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The numeric modelling of the temperature profile of moulded piece in thermostatic mould form

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Methodology of research

ABSTRACT

Purpose: The project shows the results of researches of the flow of polymer materials during the filling the mould. The main purpose of carry out research was estimate the influence thermal conditions of the mould on the temperature profile of injection moulded parts.

Design/methodology/approach: The most important issues like injection moulding process and the conditions of this process are covered in article. Moreover, the computer system used in the process of material conversion like Cadmould-3D by SIMCON is analysed in this work.The simulation of the injection moulding process is done with the variety of different parameters of conversion. The aim of this simulation was to present the distribution of the temperature in the moulded piece. The cooling system of the injection moulding form was taken into analysis during this simulation.

Findings: The results of researches enabled documentation of specific occurrences in injectionmolding process of polymer materials and comparison of those results with the results of numericalcalculations.

Research limitations/implications: Research was limited to a three thermoplastics polymers. Carrying out of simulation of injection process require data input concerning geometrical parameters of moulded piece, conditions of injection process,properties of processed plastic and data referring to injection machine into calculating program.

Practical implications: The investigation delivered information about temperature profile of moulded piece in thermostatic mould form, what can be useful in practice, when selecting the material for good quality parts.

Originality/value: In result of carried out computer simulations, extensive research material was obtained, which was subjected into detailed analysis in order to its adequate interpretation.

Keywords: Computer assistance in the engineering tasks and scientific research; Engineering Polymers; Mold flow analysis; Image analysis

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1. Introduction

Increasingly, improving the process of processing , computer modeling is used - instead of producing several prototypes, simulations are carried out. There is the possibility to observe the behavior of the workpiece in a variety of preset conditions in the early stages of design, which ultimately reduces the entire cycle of producing molded parts to a minimum. These systems are generally called CAD / CAM / CAE (Computer Aided Design / Computer Aided Manufacturing / Computer Aided Engineering), and in the molding process they are becoming an integral part of it [1-19].

The aim of this study was to analyze the process of numerical heat transfer between the fiber mold and injection mold cavity in an injection molding process. To perform computer modeling process Cadmould - 3D program was used. Based on the entering input data and set parameters for three different thermoplastics such as polyamide, polypropylene, polycarbonate, computer simulations were carried out. Taking into consideration the results achieved it was assessed what the impact of set conditions was on the temperature distribution in fiber mold in the molding process by using a thermostated injection mold.

Depending on what the desired temperature of the form is as well as its regulations , final properties are formed whatever the used plastic. You should look for the optimum temperature to be able to avoid the formation of defects to allow the final product meet established requirements. For mass-produced parts, where the primary role is an economic factor as short as possible cooling times has been set , that is the low temperature form without the its adjustment. Mild heat dissipation, so a long cooling time is necessary when high dimensional accuracy and strength of each element is required. When dealing with fiber mold of uniform thickness of walls, the cooling channels should be placed in the same distance from the mold cavity. The situation is different when the molding is of different thickness - the thicker the wall is, the closer the cooling hole to the mold cavity. The stable temperature is needed to have a final detail of good quality. Liquidity depends on the plastic mold temperature. Injection to a cold form results in reaching rapid solidification of outer layer of the mold in case of cristal material. Intensive cooling makes at first liquid core become stable in a rapid way. Conducting such a process it is not possible to obtain a high degree of crystallinity of the material. This means that different shrinkage values and a significant weakening of the mechanical properties, as the author's thesis proves. [20-25]. Details, which produce amorphous materials are used (such as ABS, PC) need temperature control forms. This allows you to produce products of consistent quality and ultimately minimizes the number of deficiencies. Conducting the process of injection molding at a lower temperature causes : shorter cycle time, predominance of the amorphous phase over the crystalline structure in the mold , stress inside the material, high secondary shrinkage.

At higher temperature it is possible to achieve: better mechanical properties, high dimensional accuracy, increased participation of the crystalline phase. A greater degree of crystallinity affects [14,15,20-30]:

- increasing the resistance to the influence of solvents,
- tensile strength, ease to resist deformation (stiffness) is much better,
- the elongation at break is less as well as the toughness,
- reduction of the permeability of all gases.

