INJECTION MOULDING SIMULATION OF POLYMER STRUCTURES MODELED WITH FINITE ELEMENT

Durbacă I., Durbacă A.C.

University Politehnica of Bucharest, Splaiul Independentei, 313, Bucharest, Romania
ion.durbaca@yahoo.com

Abstract. *The paper presents the results of finite element and computer-aided simulation of injection molding process for some polymer material parts (footwear soles) in order to establish the profiles of injection rate, pressure, temperature gradient for the polymer melt in the mould cavity and distributing channels, analyze the clamping pressure during the injection, and select the best injection point in the mold cavity to avoid incomplete filling, shorter injection time per cycle etc.*

Key words: *simulation, injection moulding, polymer, finite element.*

1. INTRODUCTION

In processing industries the computer-aided injection moulding simulation for the polymer material parts involves the determination of the *objective-function* defined by the following objectives:

– analysis of the injection rate profile;
– analysis of the mold clamping pressure during injection molding;
– presenting the evolution in the pressure and temperature gradient profiles of the polymer melt in the mold cavity and distributing channels;
– analysis of the rate vectors in the mold cavity;
– selection of the best injection point in the mold cavity to avoid incomplete filling and polymer layer penetration;
– optimization of the mold injection process variables under minimum clamping pressure, reduced injection time per cycle and minimum expenditure of energy,

by employing the following methodology:

a) establishing the polymer utilized in the injection molding of the medelled parts;
b) stating the type and technical-functional characteristics (moulding pressure; plasticizing capability, maximum injection pressure, injection rate) for the injection machine or equipment being used;
c) revealing the injection mold material and its annealing agent characteristics (density, specific heat, thermal conductibility);
d) geometrical modelling of an injected part made of polymer materials by its 2D or 3D representation on the computer monitor by finite element modelling, and modern design softwares (Pro/ENGINEER);
e) free digitization and stating the finite element network consisting of:
   – total number of nodes (NN);
   – total number of elements (NE);
   – total model volume (m^3);
   – measured model surface (m^2).
f) developing the mathematical computing model describing the physical process of injection molding;
g) processing, that is the automatic computing model solving by means of specialized softwares (e.g.: C-MOLD Rapid Designer);
h) post-processing by processing and presenting the obtained results;
i) result interpretation by the user.

The part model subjected to the injection molding simulation by means of the computer is shown in Figure 1.

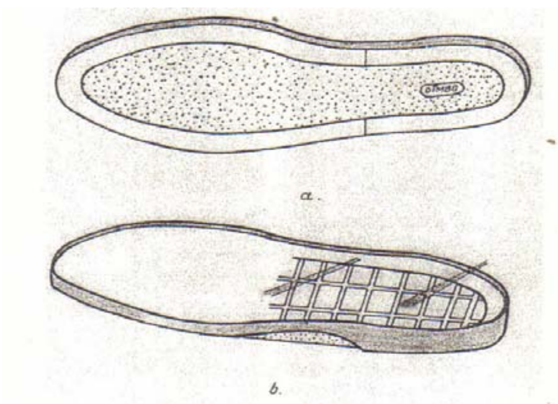

Figure 1. The part model subjected to simulation and trials: a) non-slip relief; b) plantar surface.

2. METHODOLOGY FOR THE INJECTION MOULDING AND SIMULATION

2.1 Establishing the polymer material

The polymer material utilized in making the investigated model and its injection molding simulation according to the above Figure is a thermoplastic rubber of AES/TPR SANTOPRENE 101- 44 type (copolymer containing alternating polystyrene and polybutadiene or polyisoprene blocks, obtained by solution polymerization).

2.2 Stating the employed injection machine or equipment

Computer-aided simulation of the investigated model injection molding (see Figure 1) has had in view the use of the equipemnt specialized for mono- or – bicoloured polymer material injection, 'MAT 2/12(14) – TRUSIOMA' (maximum clamping pressure 60 KN; plasticizing capability 0,036 kg/s; maximum injection pressure 175 Mpa; maximum screw rotative speed 5,83 rot/s; injection rate 2,90 m/s; number of plasticizing-injection units 2).

2.3 Injection mould and annealing agent

Geometrical modelling both for the simulated part and corresponding injection mould are obtained by the 3D representation on the computer monitor by means of modern design software involving the parameterized modelling (Pro/ENGINEER).

2.4 Mathematical modelling of the investigated structure

The computing model employs the finite element method (FEM) based on the following stages:

- dividing the D domain in subdomains by making use of a large number of nodes to which the field nodal unknowns are attached;
- by making use of a local approximation for the unknown function, the information coming from the each element and boundary conditions is concentrated on nodes by nodal equivalence relations;
- the D domain is reconstituted by the knot energy balance equation corresponding to each knot based on the knot equivalence relations, resulting in an equation system with nodal unknowns as solutions.

Basic equations for the *mathematical model*:

- continuity equation;
- energy conservation equation (thermal model);
- rheological state equation (rheological model);
- equations for correlation of physical properties with flow variables.

2.5 Digitization

Having obtained the modeled structure geometry, the programmed digitization is carried out, involving the spontaneous structure dividing into a network of triangle shaped finite elements of shell type (see Figure 2), defined by:

- Total node number, NN= 581;
- Number of structure elements, NE=1111.

