Some Aspects Regarding the Simulation of Two-Component Injection Process

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Two-component injection process has multiple uses from the manufacture of household products to manufacture of high precision parts for industry specific computer and automotive industry. Given the importance the paper presents two-component injection process simulation using plastic material and PPG40 Moldflow software. To realize the simulation it was used a research plan by Taguchi with six input parameters, each parameter with two levels, such as nozzle shape, melt temperature, mold temperature, injection time, injection pressure and accuracy imposed. The main results obtained from simulation show the variation of the mold filling time depending on the injection pressure, temperature distribution on the entire volume variation part and solidification time in matrix material.

Keywords:injection, nozzle, temperature, accuracy, simulation

Two-component injection process has many applications, such as the automotive industry in various parts of computers, household, aircraft industry, drums, and decorative parts.

Two-component injection piece can be achieved by [9]:

-Injection of the same material with different colors;

-Injection of different materials compatible or incompatible.

To do this type of injection process were created special machine tools, two-cylinder injection and integrated transport system. Using materials with different characteristics lead to new technological opportunities. The combination of hard materials and soft materials result in new products such as sealing rings of polyamide reinforced with glass fiber. For these types of machine tools, it is necessary that parameters such as temperature, injection pressure, injection speed to be independently adjustable for each injection unit separately.

Two-component injection can be done as follows:

-using special machines with horizontal two-cylinder injection and integrated transport system;

-color injection and one horizontal one vertical cylinder;

-mixed-injection, the cylinders are horizontal and parallel.

Precision injection enforces compulsory conditions regarding the adjustment of processing parameters in a certain order and rigorous control of processing conditions. Plasticization is due to heat transfer from the cylinder wall machine in the plastic material and heat of friction within the material. This heat transfer makes the granules in the molten material.

Plasticization is significantly influenced by the cooling time, which if is it reduced leads to low temperatures of plastic material and if it is increased leads to a large variation of plastic material temperature [2].

If the plastic material temperature is higher both the fluidity and mould speed fill are increasing, the injection time is also reduced [9].

Mold temperature has a critical role in cooling-solidification phase of the play. During the injection process is developed a set of forces that exert pressure on the plastic material. Pressure snail carries molten plastic material in the room cylinder car, the nozzle and the mold channels until its matrix is to be field.

The cooling process requires a relatively large network cooling channels, given the conductivity of thermoplastic materials. Productivity growth requires measures to reduce cooling time.

The final step consists of cooling the mold opening simultaneously with the beginning of the training process.

Mathematical Model

The injection molding process can be broken into three phases: filling, packing phase, and cooling phases, respectively. The process of filling a mold cavity with a polymer melt is complex. During the filling phase, plastic is pushed into the cavity until the cavity is just filled.

A mathematical representation of the mold filling phase requires solution of the equations governing the conservation of mass and momentum along with constitutive equations that describe the behaviour of polymer melt through its shear viscosity.

Fluid flow in injection molding is assumed to behave as Generalised Newtonian Fluid. The melt is a non-Newtonian fluid experiencing a phase change with its physical and transport properties changing with location in the cavity, temperature, and time.

The non-isothermal flow motion is mathematically described by the following equations [10]:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho u) + \nabla \cdot (\rho \mathbf{u} u - \sigma) = \rho g \qquad (2)$$

$$\sigma = -pI + \eta(\nabla u + \nabla u^T) \qquad (3)$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + u \cdot \nabla T \right) = \nabla(k \nabla T) + \eta \dot{\gamma}^2 \qquad (4)$$

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where:

u is the velocity vector,

T - the temperature;

t - the time,;

p - the pressure;

σ - the total stress tensor;

C_p - the specific heat, and γ is the shear rate.

In this paper, in order to describe the viscosity of the polymer melt, the Cross-WLF viscosity mode is employed [11]

$$\eta = \frac{\eta_0}{1+\left(\frac{\eta_0 \dot{\gamma}}{\tau^*}\right)^{1-n}} \tag{5}$$

with

$$\eta_0 = D_1 \exp\left[\frac{-A_1+(T-T^*)}{A_2+(T-T^*)}\right] \tag{6}$$

where:

n is the power law index,

η_0 -the zero shear viscosity,

τ^* is related to the relaxation time of the material and represents the parameter that describes the transition region between zero shear rate and the power law region of the viscosity curve, D_1, A_1 and A_2 are data-fitted coefficients.

