OPTIMIZATION OF THE PLASTIC INJECTION PROCESS THROUGH THE MODIFICATION OF THE PROCESS FUNCTIONAL PARAMETERS

Teodor - Daniel Mîndru, Ciprian Dumitru Ciofu &' Dumitru Nedelcu

"Gheorghe Asachi" Technical University of Iasi, Faculty Machine Manufacturing and Industrial Management, e-mail: mindru.daniel@gmail.com

Abstract: The paper presents the optimization of the plastic injection process through the reduction of the cooling and removing times. For the deployment of the experiment the PA 6 polyamide will be used. The SolidWorks and Moldflow software packages will be used for CAD and process simulation, the material flow into the mold, as well. The experiment aims to obtain the optimal variant of PA 6 polyamide injection through the modification of the mold as well as the melt temperature in order for the mold filling to be complete and the cooling time to be as short as possible, therefore generating an increase of productivity.

Keywords: *cooling channel, flow, melt, mold, temperature*

1. Introduction

In order to plan a plastic injection process was taken into consideration that the most important technological parameter is the temperature of the mold. We may consider that the process develops under normal condition only the temperature of the mold is stationary and may be controlled.

Depending of the plastic materials used, the injection molds can be heated [1].

The plastic injection process is a cyclic one, formed by several operations such as:

- The gauging [2];
- The heating and the melting of the material in the machine cylinder;
- The mold clamping;
- The mold charge with under pressure material;
- The solidification and the cooling of the material;
- The opening of the mold;
- The removal of the injected piece from the mold.

This paper will study the injection operation as well as the charging and the cooling operations of the material from a mold through the optimization of the inlet temperatures of the injection process.

Cooling of the injected piece from the maximum value of the temperature to the room temperature value is an operation determined by the thermal conductibility of the plastic material.

After the mold is opened, the cooling operation continues. In plastic injection cycle, the cooling times are the longest, getting up to 68% of the total period of the process [2].

The injection technology aims to obtaining the shortest cooling time possible that assures the prescribed quality of the piece.

The figure 1 presents the temperature variation inside a plastic component during the cooling operation.

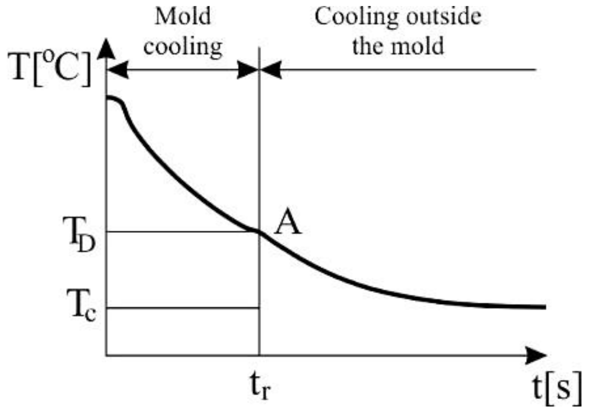


Figure 1. *Temperature variation inside a plastic piece during cooling operation; T_c – environmental temperature, T_D – mold release temperature; T_r – cooling temperature.[2]*

As a result of the analysis of figure 1, we may express the calculus formula of the total time of the injection process as:

$$t_t = t_u + t_r + t_d \qquad (1)$$

Take into consideration the relation (2):

$$t_u << t_r + t_d \qquad (2)$$

$$t_d = K \qquad (3)$$

and replacing relations (2) and (3) into relation (1), this one may be written as:

$$t_t = t_r + K \qquad (4)$$

t_t - Cycle time

t_u - Injection time

t_r - Cooling time

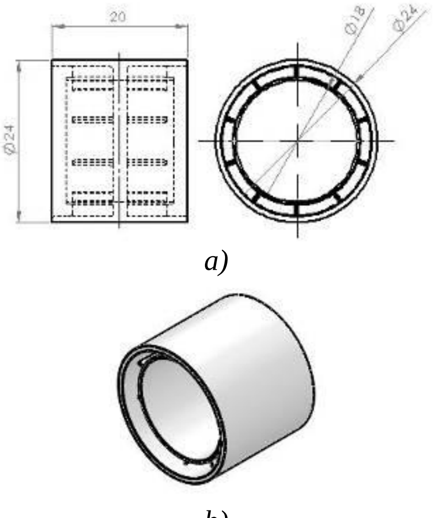
t_d - Time Cleaners

K - Constant

2. Simulation process, results and discussions

The cooling system of the mold must be designed according to the overall dimensions of the injected parts or, as the current analyzed situation, when the injection is made in cavity distribution channels, thus obtaining six components, the cooling channels must cover the entire surface of the model.