Shrinkage of polymers with crystalline structure compared to amorphous polymers is much higher (range 1.5-2.5%), moreover, secondary shrinkage may reach about 1%, where in the case of amorphous materials there is none, while a processing one reaches only to 0.8%. Large volume loss in crystallization and solidification of the polymer material require a constant and high clamping pressure and the long patency of the gate, which should be as large as possible (0.5-0.75% wall thickness) [14,15,20-30]. Negligible impact on the cooling time is on the side of the temperature of injected material. Better flow of material leads to increasing the temperature and prolonging cooling time. A crucial impact has also the location of the cooling system. The calculation of temperature distribution are the basis for forecasting trends for the molding deformation and changes in mechanical and thermal properties [20-30] depending on the material used, process parameters and thermal conditions in the form.

2. Fundamentals and principles

Simulations of injection molding process were performed using a specialized program in the test version 4.0x Cadmould 3D-F. Cadmould program belongs to the group of programs called CAE (Computer Aided Engineering). Cadmould-3D, is a modular system which includes:

- preprocessor CADMESCH, creates the geometry of space-forming and the finite element mesh,
- simulation module of a form filling phase,
- post-processor responsible for processing the results and their graphical representation.

Preparation of the simulation leads to :

- creating a slot geometry, leading and cooling channels,
- choosing suitable plastics,
- determination of parameters for processing.

Simulation studies were carried out for the following materials:

- polyamide - PA 6 Akulon F223-D (DSM),
- polypropylene - PP ADSTIF HA740N (BASEL),
- polycarbonate - PC APEC 1600 (BAYER).

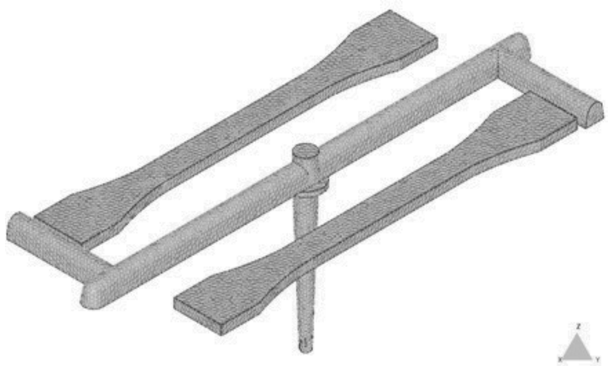

Fig. 1. Model of the molding and pouring system of the finite element net superimposed

To conduct the research both crystal structure (polyamide and polypropylene), and amorphous structure (polycarbonate) materials were used. The model used was a standard sample molding for tensile strength tests. The model constructed on the basis of technical documentation of the form, using STL program as well as gating system has been imported into Cadmould (Fig. 1), which generated MES NET consisting of 454324 tetrahedral elements. The volume used was 30,644.1 mm^3.

The model takes into account the complete infusion system, a point injection and cooling system. The analysis included simulations in which a variable parameters were: the mold temperature and the injection temperature. The values that have been introduced to the program are summarized in Table 1.

Table 1.
Mold temperature and injection temperature of the polymers investigated

		Material		
		PA6	PP	PC
Mold temperature [^{o}C]	min	60	20	85
	max	80	90	120
	optimal*	85	30	110
Injection temperature [^{o}C]	min	230	220	260
	max	290	270	320
	optimal*	260	240	330

* the optimal temperature given in the simulation program

Depending on the desired temperature of the mold the cooling time was varied. The various parameters shown in Table 2 were chosen taking into account the structure of the form.

Table 2.
Processing parameters of polymers investigated

		Mold temperature [^{o}C]	Time of the injection phase [s]	Cooling time [s]	Total time [s]
PA 6	opt.*	85	0.495	25	25.495
	min	60	0.495	25	25.495
	max	80	0.495	25	25.495
PP	opt.*	30	0.495	15	15.495
	min	20	0.495	10	10.495
	max	90	0.495	25	25.495
PC	opt.*	110	0.495	30	30.495
	min	85	0.495	25	25.495
	max	120	0.495	30	30.495

* the optimal temperature given in the simulation program

Other conditions which have been defined to form a cooling system in the simulation program in accordance with the design of the form are summarized in Table 3.

