process.

Problem is in material library in Moldex 3D, because available testing material Liten MB/ML 71 HDPE is not worldwide used and is not available in material library. It is necessary for validating simulations with experiment having the same material or material with corresponding properties.

Most suitable library materials are shown in Table 5. From these for simulations Lyondell Bassel Lupolen 5031 L HDPE was chosen.

Table 4

Input parameters for simulation

Factor	Units	Minimal value	Default value	Maximal value
Coolant temperature	°C	35	40	45
Injection temperature	°C	190	215	240
Mold temperature	°C	35	50	65
Injection pressure	MPa	-	85	-
Packing pressure	MPa	-	60	-
Packing time	sec	-	3	-
Cooling time	sec	-	10	-
Filling time	sec	-	0.5	-

Table 5

Available material models

Physical property	**Unipetrol Liten ML 71 HDPE**	**Chevron Phillips Marlex H516 HDPE**	**Lyondell Basell Lupolen 6031 M HDPE**	**Lyondell Basell Lupolen 5031 L HDPE**
Density [g/cm^3]	0.963	0.961	0.963	0.952
Melt Flow [g/10 min]	8.5	8.0	10.5	8.5
Yield stress [MPa]	25	25.5	31	26
Poisson ratio	0.40	0.38	0.40	0.40
Flexural modulus [GPa]	1.10	0.965	1.5	1

3.2. Injection temperature

The injection temperature was varied 25°C up and down from the reference value of 215°C. The injection temperature refers to the temperature of the material after the plasticizing stage.

Influence of injection temperature on filling stage. The temperature is influencing viscosity of the material. From that knowledge is possible to understand why there were short shots in the simulation with the minimum injection temperature (Fig. 2). As is visible in figure, the minimal injection temperature was unable to fill the cavities and left there 6.65% of empty volume. That characteristic also reflected in the melt front time that was longer when the melt was cooler.

The number of air traps cannot be consider for the minimum melt because of the short shot, that left a critical portion of the cavities without material.

The minimum melt temperature results caused also increasing in the number of weld lines. Weld line is the line formed by two different melt fronts joining together with sharp angle during the filling stage. It usually decreases the strength of the final product and produces optical visible defects. Maximal injection temperature (Fig. 3) also decreased the percentage of the part under high shear stress (>1MPa) [5, 6, 7].

Influence of injection temperature on packing stage. The short shot from the filling stage was almost completely filled in the packing stage. Only 0.0025% of the volume remained unfilled. It is also possible to notice in the following images that there is no visible unfilled volume, comparing to the filling phase, where the short shot was visible. That is how the ideal packing phase should work. During the filling stage, the cavities should be filled up to 90% to 99% and then, during the packing phase, also called second injection phase, the cavities should be completely filled.

The higher melt temperature leads to higher maximum average temperature during the cooling phase. The maximum cooling time needs to be increased by 13.5%.

The minimum melt temperature causes high values of volumetric shrinkage. Even being symmetrical, high values of shrinkage may lead to warpage after the part is ejected.

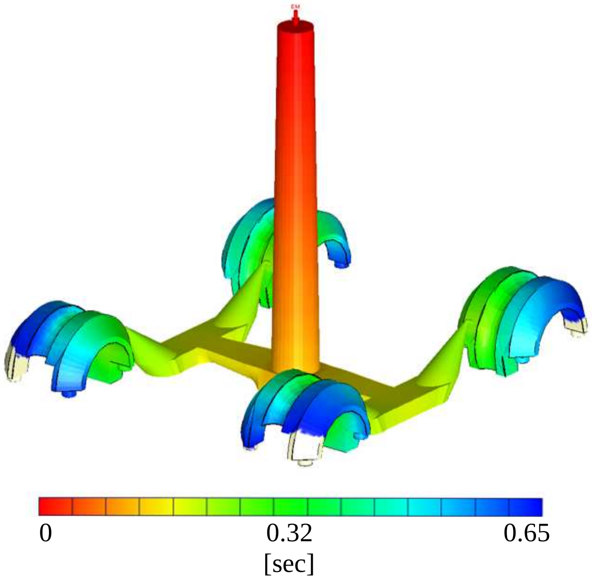


Fig. 2. Front filling time with minimal injection temperature.