The piece used for process optimizing is presented in figures 2a and 2b. The figures are realized using the SolidWorks software package.



a)

b)

Figure 2: *The bushing type piece drawing, a) 2D Model, b) 3D Model*

The six cavities along the distribution channels and their placement in the mold are represented in Figure 3.

It was considered the cold type of sprue. The initial parameters are as follow:

- Conical ledge: 23 mm;
- Inlet diameter: 5 mm;
- Outlet diameter: 9 mm;
- Semicircular runners type: 10 mm;
- Conicalgate: inlet diameter 5 mm. outlet diameter 3mm;
- Dimensions of mold active parts: 165x105x50mm;
- Used material for mold: P20.

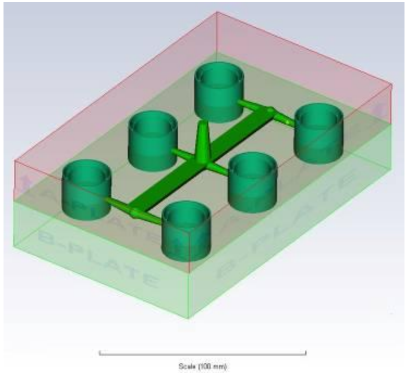


Figure 3: *The 3D general view fo injection mold*

The material used during the simulation is PA6 polyamide. In figure 4 it may be seen the variation of the viscosity depending on the working temperature. In figure 5 is presented the variation of the specific volume by temperature.

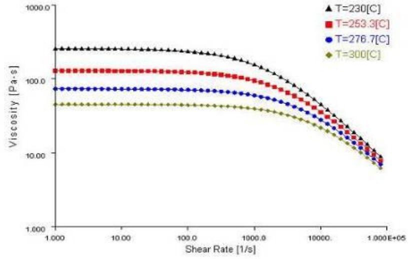


Figure 4: *The viscosity variation by temperature*

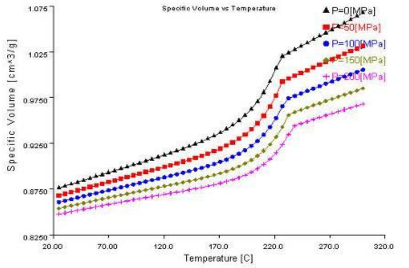


Figure 5: *The specific volume by temperature*

In order to obtain accurate components, special attention must be applied to the placement of the cooling channels in relation to the component, to the injection sites, the filling direction of the mold etc. For a better cooling there were realized several types of runners: with rectangular shaped section, square shaped section and triangular shaped section. As a result of the experiments, it was noticed that the most efficient runners are experimentally the square shaped ones and theoretically the rectangular ones, see figure 6, a and b. Constructively speaking, the easier to make are the circular ones, because they are just drilled, see figure 7 [2].

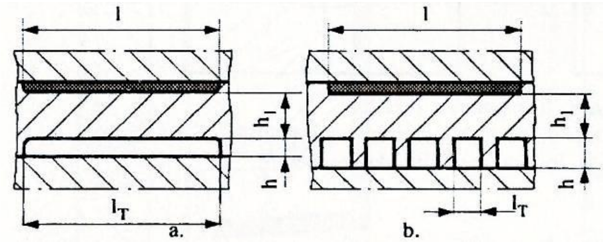


Figure 6: *Runners. a) Rectangular shaped runner; b) Square shaped runner.*

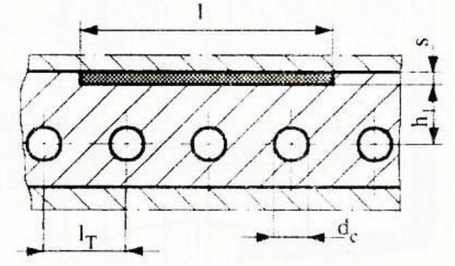


Figure 7: *Drilled runners*

The most often used cooling circuit is made out of straight runners. The connections between the runners are made with the help of supplementary runners, applied to the mold plates. The role of the runners in the injection process is to maintain the temperature of the mold plates at the established value, without considerable variations.

The injection process's inlet parameters are: mold temperature 70-110^{o}C, melted material temperature 230-300^{o}C and maximum injection pressure 180 MPa.

2.1 Process simulation

The analysis with Autodesk Moldflow of the injection process offers the possibility of visualizing the process evolution without being necessary to build the mold and to solve the eventual problems that can occur in the designing process of new parts [3].

