Study of the Cooling Time for the Injection of the Plastic Materials

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The cooling time of the plastic materials obtained through injection represents a very important component of the total duration of the injection cycle. Due to this fact, the specialized literature mentions a large number of theoretical and experimental researches which make reference to the importance of the cooling speed for the economy of the injection process. This paper presents a comparative study regarding the application of more mathematical models that may permit the determination of the cooling time for a complex material obtained through injection within a mono cavity mould.

Keywords: cooling time, injection moulding, plastic materials

The productivity of the injection machine and the economical efficiency of the whole assembly is essentially determined by the plasticization-injection capacity of the plastic material and the total length of the operations carried out within the mould. These operations are to be found, at different weights, for the value of the parameter named *the duration of the total injection cycle within the mould.*

The length of the total injection cycle is formed by the technological processes duration related to the production of a final piece . The place of each operation in the total value of the injection cycle can be see in figure 1 [1]. It can be observed that the cooling time is the most important component of the injection cycle. The cooling time of the injected pieces is annalitically determined, in the hypothesis of cooling on both sides of a flat plate having a constant thickness without convection, in the mould cavity and with the negligence of the marginal effects.

The cooling time is influenced by the form, dimmensions and material of the piece being injected, but also by the temperature of the mould. This is one of the most important technological parameters that influences the quality of the plastic material injected pieces. The injection process can be carried out within optimal conditions provided that the temperature of the mould is stationary and controlled. This implies the existence of a network through which there might circulate a heating-cooling medium intended the adjustment of the mould temperature.

Due to the fact that within the injected mould there are plastic materials processed at different temperatures, their flow depends on the mould temperature. In some cases, depending on the nature of the processed plastic material, the mould to be injected has to be heated using oil as heating medium, which circulation in heated condition is realised by the aid of a mobile assembly equipped with a temperature heating and adjustment system.

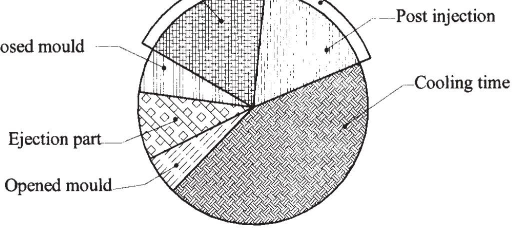

Fig. 1. The place of eatch operation in the total value bz the injection czclecycle by injection (100%) in the case of PP

The heating of the moulds is used relatively rarey, only for the injection of certain plastic materials types and usually only at the beginning of the injection process, up to the working conditions temperatures. On the other hand, the corresponding cooling of the injected moulds should be provided in all the cases in order to reduce the duration of the injection cycle and to obtain some pieces injected with minimum contractions. In order to carry out the process correctly, the temperature of the injected mould should be correlated with a series of other factors, for example: the type of the injection system, the injection pressure, the injection tmperature, the injection network section etc. The complexity of the injection process and the great number of the variable factors do not permit the operation of exact calculations for the dimension of the cooling system of the mould to be injected.

Out of the factors influencing the injection process, the mould temperature is one of the most important. The mould temperature should follow two main requirements:

- injection cycles having a duration as reduced as possible, as a result of the heat fast ejection out of the mould;
- the quality of the piece injected as a function of the temperature value of the mould and the uniformity of the temperature distribution.

Theoretical analysis

The cooling speed of the fixed points obtained through injection within the mould has a determinant role in establishing the total length of the injection cycle and implicitly the productivity of the process.

Within the injected piece, as well as within the mould, could appear the complex heating transfer processes described by complex differential equations. There are special softs that use advanced numerical techniques to solve these equations.

There are still necessary more precise and faster methods that analysing the heating transfer phenomena within the injected piece, could allow the estimation of the cooling time.

The specialized literature presents different theoretical models to establish cooling time of the polymer melt during the injection within the mould.

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Ballman and Shusman [2, 3] present the following relation for the cooling time calculation

$$t = \frac{s^2}{2\pi\alpha} \cdot \ln\left[\frac{\pi}{4}\left(\frac{\theta_i - \theta_w}{\theta_e - \theta_w}\right)\right], \qquad (1)$$

where:

t is the cooling time, in [s];

s – the maximum cavity thickness, in [mm];

α – the diffusivity coefficient, in [mm^2 · s];

θ_i – the melt temperature at injection, in [^{o} C];

θ_w – the mould temperature, in [^{o} C];

θ_e – the ejection temperature [^{o} C].