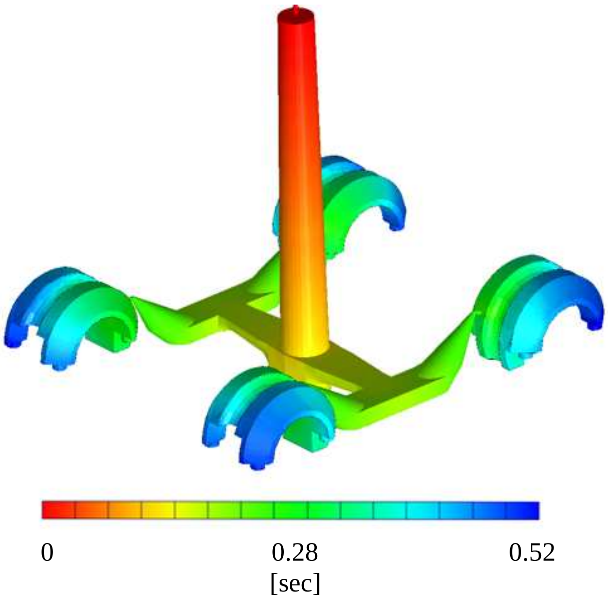


Fig. 3. Front filling time with maximal injection temperature.

3.3. Mold temperature

The mold temperature was varied from 35°C to 65°C and compared to the reference simulation, which mold temperature was 50°C. The mold temperature refers to the temperature of the cavity that is filled during the injection phase.

Influence of mold temperature on filling stage. The melt front time increased with decreasing of the mold temperature due the effect of temperature on the material viscosity. There were no significant variations in the number of air traps and weld lines. There was a substantial increase in the percentage of the part under high shear stress (>1MPa) in the simulation with lower mold temperature (Fig. 4). When the mold is cooler, the material near the mold's wall freezes and it causes increasing of the shear rate.

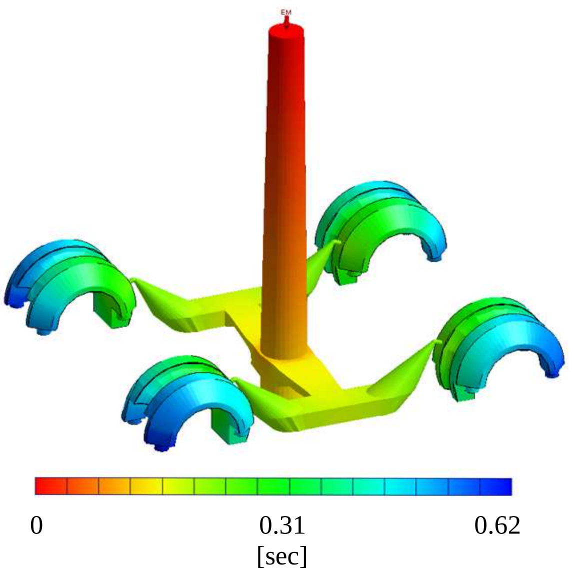


Fig. 4. Filling Melt Front time with minimal mold temperature.

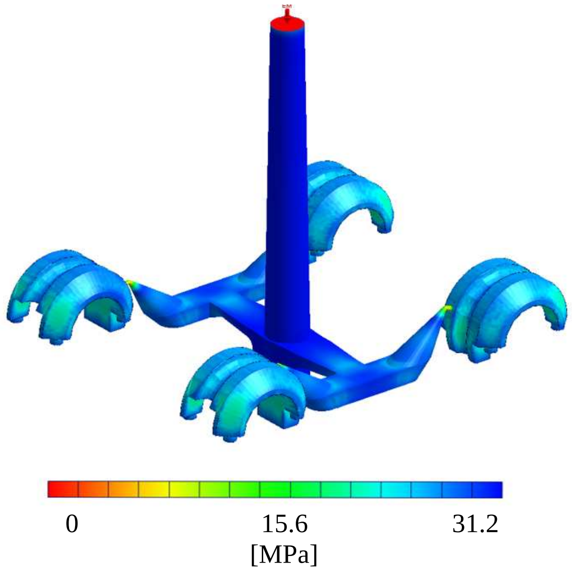


Fig. 6. Packing shear stress with minimal coolant temperature.