Due to the fact that the simulation is made for an injection cycle, the experimental plan will not take into consideration the runners but only the temperature variation of the mold and of the melted material.

The mechanical properties of the material used for the simulation part are presented in table 1. In table 2 are presented the process parameters recommended by the manufacturers [4].

Table 1 *The mechanical proprieties of the used plastic material*

Elastic modulus	2910 MPa
Poisson ratio	0.386
Shear modulus	1050

Table 2 *The process parameters*

Mold temperature range – minimum	70^{o}C
Mold temperature range – maximum	110^{o}C
Melt temperature range – minimum	230^{o}C
Melt temperature range – maximum	300^{o}C
Absolute maximum melt temperature	340^{o}C
Ejection temperature	133^{o}C
Maximum shear stress	0.31 MPa
Maximum shear rate	100000 1/s

Table 3 highlights the parameters of the simulation and the number of experience. As it may be noticed, during the first nine experiments the temperature of the melted material is constant and we varied the temperature of the mold. During the following 8 experiments the temperature of the mold is constant and we varied the temperature of the melted material 10^o like step adh 5^o for mold heating temperature.

Table 3 *Parameters and experiments number*

Exp. Nr.	Mold temp. [^{o}C]	Melt temp. [^{o}C]	Exp. Nr.	Mold temp. [^{o}C]	Melt temp. [^{o}C]
1	70	265	10	90	230
2	75	265	11	90	240
3	80	265	12	90	250
4	85	265	13	90	260
5	90	265	14	90	270
6	95	265	15	90	280
7	100	265	16	90	290
8	105	265	17	90	300
9	110	265			

The paper presents the highlights experiments from table 3

2.2 Results of the simulation

Following the simulation, we may analyze the result presented in tables 4, 5, 6, 7 and 8 as well as in the figures attached to each experiment.

Table 4 *The simulation results*

Experiment 1 – Figure 8,9,10	
Actual filling time	0.32 (s)
Actual injection pressure	28.440 (MPa)
Clamp force area	24.8234 (cm^2
Max. clamp force during filling	5.216 (ton)
Velocity/pressure switch-over at % volume	99.02 (%)
Velocity/pressure switch-over at time	0.31 (s)
Estimated cycle time	7.38 (s)
Total part weight	11.028 (g)
Shot volume	18.4877 (cm^3)
Cavity volume	11.8609 (cm^3)
Runner system volume	6.6268 (cm^3)

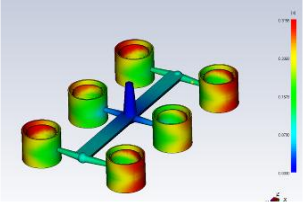


Figure 8: *The filling time distribution*

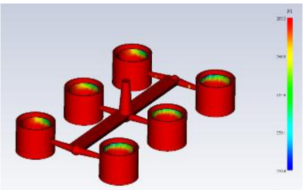


Figure 9: *The temperature at flow front*

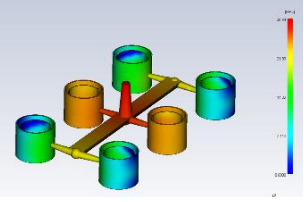


Figure 10: *The pressure at end of fill*

Table 5 *The simulation results*

Experiment 5 – Figure 11,12,13	
Actual filling time	0.31 (s)
Actual injection pressure	26.145 (MPa)
Clamp force area	24.8234 (cm^2
Max. clamp force during filling	4.862 (ton)
Velocity/pressure switch-over at % volume	99.11 (%)
Velocity/pressure switch-over at time	0.31 (s)
Estimated cycle time	8.37 (s)
Total part weight	10.947 (g)
Shot volume	18.4877 (cm^3)
Cavity volume	11.8609 (cm^3)
Runner system volume	6.6268 (cm^3)