Busch, Field si Rosato [2, 3] have proposed a model in order to estimate the cooling time, also considering the part weight

$$t = 1{,}35 \cdot \frac{s^2}{2\pi\alpha} \cdot \ln\left[\frac{8}{\pi^2}\left(\frac{\theta_i - \theta_w}{\theta_e - \theta_w}\right)\right] + 0{,}0151 \cdot w_p \cdot N_{cav} + 8{,}87, \qquad (2)$$

where:

w_p is the part weight;

N_{cav} - the number of cavities of the mould.

Yu and Sundelard [2, 5] have established a calculation relation of the cooling time and the ejection temperature, by using a combination of experimental, analytical and statistic methods:

$$\theta_e^* = a_1 + a_2 \cdot \alpha + a_3 \cdot \theta_i + a_4 \cdot \theta_w; \qquad (3)$$

$$t = b_1 + b_2 \cdot \frac{s^2}{\pi\alpha} \cdot \ln\frac{\pi \cdot \theta_e^*}{4} + b_3 \cdot \ln\theta_e^*; \qquad (4)$$

where:

−1 a, b are constants that depend on the material;

θ_e* - the dimentionless ejection temperature, calculated with the expression

$$\theta_e^* = \frac{\theta_i - \theta_w}{\theta_e - \theta_w}. \qquad (5)$$

The equations (2) and (3) are characteristic for each plastic materia. For the amorphous materials with low thermic diffusivity, the amorpheous materials with high termic difussivity the crystalline and semicristalline materials can be used separate regression equations.

In the relations 1, 2, and 4, the diffusivity coefficient α is considered to be constant. Due to the fact that the diffusivity is a time function, for the cooling time calculation, it is also recommended [6-8] to use an average value also called effective of the diffusivity, α_{eff}

$$t = \frac{s^2}{\pi^2 \cdot \alpha_{eff}} \cdot \ln\left[\frac{4}{\pi^2}\left(\frac{\theta_i - \theta_w}{\theta_e - \theta_w}\right)\right]. \qquad (6)$$

In the case of the semi-crystalline polymers, the cooling time is calculated with the relation [2]

$$t = \frac{s^2}{\pi^2 \cdot \alpha_{eff}} \cdot \ln\left[\frac{8}{\pi^2}\left(\frac{\theta_i - \theta_w}{\theta_e - \theta_w}\right)\right]. \qquad (7)$$

For the thin walls pieces, Berlot [2, 6] proposes the following simplified equation

$$t = k \cdot s^2, \qquad (8)$$

where:

k is a proportion constant depending on the cooling system quality of the mould, in [s/mm^2];

s – the thickness of the piece in [mm].

Liang [2] considers that a unidimensional model is precise enough to estimate the cooling time

The distribution of the temperature in the piece is described by the equations of the thermic diffusivity

$$\frac{\partial\theta}{\partial t} = \alpha_{eff} \cdot \frac{\partial^2\theta}{\partial x^2}, \qquad (9)$$

where x is the coordinate of the piece thickness (fig. 2)

The outline conditions and the initial conditions lead to

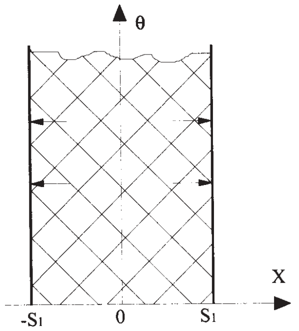

Fig. 2. Scheme of the heat transfer in the injected piece [2]

$$\begin{cases} \theta\big|_{x=s_1} = \theta_w; \\ \dfrac{\partial\theta}{\partial x}\Big|_{x=0} = 0; \\ \theta\big|_{t=0} = \theta_i \theta\big|_{t=0} = \theta. \end{cases} \qquad (10)$$

Liang [2], using the separation method of the variables of the model expressed by the relation (10), has obtained a solution in the form of the infinite series that lead to the calculation equation of the cooling time

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$$t = \frac{4 \cdot s_1^{\,2}}{\alpha_{eff}} \cdot \ln\left[\frac{2\sqrt{2}}{\pi}\left(\frac{\theta_i - \theta_w}{\theta_e - \theta_w}\right)\right]. \qquad (11)$$

Experimental part

We intended to make a comparative study regarding the application of more mathematical models (relation 6, 7, 11) that could allow the determination of the cooling time for a complex fixed part obtained through injection in a mono cavity mould.

There has been analysed the “flow condition modification piece” (fig. 3a)a component the structure of a water purification filter using finite element method (fig 3.b). The piece is fited within a water purification filter and helps to obtain an uniform jet at the ejection of this one. The fragmentation of the fluid mass through the lateral wing uniforms the flow direction within the filter towards the final part. The pressure losses within do not increase through this local fragmentation of the fluid mass.