The packing phase begins after the cavity has just filled. This involves the further application of pressure to the material in an attempt to pack more material into the cavity in order to produce uniform shrinkage at reduced levels and consequently reduce component warpage [11].

If one region of a part is less densely packed than an adjacent region, then polymer will flow into the less dense region until equilibrium is reached. This flow will be affected by the compressibility and thermal expansion of the melt in a similar way to which the flow is affected by these factors in the filling stage.

The modified Tait equation is used to describe the material PVT characteristics and to provide the necessary information (density variations with pressure and temperature, compressibility and thermal expansion data) so that when combined with the material viscosity data accurate simulation of the material flow during the packing phase is possible [9, 11]:

$$V(P,T) = V(0,T)\left[1 - C \cdot \ln\left(1+\frac{P}{B(T)}\right)\right] + V_t(P,T) \tag{7}$$

$$T > T_t,\ V_0(T) = b_{1m} + b_{2m}(T - B_5) \tag{8}$$

then

$$B(T) = b_{3m}\exp(-b_{4m}T), \tag{9}$$

$$V_t(P,T) = 0. \tag{10}$$

If

$$T < T_t,\ V_0(T) = b_{1s} + b_{2s}(T - B_5) \tag{11}$$

then

$$B(T) = b_{3s}\exp(-b_{4s}T), \tag{12}$$

$$V_t(P,T) = b_7\exp(b_8 T - b_9 p) \tag{13}$$

where:

T_t is the transition temperature,

b_1 to b_9 are the PVT model coefficients,

C=0.08494 is a universal constant.

Results and discussions

General simulation methodology used followed the steps from [7]. Originality is the Taguchi method to develop a strategy, thus resulting in a sufficient standard practice today.

Determination of parameters presents three original aspects:

-reducing effects by leaving unchanged the causes cannot be reduced;

-main quality criterion of a process is its performance relative dispersion;

-Taguchi has developed a linear graphic representation of the damage factors in columns orthogonal arrangement.

The main advantages of Taguchi method are to achieve a real level of civil trials, reducing the number of research study may contain a large number of factors, the establishment of interactions between factors, yield results with high precision and no errors in interpretation of results, obtaining a mathematical model of the system studied.

Acquisition of new knowledge to improve product quality and processes is based on a gradual process, often based on experimentation.

Plan of experience is a method of optimizing the process of acquiring knowledge interesting and Taguchi's intervention obviously simplifies the procedure for the development of a fractional plan. Proceed Taguchi was designed to improve the performance of a process under the influence of various factors.

Easy to be studied is another proposed model [7], matrix model system consisting of "and" factors: F_1, F_2 ... F_i each factor having some levels:

$$\begin{aligned}
Z_t = M &+ \left\lfloor E_{F_1^1} E_{F_1^2} \ldots E_{F_1^{n_1}} \right\rfloor \cdot [F_1] + \left\lfloor E_{F_2^1} E_{F_2^2} \ldots E_{F_2^{n_2}} \right\rfloor \cdot [F_2] + \ldots + \left\lfloor E_{F_i^1} E_{F_i^2} \ldots E_{F_i^{n_i}} \right\rfloor \cdot [F_i] + \\
&+^t [F_1] \cdot \begin{vmatrix} I_{F_1^1 F_2^1} & I_{F_1^1 F_2^2} & \ldots & I_{F_1^1 F_2^{n2}} \\ I_{F_1^2 F_2^1} & I_{F_1^2 F_2^2} & \ldots & I_{F_1^2 F_2^{n2}} \\ \ldots & \ldots & \ldots & \ldots \\ I_{F_1^{n1} F_2^1} & I_{F_1^{n1} F_2^2} & \ldots & I_{F_1^{n1} F_2^{n2}} \end{vmatrix} \cdot [F_2] +^t [F_1] \begin{vmatrix} I_{F_1^1 F_3^1} & I_{F_1^1 F_3^2} & \ldots & I_{F_1^1 F_3^{n3}} \\ I_{F_1^2 F_3^1} & I_{F_1^2 F_3^2} & \ldots & I_{F_1^2 F_i^{n3}} \\ \ldots & \ldots & \ldots & \ldots \\ I_{F_1^{n1} F_3^1} & I_{F_1^{n1} F_3^2} & \ldots & I_{F_1^{n1} F_i^{n3}} \end{vmatrix} \cdot [F_3] + \ldots \\
&\ldots +^t [F_1] \cdot \begin{vmatrix} I_{F_1^1 F_i^1} & I_{F_1^1 F_i^2} & \ldots & I_{F_1^1 F_i^{n_i}} \\ I_{F_1^2 F_i^1} & I_{F_1^2 F_i^2} & \ldots & I_{F_1^2 F_i^{n_i}} \\ \ldots & \ldots & \ldots & \ldots \\ I_{F_1^{n1} F_i^1} & I_{F_1^{n1} F_i^2} & \ldots & I_{F_1^{n1} F_i^{n_i}} \end{vmatrix} \cdot [F_i] + \ldots +^t [F_{i-1}] \cdot \begin{vmatrix} I_{F_{i-1}^1 F_i^1} & I_{F_{i-1}^1 F_i^2} & \ldots & I_{F_{i-1}^1 F_i^{n_i}} \\ I_{F_{i-1}^2 F_i^1} & I_{F_{i-1}^2 F_i^2} & \ldots & I_{F_{i-1}^2 F_i^{n_i}} \\ \ldots & \ldots & \ldots & \ldots \\ I_{F_{i-1}^{n_i-1} F_i^1} & I_{F_{i-1}^{n_i-1} F_i^2} & \ldots & I_{F_{i-1}^{n_i-1} F_i^{n_i}} \end{vmatrix} \cdot [F_i]
\end{aligned} \tag{14}$$