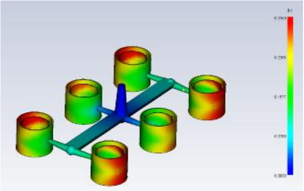


Figure 11: *The filling time distribution*

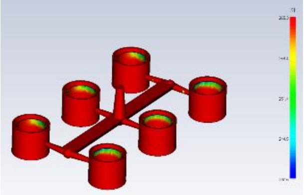


Figure 12: *The temperature at flow front*

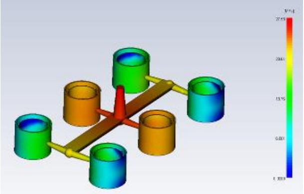


Figure 13: *The pressure at end of fill*

Table 6 *The simulation results*

Experiment 9 – Figure 14,15,16	
Actual filling time	0.32 (s)
Actual injection pressure	27.526 (MPa)
Clamp force area	24.8234 (cm^2
Max. clamp force during filling	5.130 (ton)
Velocity/pressure switch-over at % volume	99.11 (%)
Velocity/pressure switch-over at time	0.31 (s)
Estimated cycle time	7.36 (s)
Total part weight	10.989 (g)
Shot volume	18.4877 (cm^3)
Cavity volume	11.8609 (cm^3)
Runner system volume	6.6268 (cm^3)

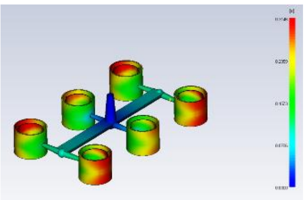


Figure 14: *The filling time distribution*

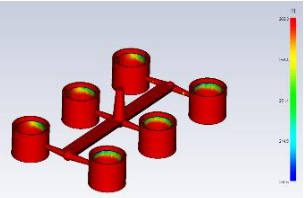


Figure 15: *The temperature at flow front*

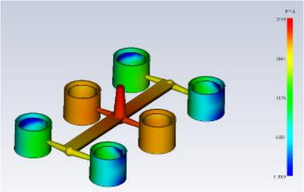


Figure 16: *The pressure at end of the*

Table 7 *The simulation results*

Experiment 10 – Figure 17,18,19	
Actual filling time	0.70 (s)
Actual injection pressure	111.486 (MPa)
Clamp force area	24.8234 (cm^2
Max. clamp force during filling	25.222 (ton)
Velocity/pressure switch-over at % volume	99.00 (%)
Velocity/pressure switch-over at time	0.64 (s)
Estimated cycle time	8.35 (s)
Total part weight	11.724 (g)
Shot volume	18.4877 (cm^3)
Cavity volume	11.8609 (cm^3)
Runner system volume	6.6268 (cm^3)

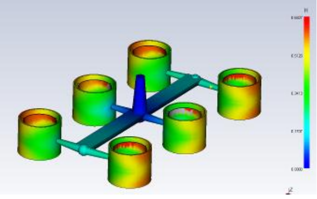


Figure 17: *The filling time distribution*

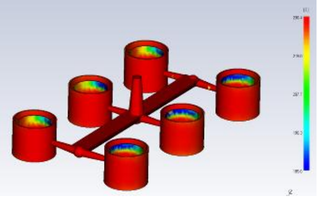


Figure 18: *The temperature at flow front*

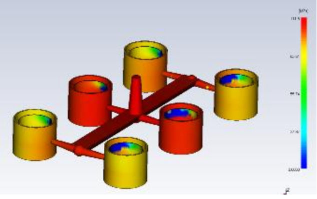


Figure 19: *The pressure at end of the fill*

Table 8 *The simulation results*

Experiment 17 – Figure 20,21,22	
Actual filling time	0.16 (s)
Actual injection pressure	23.683 (MPa)
Clamp force area	24.8234 (cm^2
Max. clamp force during filling	4.814 (ton)
Velocity/pressure switch-over at % volume	99.09 (%)
Velocity/pressure switch-over at time	0.16 (s)
Estimated cycle time	7.56 (s)
Total part weight	10.717 (g)
Shot volume	18.4877 (cm^3)
Cavity volume	11.8609 (cm^3)
Runner system volume	6.6268 (cm^3)

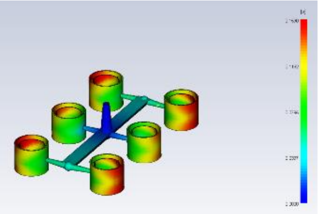


Figure 20*: The filling time distribution*

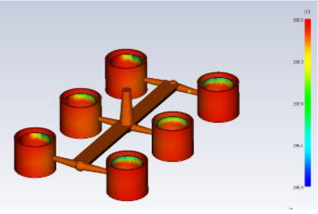


Figure 21: *The temperature at flow front*

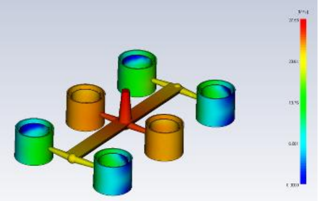


Figure 22: *The pressure at end of fill*

2.3 Discussions

As a result of the experiments we can draw graphics for the variation during the injection process. In the figure 23 is presented a graphic for the first 9 experiments, during which the temperature of the melt temperature is constant. The figure 24 presents the graphic display of the variation during the last 8 experiments, for which the temperature of the mold is constant.