Table 3.
The process conditions

The intensity of flow in channels		450	[cm^3/s]
Material	Molding material	Akulon F223 - D; Adstif HA740N; Apec 1600	
	Cooling medium	Water	
	Material forms	Steel 1.2312	
Heat flow	Env. Temperature	20	[^{o}C]
	Heat conductivity of the surrounding area	10	[W/(m·K)]
Elements of the cooling system	The length of a single item	130.571	[mm]
	Number of items	14	
	Percentage distribution of elements in length*	7.143	[mm]
	Total length	1828	[mm]
Simulation	Maximum number of cycles**	20	
	Acceptable temperature difference ***	2.00	[^{o}C]

* Percentage distribution of the element length to the length of a single segment of the cooling channel
** The number of cycles, assumed in case of the form to be reached - so-called thermal stability for subsequent cycles form
*** Maximum temperature difference between the cyclic form in the state of its so-called thermal stabilization.

3. Results of investigation

Sample results of computer simulations of the temperature distribution after filling the mold cavity and the results of the analysis taking into account the effect of cooling temperature during the course of the molding cavity filling are summarized in Figures 2-11.

In the case of simulation of the injection molding of polyamide 6 the temperature after completing a molding cavity varies from 230°C to 232.5°C (Fig. 2). Analyzing the length of the polymer flow path a slight increase of temperature can be seen - 210 mm. Temperature distribution after filling the slot is similar in the case of increasing the mold temperature, while at the ends of the slot higher temperature is maintained at a slightly larger area. By increasing the injection temperature to 260°C at a lower temperature of the form, the temperature distribution is ranging from 260°C to 261.8°C, that proceeds in a similar way as in the case of lower temperature injection. In this case, an increase in mold temperature of 85°C change of temperature takes place, higher temperatures were recorded for the polymer flow path at about 252.5 mm.

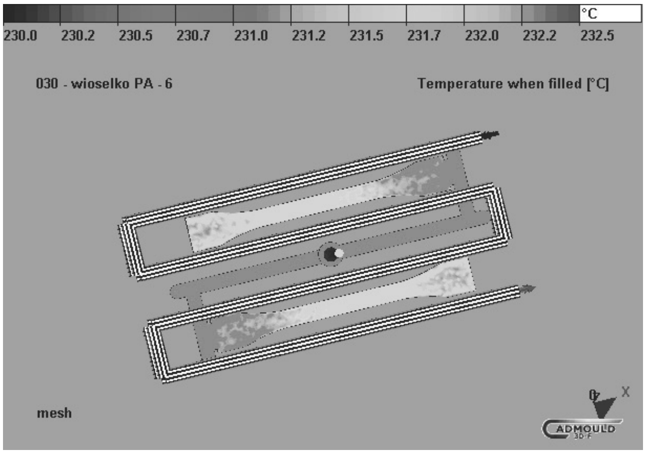

Fig. 2. Simulation results of temperature distribution at 230°C injection temperature and mold temperature of 80°C PA6

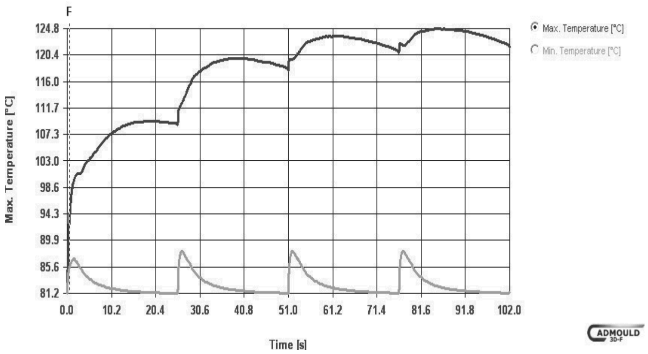

Fig. 3. Results of analysis taking into account the form of temperature stabilization effect of the cooling system at 230°C injection temperature and mold temperature of 80°C PA6

In case of polyamide 6 injection time and number of thermal cycles to stabilize the form was the same for all cases of change of temperature and temperature of processing forms.