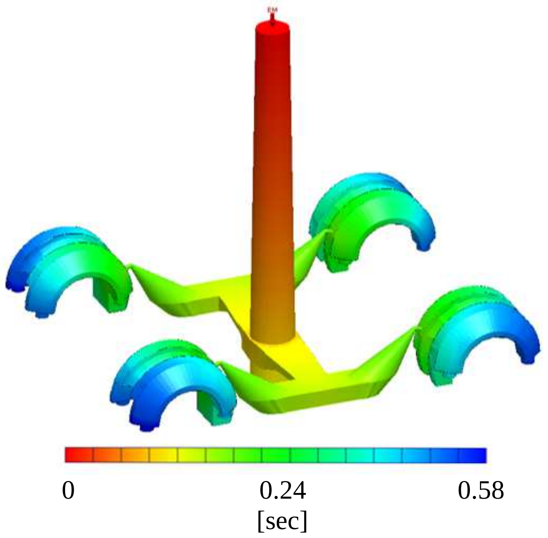


Fig. 5. Filling Melt Front time with maximal mold temperature.

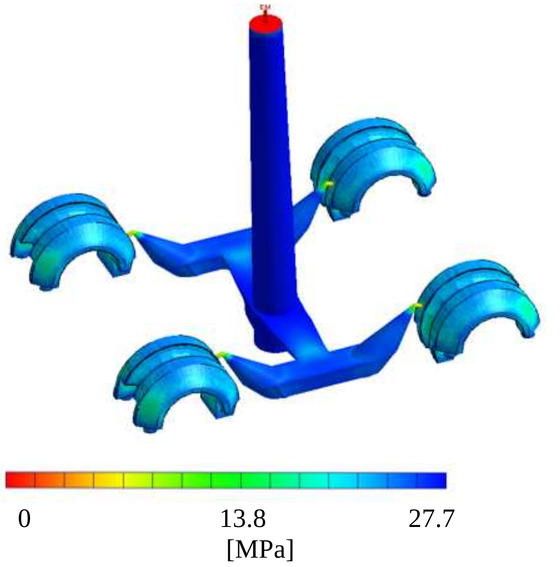


Fig. 7. Packing shear stress with maximal coolant temperature.

Influence of mold temperature on packing stage. During the packing analysis, no significant variation of the parameters was noticed. The region under high shear stress after packing slightly decreased with the increase of the mold temperature. The opposite also happened, with the decrease of mold temperature, the shear stress increased (Fig. 5). The cooling time increased with the rise of mold temperature.

3.4. Coolant temperature

Coolant temperature is the temperature of the coolant liquid that pass through the cooling channels inside the mold. It can be seen in the following images. The minimum coolant temperature applied at the simulation was 35°C (Fig. 6), the maximum was 45°C (Fig. 7) and the reference value was 40°C [9, 10].

Influence of coolant temperature on filling stage. The melt front time that shows the position of the melt front with respect to time during the filling stage, has decreased with the increase of the coolant temperature.

The volumetric percentage of the part under high shear stress (<1MPa) during the filling stage is increased significantly with decreasing of the coolant temperature.

There were no short shots, in other words, the mold’s cavities were completely filled. There were air traps, but in the same number as in default simulation, so no influence was noticed. The number of weld lines from both simulations with the coolant temperature variation is at same level with default simulation [4].

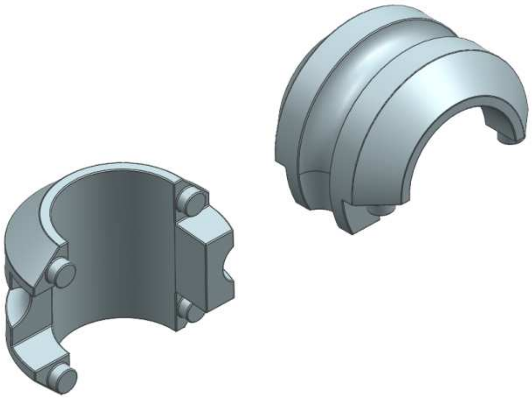
Influence of coolant temperature on packing stage. There were no alterations in the size of short shots (it was already zero in the filling phase), number of air traps and weld lines. The percentage of the part under high shear stress (>1MPa) followed the filling results. It hase increased with the decrease of the coolant temperature.

4. EXPERIMENT

For validating of virtual simulation experimental injection molding (Fig. 8) with default parameters mentioned above was performed. The result (produced part) (Fig. 9,*b*) is than compared with virtual result from CAE simulation (Fig. 9,*a*) [11, 12, 13].

There are not significant differences in both parts. In real experiment there are no short shots and optical properties are at suitable level. According to warpage measurement both products are comparable and virtual simulation gives us correct results.

Fig. 8. Experimental injection molding device.



a

b

Fig. 9. Part: *a* – CAD virtual products; *b* – real final product from experiment.