where:

Z_t is the theoretical response of the system;

M - the overall mean responses and is calculated as the ratio of the sum values and number of experiments conducted responses;

$[F_i]$ - a vector indicating the factor F_i is a column matrix with elements equal to zero less than one 1 and is in "i" corresponding to the factor considered;

E_{Fi} - is the effect of environmental factor response system be located at j, and is calculated by subtracting the average response system overall average M;

$\left\lfloor I_{F_i^j F_k^t} \right\rfloor$ - the interactions between factors F_i and F_k and calculated by subtracting the average response system (the factors F_i are at j level and the factors F_k are at t level) the overall average (M)- $E_{F_i^j}$.

It will apply using Taguchi's matrix modeling and model writing by Viger and Sisson. It will seek to determine the coefficients of a model type

$$Z_t = M + N_s + T_m + T_M + T_i + P_i + P_{imp} + N_s \cdot T_m + \\ + N_s \cdot T_M + N_s \cdot T_i + N_s \cdot P_i + N_s \cdot P_{imp} + P_i \cdot T_i \qquad (15)$$

where:

(M) - the overall average;

(N_s) - nozzle shape;

$(T_m$, [°C]) - melting temperature of the material;

$(T_M$, [°C]) - mold temperature;

$(T_i$, [s]) - injection time;

$(P_i$, [MPa]) - injection pressure;

$(P_{imp}$, [mm]) - accuracy imposed.

Given that each input parameter is considered at two levels, so we have 6 . (2-1) = 6 degrees of freedom for the individual parameters and 6 . (2-1) . (2-1)=6 degrees of freedom for interactions between parameters. Number of degrees of freedom model is given by:

$$N_{n,m} = n_g l_n \cdot n_g l_m = (n_i v_n - 1)(n_i v_m - 1) \qquad (16)$$

hence the $n_g l_n$ and $n_g l_m$ are the number of degrees of freedom of factor n and m respectively, and $n_i \upsilon_n$ and $n_i \upsilon_m$ the number of their levels. So for the model, the number of degrees of freedom is the sum of degrees of freedom of the effects of input factors and interactions between them, plus a degree of freedom for the average effect of M, so: 1+6+6=13 degrees of freedom. Taguchi divides the input factors such table 1.

For the model above, dividing the groups is as follows (table 2).

Building a fractional level of variation in levels of input parameters (table 3) is not a simple problem.

To achieve the split experiment several conditions must be verified. A prerequisite to calculate the effects of one independent factor by others factors is the orthogonality condition. Two disjoint actions (which have not common factors) are orthogonal if every level of one, is associated with the same number of times in the experimental program. An experimental plane is orthogonal with respect to a model where all actions are disjoint orthogonal model

Table 1
GROUPS OF INPUT FACTORS [7]

I Group	II Group	III Group	IV Group
Very difficult modifiable factors	Hardly modifiable factors	Factors slightly modified	Factors very slightly modified

Table 2
GROUPS OF MODEL INPUT FACTORS STUDIED

I Group	II Group	III Group	IV Group
--	---	N_s, P_{imp}	T_m, T_M, T_i, P_i

Table 3
LEVELS OF VARIATION OF INPUT PARAMETERS

Input Parameter / Levels	N_s	T_m [°C]	T_M [°C]	T_i [s]	P_i [MPa]	P_{imp} [mm]
First level	conical	230	60	1	100	0,1
Second level	cylindrical	280	80	0,5	500	0,2