In the case of polymers with high crystallization ability, high temperature form is not required. For polypropylene significant changes in the temperature distribution by increasing the temperature of the injection molding process were recorded. Temperature distribution after filling the slot at a temperature of 220°C injection ranges from 219.5 to 220.9°C (Fig. 4). The temperature change is visible at the end of the forming slot - for about 280 mm of a flow path.

Increasing the temperature of the injection process the reduction of the temperature gradient has been seen, maximum temperature is maintained longer in about 3 / 4 cavity mold. Increase of a mold temperature slightly affects the temperature distribution.

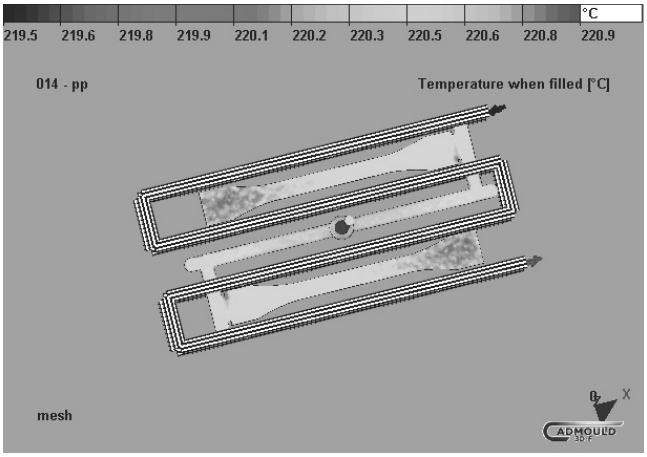

Fig. 4. Simulation results of temperature distribution at 220°C at the injection temperature and mold temperature of 20°C PP

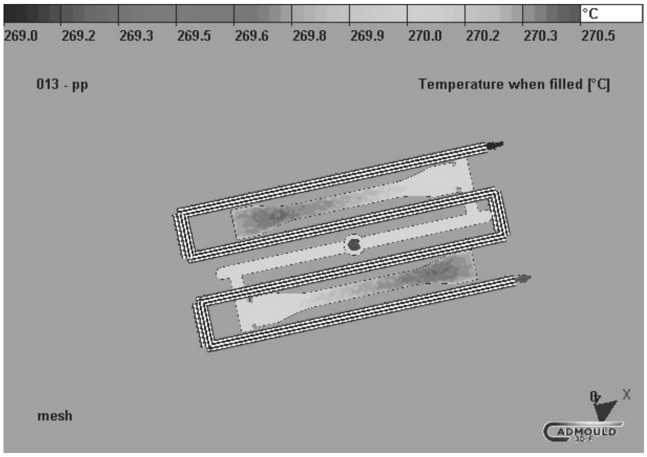

Fig. 5. Simulation results of temperature distribution at 270°C at the injection temperature and mold temperature of 20°C PP

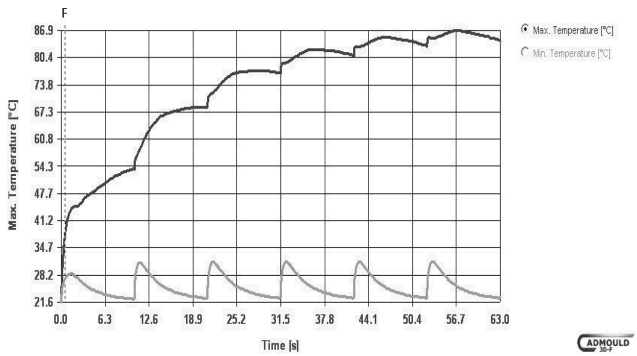

Fig. 6. Results of temperature stabilization analysis taking into account the cooling system effect at 220°C injection temperature and mold temperature of 20°C PP

Thermal Stabilization of the mold takes place after 6 and 7 cycles and it is dependent on the injection temperature and mold temperature (Figures 6,7). At higher temperature of a form the cycle time is extended, but the number of cycles needed for stabilization is reduced to 4, at mold temperature of 90°C.

