Aspects Regarding the Use of FEM for Calculus at the Injection Moulding of a High Accuracy Part

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The paper presents the use of FEM (Finite Element Method) for calculus performing at the injection moulding of a high accuracy part made of plastic material type Polyacetal, referring at: pumping of the mould cavity, thermal resistance and mechanical strength. There are presented: diagrams of variation for the pumping full degree function of time at four temperatures of the mould, thermal representation of the part for the temperature of the mould at 80°C, the results obtained after the part's testing at drop-test, the results of static stress for the part made of injected plastic material.

Keywords: injection moulding, pumping, thermal resistance, mechanical strength

Injection moulding is a cyclic process based on several operations. The main steps to go through at the injection moulding for a high accuracy part are:

- feeding of machine with raw material (grain plastic material);
- heating and melting of the raw material in the machine cylinder;
- mould closing;
- the injection under pressure of the melted plastic material inside the mould;
- mould opening;
- part removal.

Precision injection imposes the compliance of some compulsory conditions regarding to the adjusting of processing parameters in a certain order and rigorous control of processing conditions.

The equation to describe the rheological behavior of plastic materials is the equation of Coulomb [6]

$$\tau_n = k + \sigma_n tg\phi \qquad (1)$$

where: τ_n is the unit tangential stress with influence upon the sliding of particles along a plane having the normal n; σ_n represents the unit normal stress of compression in the normal direction n; φ is the angle of internal friction with very small adherence.

For pumping the material, the worm executes an injection motion. The theoretical degree of the mould cavity filling can be determined with relation 2, [1].

$$V_i = \frac{\pi d^2 S_i}{4} \qquad (2)$$

where: d is the diameter of the worm and S_i represent the injection stroke length.

The real degree of the mould cavity filling is given by relation 3, [1]

$$V_r = f \cdot V_i \qquad (3)$$

where f is a correction factor depending on the abutment span and on the size of the injected products. The values of this coefficient are in the range (0.6-0.9), [6].

The theoretical flow rate of material in the feeding area can be calculated with relation (4), [2]:

$$Q_a = 0{,}5(k_G \cdot \rho_V)\cdot(E i_b D b_l h_l)\cdot \omega \qquad (4)$$

where: k_G is a flow rate factor, function of the coefficient of material sliding in relation to the worm surface and of the grains speed; $E = 1 - \frac{h_l}{D}$; D is the internal diameter of the cylinder; $b_l = \frac{\pi(D - h_l)\sin\phi}{i_b}$ represents the average width of the groove and i_b the number of creeper beginning.

The real flow rate of material in the feeding area can be determined with relation (5):

$$Q_{ar} = \frac{V}{S_d} = \frac{4V}{\pi d^2} \qquad (5)$$

where: V is the actual volume of plastic material injected for obtaining the part and d is the diameter of the injection nozzle.

The main process steps of the precision injection are plasticization, mould filling, compaction, cooling and de-moulding [3].

Plasticization takes place both due to the heat transfer from the machine cylinder wall towards the plastic material and due to the friction heat from the material inside. This heat transfer transforms the grains in melted material. Plasticization is significantly influenced by the cooling time which if it is reduced leads to the decreasing of the plastic material temperature and if it is increased leads to large variations of the plastic material temperature, in relation to the adjusted value.

Mould filling is the process step with an important role upon the accuracy of the injected part. This can influence both the temperature of the melted material and the macro-molecular structure of the part. By the mould filling, the pass of the plastic material from the stationing area of the injection machine towards the interior of the mould is provided.

Further on, the melted material must be compacted because the thermoplastic materials have a smaller specific volume at the processing temperature than at the