The analysed piece is made up of PP type J-500 and s =2.75 mm (fig. 4).

The parameters of the process are:

θ_i = 250°C;
θ_w = 30°C;
θ_e= (85; 90; 95; 100)°C;
α_{eff}= 0.065.

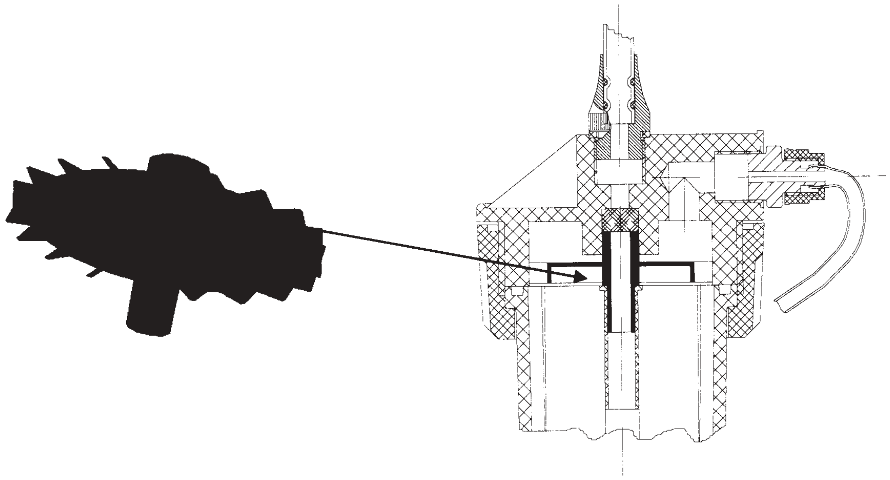

Fig. 3a. The analysed piece with fusion type elements; b. partial section within the water purification filter

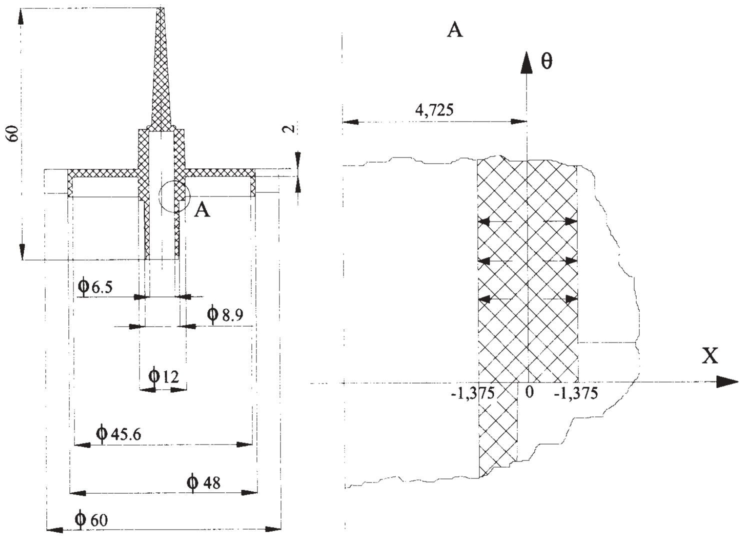

Fig. 4. Scheme of the heating transfer in the "Flow condition modification piece"

Table 1

THE VALUES OF THE COOLING TIME FOR THE PIECE ANALYSED USING DIFFERENT MATHEMATICAL MODELS

θ_e [°C]	t [s]		
	Ec. (6)	Ec. (7)	Ec. (11)
85	25	19,67	20,9
90	23,41	18,10	19,33
95	22,02	16,71	17,94
100	20,78	15,47	16,70

There have been determined the cooling time values for different ejection temperatures using the models described by the equations (6), (7) and (11). The obtained results have been centralized in table 1.

Conclusions

It can be observed that in all the analysed cases, after the calculations using different mathematical models, once the parameter increases, the cooling time decreases . The diminution of the cooling time leads to the decreases of the total decreases of the injection cycle and implicitly determines the increase of the productivity.

The parameter has a superior limit due to the fact that the ejection temperature of a piece in the mould should ensure the maintenance of the physical and geometrical properties of the injected piece after its cooling and until it reaches the temperature of the environment.

The cooling times calculated with the relations (6) and (11) are higher than the ones calculated with the equation (7) because, in the first two cases the temperature in the median plan has to be equal with the moulding temperature, while in the third case, there has been considered a medium temperature of the analysed fixed part section.

The values of the cooling time calculated with the relations (6) and (11) are closer to the recommendations made as a result of the experimental studies[9], respectively t = (20 ÷ 90) s .

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