In case of amorphous polymers the amount of heat lost on cooling is much smaller compared to the amount of exhaust heat in crystalline polymers. For the polycarbonate, while maintaining constant temperature of injection and increasing the mold temperature, the temperature gradient increases. At a lower temperature of injection, lower temperature values of the mold gating were recorded. (Fig. 8).

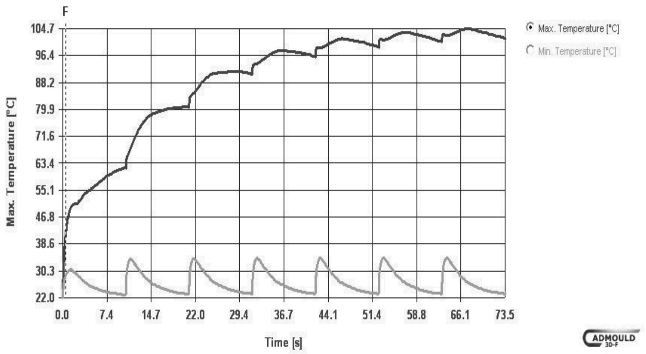

Fig. 7. Results of temperature stabilization analysis taking into account the effect of the cooling system at 270°C injection temperature and mold temperature of 20°C PP

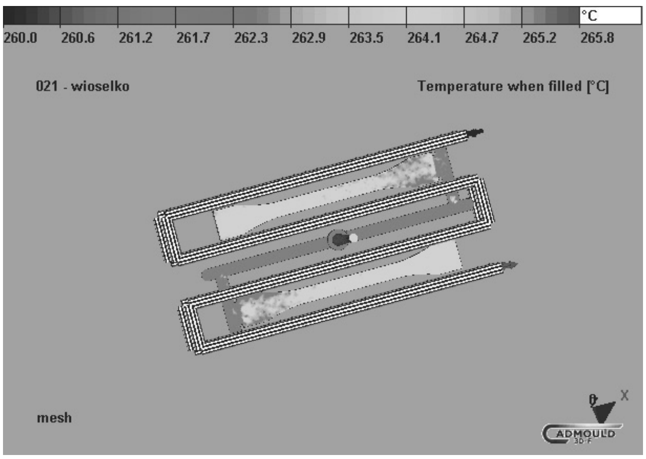

Fig. 8. Simulation results of temperature distribution at 260°C injection temperature and mold temperature of 85°C PC

4. Discussion and conclusions

Conducting computer simulations allowed us to analyze the temperature distribution of a mold in thermostated molding injection slot in case of injection molding process with varying temperature and the temperature of injection mold based on the design and material and temperature control conditions.

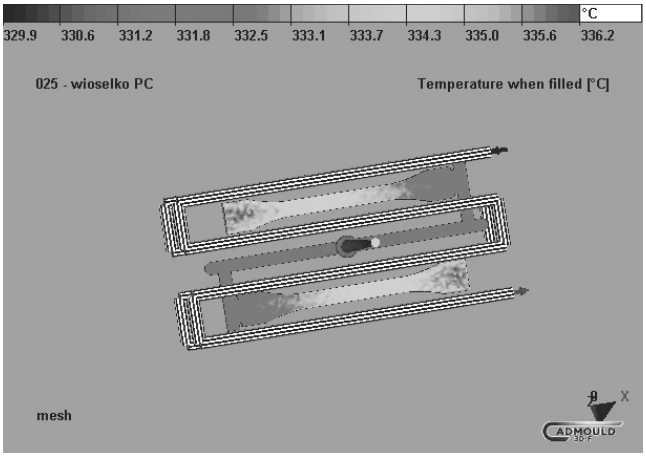

Fig. 9. Simulation results of temperature distribution at 330°C injection temperature and mold temperature of 120°C PC