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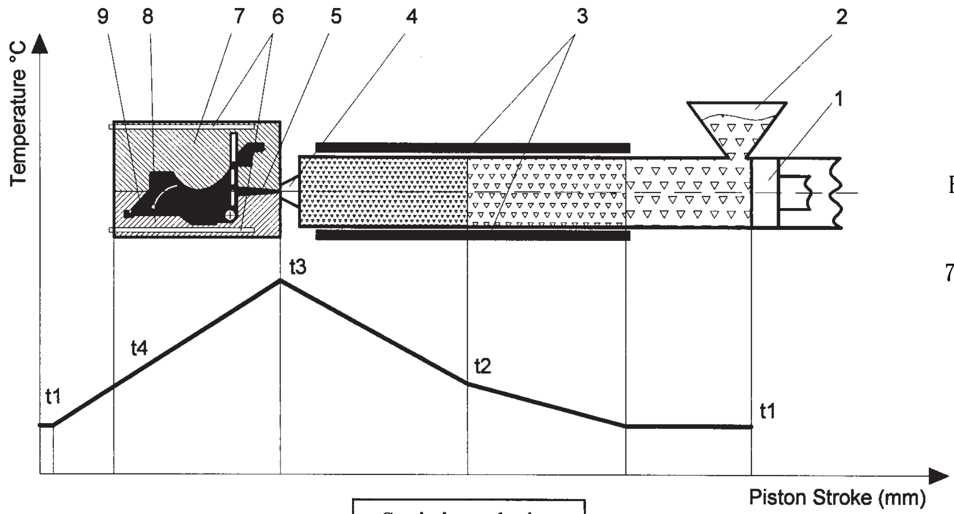

Fig.1. General scheme of injection areas: 1-piston, 2-vat, 3-heating resistances, 4-bean, 5-abutment, 6-cooling conduits, 7-superior part of mould, 8-inferior part of mould, 9-injected piece

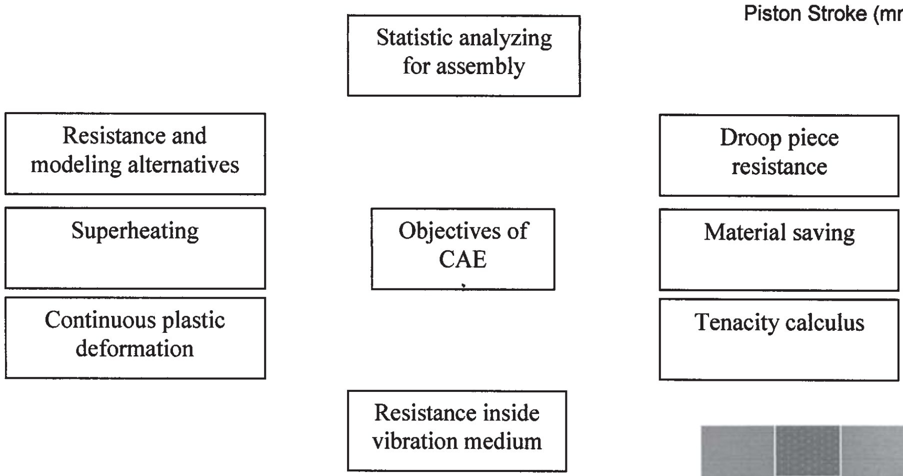

Fig. 2. Objectives of CAE

environmental temperature. So, compaction implies the introduction of a supplementary quantity of melted material in the mould cavity.

Cooling process needs a relative large time, considering the conductivity of the thermoplastic materials. So, the increase of productivity imposes adoption of measures to decrease cooling time.

Final step of the cooling consists in the starting of mould opening simultaneously with the beginning of the de-moulding process.

The general scheme of the injection zones with the temperature variation is presented in figure 1, where: t_1 initial and plasticizing zone, t_2 transition temperature from the solid phase to the melted one, t_3 temperature for the melted state of the plastic material and t_4 temperature of the part at mould opening.

In the Laboratory of Fine Mechanics and Nano-technologies, with certification SR EN ISO 9001: 2001 (certificate CertInd no. 1751C/2008) and re-certification ESYD-Greece (certificate no. 284/2008), from the Department of Machine Manufacturing Technology, Faculty of Machine Manufacturing and Industrial Management, Technical University "Gh. Asachi" of Iasi, there exist the injection moulding machine type SZ-600H.

In the research, the main modules CAD/CAE have been used as following: CAD-3D for the part realization; CAE used for simulation of the contractions and deformations using FEM.

The main objectives of the CAE system for realizing a part from plastic material are presented in figure 2.

In figure 3, the geometrical transposing of the physical model for the injected part is presented.