5. CONCLUSIONS

The *coolant temperature* has a small/none influence in the process parameters and in the final product at the analyzed interval of temperature variation. The part percentage under high shear stress (>1MPa) increased substantially during the filling phase, but it came back to the expected values in the packing phase, similar to the reference value.

There were no significant alterations in comparison with the reference simulation in the analyzed data.

The *injection temperature* has important influence on the process and on the final product. High injection temperatures present lower viscosity, representing better flow characteristics, as seen in the filling melt front time: it was smaller for higher melt temperatures.

However, the injection temperature increase may lead to lower density of the final part, as showed, which result in worse impact resistance as well as higher energy consumption in molding and longer cycle time. High melt temperature also can lead to polymer degradation and burn problems.

Low melt temperatures influences material flow, resulting in short shots and weld lines. To work with lower temperatures, higher pressure is necessary so the friction heating, as a result of shear stress, helps the flow decreasing the viscosity of the melt.

The optimum temperature must be found to ensure process and product quality. The combination of low melt temperature with high mold temperature is suggested as an efficient alternative to parameters set up.

The *mold temperature* influences in the shear stress, decreasing the shear stress values with the rise of mold temperature. It also influences in the cooling time, hence the cycle time. No further parameters variations were noticed by results interpretation.

However, the mold temperature has a determinant role in the microstructure of the final product. In amorphous polymers such as ABS and polycarbonate, higher mold temperatures produce lower levels of molded-in stress and consequently better impact resistance, stress-crack resistance, and fatigue performance.

In semi-crystalline materials the mold temperature is an important factor in determining the degree of crystallinity in the polymer. The degree of crystallinity governs many performance parameters, including creep resistance, fatigue resistance, wear resistance, and dimensional stability at elevated temperatures.

Crystals can only form at temperatures below the melting point but above the glass-transition temperature (Tg) of the polymer. As mentioned, the combination of low melt temperature with high mold temperature is suggested as an efficient alternative to parameters set up.

This study involved analyzing of the parameters influence on the final product using computer aided tools and consisted of two parts:

- Variation of each one parameter at time and conduct computer simulations to investigate the influence at the part and other process conditions.
- Applying the primary results to suggest an optimized set of process parameters to implement in a real injection process. These two results (simulation and real

Table 6

Input parameters for simulation

Factor	min	ref	max	Main influence on part	Influence on process
Coolant Temp	30	40	45	-Shear Stress -Volumetric Shrinkage	-Cycle Time
Melt Temp	190	215	240	-Shear Stress -Volumetric Shrinkage -Density -Weld Lines	-Cycle Time -Melt Front Time -Air Traps
Mold Temp	35	50	65	-Shear Stress -Structure	-Cycle Time

experiment) were compared with and validated simulation procedure.

Summary of all results is in Table 6.

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REFERENCES

[1] Sepe, M., *The Importance of Melt and Mold Temperature*, Plastics Technology, December 2011.

[2] Bozzelli, J., *Injection Molding: Understanding Pressure Loss in Injection Molding*, Plastic Technology, December 2010.

[3] Bozzelli, J., *Injection Molding: How to Set Second-Stage (Pack and Hold) Pressure*, Plastic Technology, February 2011.

[4] Miller, M., *Avoiding and Solving Injection Molding Problems Using Shear Rate Calculations-Part 1*, Plastics Today, February 2007.

[5] Bozzelli, J., *What to Do About Weak Weld Lines*, Plastics Technology, April 2008.

[6] Bozzelli, J., *Injection Molding: Develop Guidelines-Not Strict Procedures-For a Robust Molding Process*, Plastics Technology, December 2015.

[7] Routsis, A., *Troubleshooting: Injection Molding Seven Steps Toward Scientific Troubleshooting*, Plastics Technology, December 2010.

[8] Zhou, H., *Computer Modeling For Injection Molding*. 2013: A John Wiley & Sons, Inc., Publication.

[9] Salimi, A., et al., *Prediction of flow length in injection molding for engineering plastics by fuzzy logic under different processing conditions*. 2013.

[10] Tang, S.H., et al., *Design and thermal analysis of plastic injection mold*, Journal of Materials Processing Technology, 2006.

[11] Moayyedian, M., Abhary, K., Marian, R., *New Design Feature of Mold in Injection Molding For Scrap Reduction*, 2015.

[12] Zheng, R., Tanner, R., Fan, X., *Injection Molding: Integration of Theory and Modeling Methods*, Springer-Verlag, Berlin, 2011.

[13] Crawford, R. J., *Plastic Engineering*, Butterworth-Heinemann, Oxford, 2001.