Table 4
ORTHOGONALITY CONDITION

N_s 2	*											
T_m 2	2^2	*										
T_M 2	2^2	2^2	*									
T_i 2	2^2	2^2	2^2	*								
P_i 2	2^2	2^2	2^2	2^2	*							
P_{imp} 2	2^2	2^2	2^2	2^2	2^2	*						
N_sT_m 2^2	*	*	2^3	2^3	2^2	2^3	*					
N_sT_M 2^2	*	2^3	2^3	*	2^3	2^3	2^3	*				
N_sT_i 2^2	*	2^3	2^3	2^3	*	2^3	2^3	2^3	*			
N_sP_i 2^2	*	2^3	2^3	2^3	2^3	*	2^3	2^3	2^3	*		
N_sP_{imp} 2^2	2^3	2^3	2^3	*	*	2^3	2^3	2^3	2^3	2^3	*	
P_iT_i 2^2	2^3	2^3	2^3	*	2^3	*	*	*	*	*	*	*
	N_s 2	T_m 2	T_M 2	T_i 2	P_i 2	P_{imp} 2	N_sT_m 2^2	N_sT_M 2^2	N_sT_i 2^2	N_sP_i 2^2	N_sP_{imp} 2^2	P_iT_i 2^2

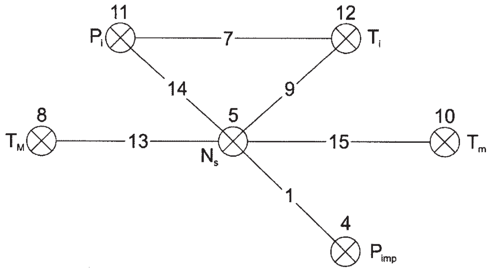


Fig. 1 The model graph

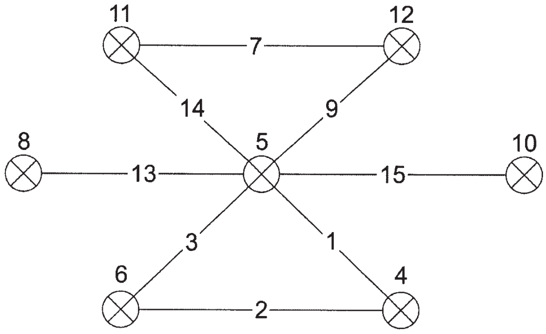


Fig. 2 Taguchi standard graph, [7]

Table 5
ASSIGN COLUMNS INDEPENDENT FACTORS

Factors Number of tests	N_s	T_m	T_M	T_i	P_i	P_{imp}
1	1	1	1	1	1	1
2	1	1	2	2	2	2
3	2	2	1	1	2	1
4	2	2	2	2	1	2
5	1	1	2	2	1	1
6	1	1	1	1	2	2
7	2	2	2	2	2	1
8	2	2	1	1	1	2
9	2	1	1	2	1	1
10	2	1	2	1	2	2
11	1	2	1	2	2	1
12	1	2	2	1	1	2
13	2	1	2	1	1	1
14	2	1	1	2	2	1
15	1	2	2	1	1	2
16	1	2	1	2	1	2