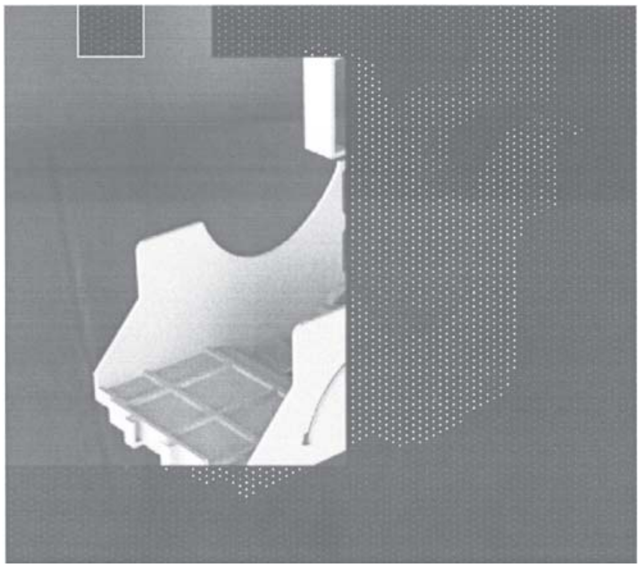

Fig. 3 Geometrical transposition of physical model

Results and discussions

Calculus for the injected part made of plastic material

The injected part must be constructively transposed starting from the physical model. For numerical representation of the injected part, the following problems must be solved: rheological representation, thermal representation and mechanical representation, using FEM from Cosmos software.

In figure 4, the variation of the filling degree function of time is presented. More exactly, this variation is presented for four temperatures of the mould (60, 80, 100, 120°C) between the times t_3 and t_4 (fig. 1). The diagram helps to establish the optimal time for the injection of the plastic material, function of the mould temperature and reverse.