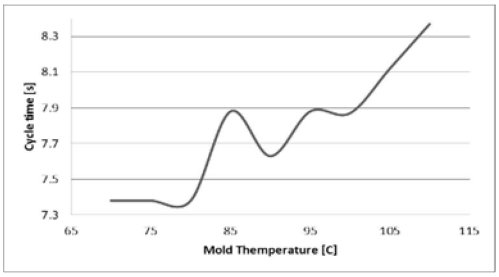


Figure 23: *The variation of the process time by the mold temperature.*

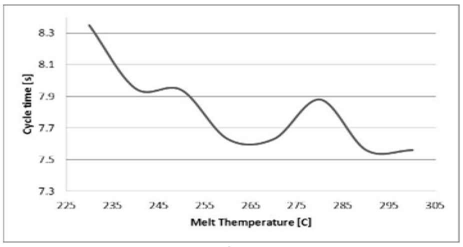


Figure 24: *The variation of the process time by the melt temperature.*

Analyzing these graphics we may observe that the optimal variant for designing the injection process is by setting the technological parameters to: melt material temperature, 265°C mold temperature, 90°C. The optimal values were used while performing five experiment. The values for all the inlet parameters of the process may be found in table 5. The simulation may be visualized in figures 11, 12 and 13.

If go back to Eq. 1, and set the experimental data into this formula, the cooling time for the injection process using PA 6 polyamide may be expressed as:

$$7.63 = 0.32 + t_r + t_d \qquad (5)$$

Applying Eq. 3, we obtain:

$$t_r = 7.31 - K \qquad (6)$$

Following there are several information resulted from the simulation of number 5 experiment during the multi-cavity injection process.

Figure 25 graphically presents the variation of the temperature during the injection process. The difference between the maximum value of the temperature and the minimum is 3,735 °C.

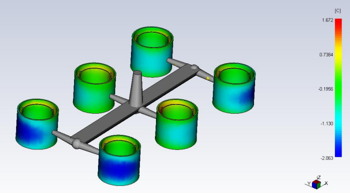


Figura 25: *The temperature variation*

Figure 26 presents the variation of the cooling time. The difference between the maximum and the minimum obtained values is 0,5337 s.

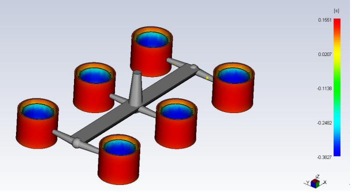


Figura 26: *The cooling time distribution*

During the simulation of the 10th and the 11th experiment appeared a production fault, named incomplete filling, presented in figure 27. As a result of these two experiments, we had wastage.

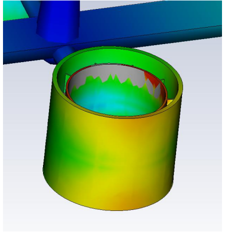


Figure 27: *The incomplete filling*

3 Conclusions

After the experimental research the main conclusions are as follow:

- The time of deployment for an injection process is increasing by maintaining constant the temperature of the melting material and the increase of the mold temperature;
- When the mold temperature is constant and the melting material temperature is increasing, the deployment time is decreasing;
- The injection time, as minimal value could be obtain using the overlap of figure 23 and 24 and thuts result the process parameters;
- The obtained results confirm that the injection pressure decreases by the increase of the injection time if the melted material temperature is constant. The value of the pressure in this case decreases from 28.440 MPa down to 26.145 MPa;
- If the mold temperature is constant, the injection pressure decreases by the melted material temperature from 111.486 MPa down to 23.683 MPa.

Acknowledgement

This paper was realised with the support of POSDRU CUANTUMDOC “DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH AND INOVATION” ID79407 project funded by the European Social Found and Romanian Government.

4 References

[1] Fetecău, C., *Injectarea materialelor plastice*, Bucharest, 2005, pp 127 - 156

[2] Şeres, I., 1996, *Injectarea materialelor termoplastice*, Imprimeria de Vest Publisher, Oradea (1996), pp 254 - 300

[3] Fetecau C., et all. *Overmolding injection molding simulation of tensile test specimen*, International Journal of Modern Manufacturing Technologies, Vol. II, No. 2/2010, Politehnium Publishing House, ISSN 2067-3604.

[4] *** Plastics Data Charts - www.plastemart.com Accesed: 23.12.2010