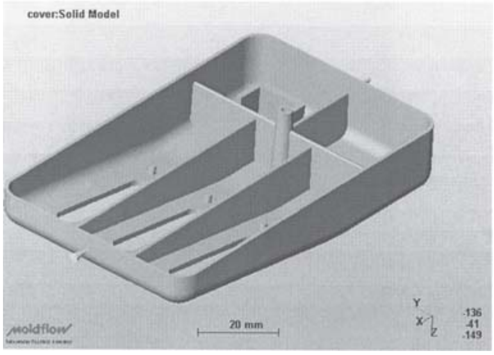


Fig. 3. The geometrical transposing of the physical model

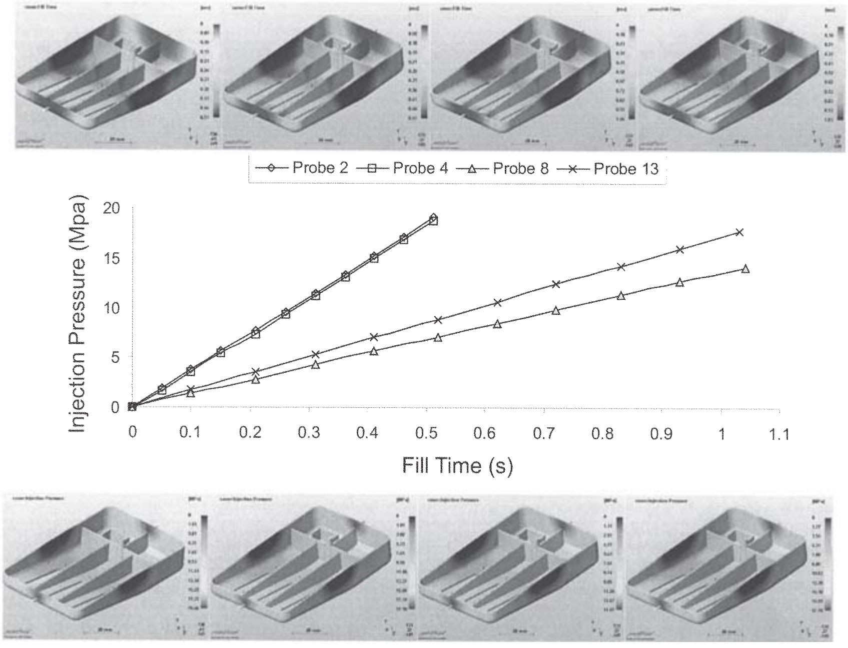


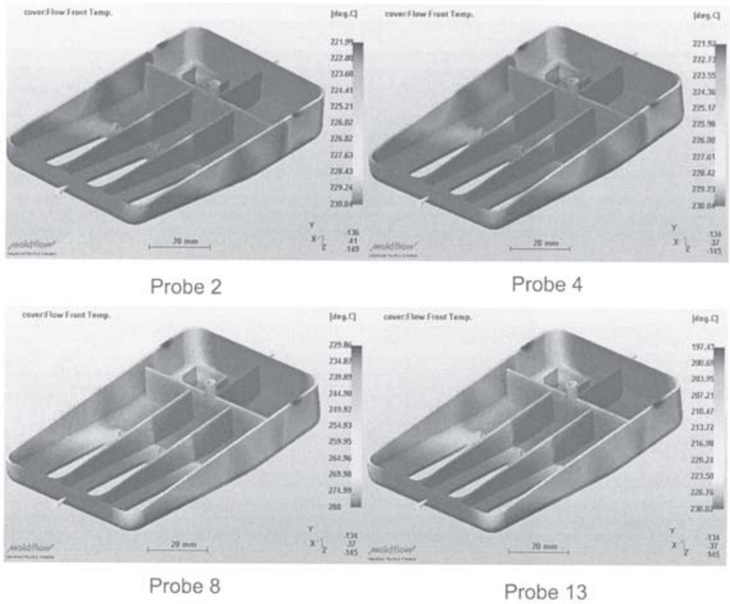
Fig. 4. The fill time variation based on injection pressure

in the experimental program. Checking the condition of orthogonality for table 4 was performed, resulting in its analysis that the smallest orthogonal program that could be done, is a plan that must also include experimental tests 8.

A second condition is to check the number of degrees of freedom. Number of degrees of freedom of a model showing the number of values must be calculated to know all the model coefficients. It should be done at least as many tests as the number of degrees of freedom in the model. As shown above, we have 13 degrees of freedom for the model, so the experimental program must have at least 13 attempts. Next is carried graph model presented in figure 1, which is compared with the standard presented by Taguchi (fig. 2), resulting in award columns independent factors (table 5).

Figure 3, presents implementation of the physical model and geometrical position of the injection nozzles.

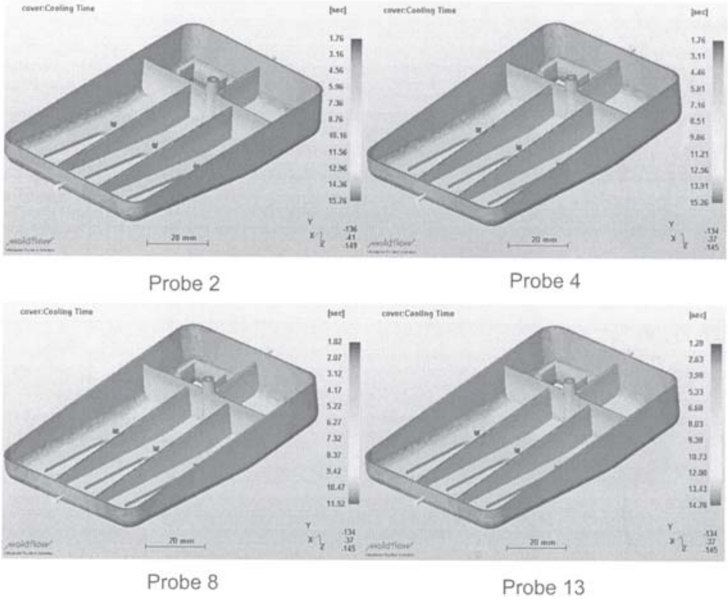
The injected part must be constructively transposed starting from the physical model. For numerical