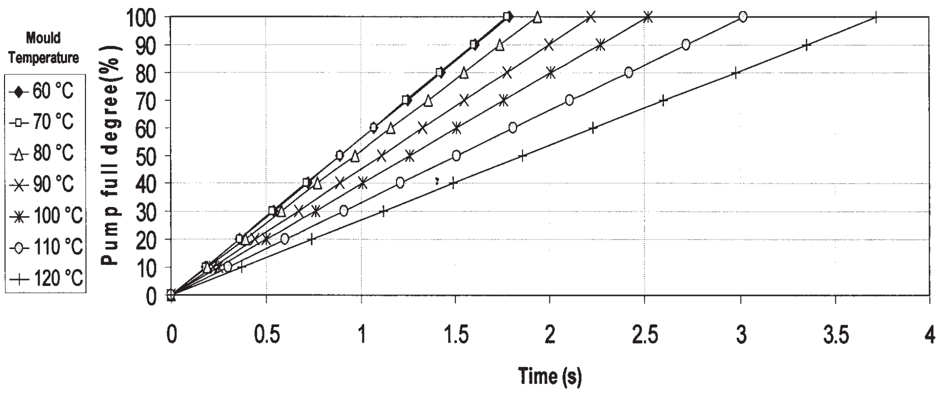

Fig. 4. Variation of pump full degree

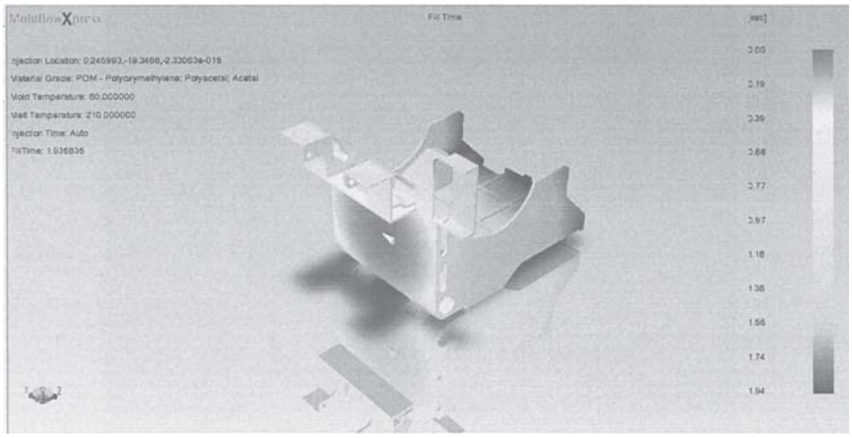

Fig. 5. Thermal representation with one injection point

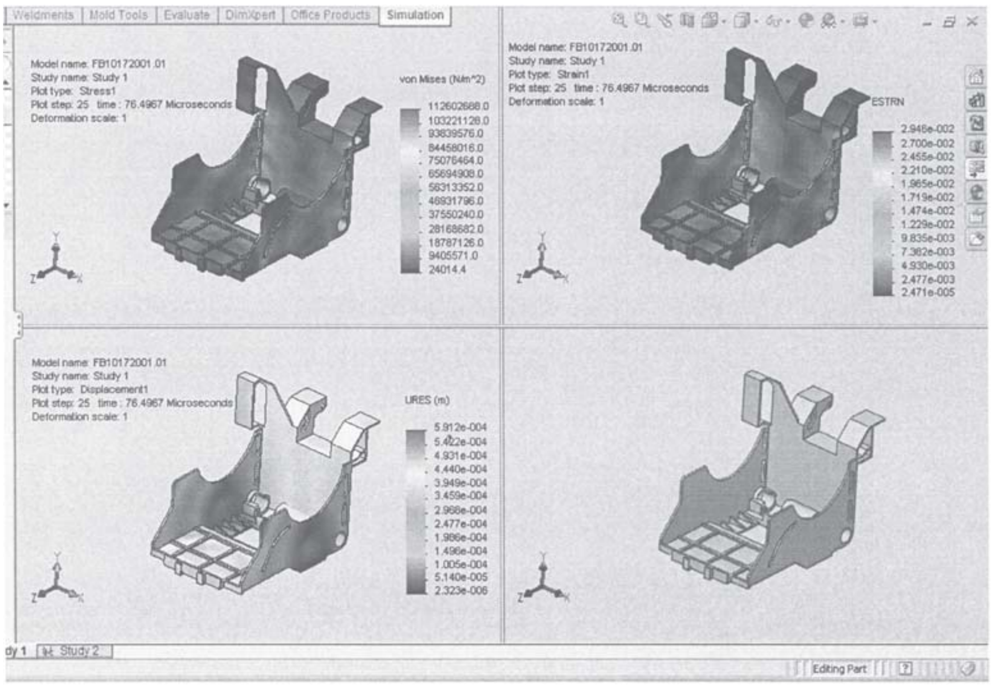

Fig. 6. Results obtained after droop test

The plastic material Polyacetal was used, having the following properties: elastic modulus 2600N/mm^2, Poisson ratio 0.3859, density 0.00139 g/mm^3, thermal conductivity 0.221W/mK, specific heat 1378 J/KgK, tensile strength 71.5N/mm^2.

For the realization of the thermal representation of the injected part, the software of FEM analysis was used, because it has some advantages such as: it considers the non-stationary bi-dimensional thermal conduction and also different conductivities for the material of the mould and the material of the injected part; uses elements of specific calculus; includes different reports of heat transfer; considers starting conditions of processing.

In figure 5, the thermal representation for the injected part with single point filling, mould temperature 80°C and 210°C melting temperature of the plastic material is presented.

Similar representations of the thermal field for the other mould temperatures considered at the variation of the filling degree function of time can be obtained (fig. 4).

Distinct behaviour of the plastic material must be considered for mechanical representation. For parts made of plastic material, mechanical representation must consider also the environmental influence upon the chemical structure.

In figure 6, the results obtained after the plastic material part testing at drop-test are presented. The following have

Table 1
DROOP TEST VALUES RESULTS

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises Stress	24014.4 N/m^2 Node: 20211	(-5.50017 mm, 7.49305 mm, -17.0937 mm)	1.12603e+008 N/m^2 Node: 19962	(24.0133 mm, -5.75506 mm, 4.35096 mm)
Displacement1	URES: Resultant Displacement	2.32336e-006 m Node: 15430	(-24.0001 mm, -23.0972 mm, 25.2988 mm)	0.00059123 m Node: 14149	(24.0035 mm, -8.2424 mm, 59.1506 mm)
Strain1	ESTRN: Equivalent Strain	0 Element: 9775	(13.9766 mm, 1.8284 mm, -4.29339 mm)	0.0294557 Element: 7878	(24.5203 mm, -5.60975 mm, 4.60332 mm)