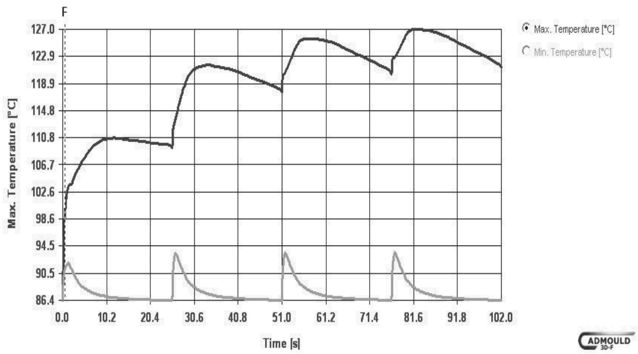

Fig. 10. Results of temperature stabilization analysis taking into account the effect of the cooling system at 260°C injection temperature and mold temperature of 85°C PC

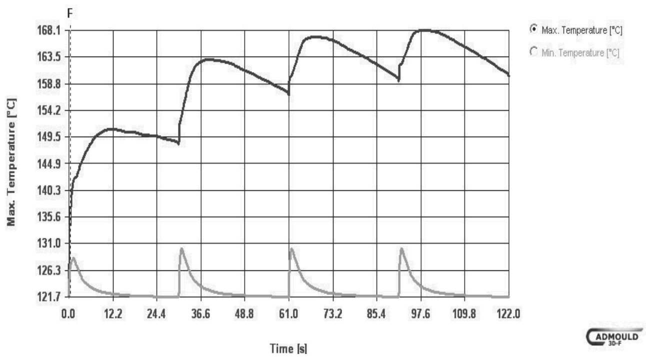

Fig. 11. Results of temperature stabilization analysis taking into account the effect of the cooling system at 260°C injection temperature and mold temperature of 85°C PC

This is important as far as the characteristics of compacts dependant on processing conditions, as well as in selecting optimal parameters of the process temperature, to obtain products that meet specific quality requirements. Simulation programs reflect the actual situation. A At the design stage, they allow to optimize the process, eliminate many errors in the design and implement new production. The conducted simulations of the injection molding PA6, PP and PC, in which the mold temperature and the injection temperature were used as variable parameters, allow to reach the following conclusions:

For PA 6:

- Maintaining the injection temperature and increasing the mold temperature, the temperature distribution does not change, it is maintained at the same level.
- The higher the temperature of the injection, the smaller distribution observed.
- In each case the results of simulation obtained, the location and intensity of the color assigned to a given temperature on the scale is preserved, with minor modifications. Little change of temperature were registered.
- When filling out the mold form with the material, thermal stability is reached at the same time.
- Regardless of changes in value in each case of a change in process temperature and mold temperature in the fourth cycle, the process will be stabilized.

For PP:

- Increasing the injection temperature at low form temperatures a smaller range of temperature gradient was registered. Appropriately increasing the temperature of the mold, earlier temperature gradient changes from the side of the gating system are visible.
- After completing the molding cavity, temperature gradient is recorded in the small range 1.4°C ±0.1.
- The maximum temperature during mold filling are reached at different times, in contrast to the PA 6.
- Number of cycles, after which the process is stabilized varies from 4 to 6 for PA6 for injection molding temperature of PP at 220°C and 240°C, while at 270°C to 7.

For PC:

- Maintaining a constant temperature of the injection while increasing form temperature, the temperature gradient increases.
- In case of the injection temperature of 320°C and 330°C the material after completing the molding cavity behaves similarly, different situation is observed in case of temperature of 260°C - maximum temperature gradient is visible only for the moving parts of the mold.
- The injection temperature of 320°C and 330°C, four cycles are needed to make the process be stabilized. At the lowest temperature of 260°C, three cycles are needed.

In any case:

- The temperature distribution is symmetric and for the PC takes the highest values.
- The lowest temperature was recorded at the gating system.
- The highest temperature were recorded at the end of the molding cavity.

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