Probe 2 Probe 4

Probe 8 Probe 13

Fig. 5. The flow front temperature



Probe 2 Probe 4

Probe 8 Probe 13

Fig. 6. The cooling time variation

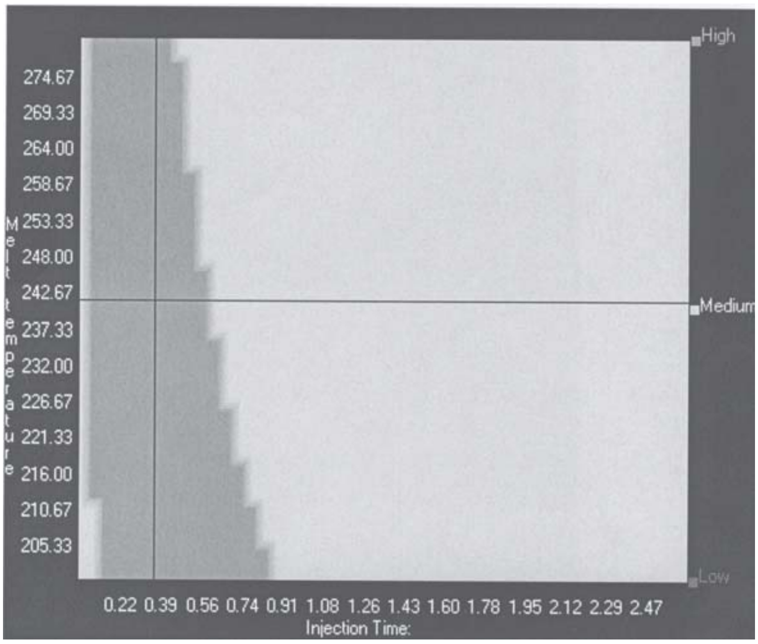


Fig. 7. Variation of the melting temperature for material PPG 40

representation of the injected part, the following problems must be solved: piece geometric analysis concerning the complexity and the optimal point between injection time and the melting temperature. The best results from Taguchi plan was for 2, 4, 8, 13 experimental simulation.

Figure 4 presented the variation of time depending on the filling pressure injection. It was used in polyamide plastic material PPG40, with the following properties: elastic modulus 7630.42MPa; Poison ratio 0.4387; shear modulus 1724.39MPa; melt density 1.2221g/mm^3; solid density 1,378g/mm^3; thermal conductivity 0.19 W/mK; specific heat 2230 J/KgK.

Figure 5 presents the flow front temperature and in figure 6 is presented the cooling time variation.

It is very important to know the range of melting temperature during the time of injection of material used PPG40. This variation is shown in figure 7.

Conclusions

The purpose of this simulation is to find out if we get a complex piece of precision with a plastic required in terms of change in input in the process of manufacture.

Following Taguchi plan with 16 experimental researches, each factor having two levels, the simulations are presented for only four representative experiments.

The main objective of the injection process is to obtain high precision parts and complete filling of the mold.

As it can be observed for high injection pressure the filling times for experiment 2 and 4 have very similar values while the simulations 8 and 13 for comparable pressures registering time filling with differentiated values.

Concluding, we can say that once the injection pressure increased we observed a significant decrease in injection time.

As it can be seen from figure 4, curves of sample 1 and sample 2 are very close. This is because, for these two samples the temperature was kept constant.

From the literature, in terms of material properties used, PPG40, we notice the following: to obtain a high quality piece must have curves of variation of time depending on the injection pressure in the area specified in figure 7.

Thus, for these simulations we choose the sample 2 and sample 4 as the optimum for obtaining the piece using the two-component injection.

For flow temperature variation are observed similar changes for test 2 and 4, respectively, 8 and 13 variations that are taken into account when filling the mold.

The variation of cooling time is similar for the four simulations, so that we can consider that each level of input parameters is best to get a piece of high quality and completely fill the mould.

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