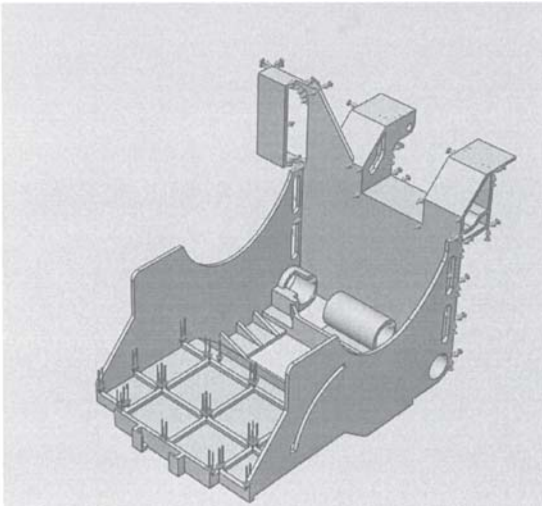

Fig. 7. General requisitions scheme of piece

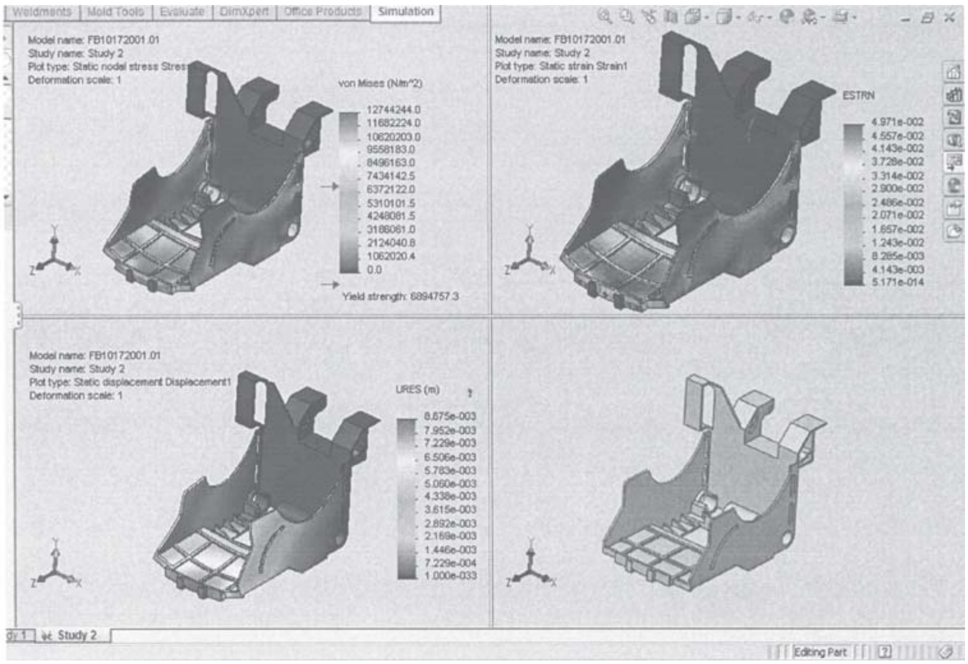

Fig. 8. Static results obtained

Table 2
STATIC REQUISITION VALUES RESULTS

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises Stress	6.15208e-011 N/m^2 Node: 5157	(-2.82143 mm, -3 mm, -10 mm)	1.27442e+007 N/m^2 Node: 20059	(-24.9349 mm, -15.7057 mm, 2.85898 mm)
Displacement1	URES: Resultant Displacement	0 m Node: 294	(-6 mm, 0.5 mm, -1.64628e-015 mm)	0.00867506 m Node: 1288	(4.63959 mm, -46.4011 mm, 74.878 mm)
Strain1	ESTRN: Equivalent Strain	5.17088e-014 Element: 6870	(-14.0625 mm, 12.6464 mm, -17.3333 mm)	0.0497121 Element: 7861	(-24.5733 mm, -4.94007 mm, 3.9341 mm)

been considered: falling height 2m, gravitational acceleration 9.81m/s^2 and normal falling on the impact plane.

In table 1 the values of the test results are presented.

In figure 8 the results of static stress for the part made of injected plastic material (fig. 7) are presented. The following have been considered: temperature of 24.85°C (298K) for part and pressing force of 20N.

In table 2 the values of the results of static stress test for the part made of injected plastic material are presented.

Conclusions

Variation of the filling degree is almost the same around the temperatures of 60 and 70°C of the mould. Comparable variations of the filling degree are registered for temperatures of 80, 90 and 100°C. Starting with the temperatures of 110 and 120°C differences of the variations of the filling degree function of time are registered. At high temperatures of the mould, the thermal field, the highest as values, has a bigger zone of propagation around the injection point, which leads to the increase of the cooling time for the part and respectively of the injection time. The effect is reverse for low temperatures of the mould (fig. 5).

In comparison to a mechanical part, the deformation of an injected part of plastic material is influenced both by the external load and by the load evolution and by the initial temperature evolution (figs. 6 and 8).

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