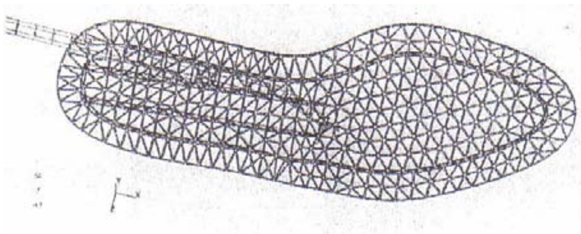

Figure 2. Programmed digitization for the modeled structure

2.6 Pre-processing

To obtain the simulation of injection molding of the modeled structure from the polymer referred to above the mathematical model presented previously is described by pre-processing to establish the following:

a) injection rate profile for a consistent advancing speed of the melt;
b) temperature in the mold cavity and its distributing channel during the filling with the polymer melt,

by the following *procedure*:

- the functionals such as speed (v) and temperature (T) - characteristic for the polymer melt in the injection mold cavity are computed by direct method of nodal equalization;
- the extreme for the functionals (v, T) is determined by variation computing for every finite element based on the values for nodal unknowns;
- the determined nodal unknowns are plotted.

2.7 Processing

Solving the equations of mathematical model by the suggested calculation methodology, underlying the adequate software in C^{++} language by which the polymer temperature distribution during the injection mould cavity filling for the modeled structure is established (see Figure 3).

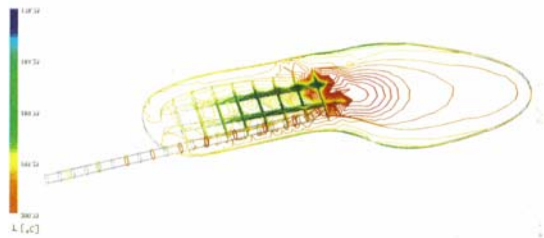

Figure 3. Distribution of the averaged temperature in the injected piece body at the end of filling stage

The other objectives of the injection mold process simulation as a modeled structure make use of specialized softwares (e.g. C-MOLD Rapid Designer) to establish:

- pressure distribution in the mold at the end of filling stage (see Figure 4);
- polymer advancing speed (see Figure 5);
- changes in clamping pressure during filling (see Figure 6);

Figure 4. Pressure distribution in the mould during the end of filling stage

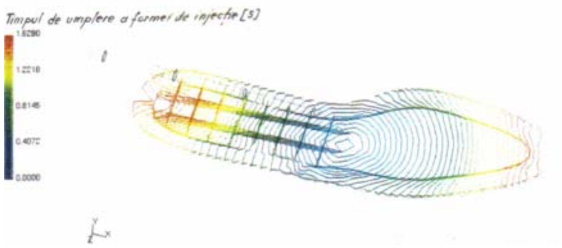

Figure 5. Polymer advancing speed during the filling of injection mould cavity

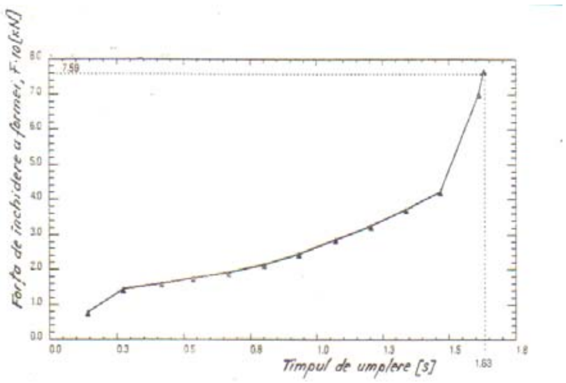

Figure 6. Changes in the clamping pressure during the filling stage

3. CONCLUSIONS

In view of results from post-processing, and from the plot in Figures 6-10 the problem of polymer melt flow in the injection mold cavity can be thought to be entirely solved by means of the mathematical modeling and computer-aided simulation based on the digitization provided by the finite element method; the following *conclusions* can be drawn:

a) the maximum injection pressure is of 16 MPa, and pressure in the mould at the end of filling stage has shown a level distribution (pressure variation less than 4 MPa in the mould cavity and less than 2 MPa in the extreme piece areas).
b) for the selected sealing point, the filling is balanced (the melt advance reaches the cavity extremities simultaneously);
c) the averaged temperature in the cavity at the end of injection has shown low changes in the low thickness areas where the polymer is cooled;
d) faster. In the higher thickness areas the temperature has shown a level distribution;
e) the clamping pressure during injection has shown no sudden leaps, reaching a value of 76 KN maximum at the end of injection. To obtain a proper amount of footwear sole (without mould opening during injection) the clamping pressure has to be increased up to 85-90 KN;
f) an uniform filling with a consistent melt advancing speed is obtained when the best profile of the injection speed resulting from simulation is used.

The simulation of polymer melt flow in the injection mould cavity has been proved to be possible for any type o application of polymer injection in moulds with cavities of different shapes, from the most simple (cylindrical) up to the most complex ones (footwear soles) based on the mathematical modelling and data processing, before the actual trial of such process

4. REFERENCES

[1] Jinescu, V. V., Proprietățile fizice şi termomecanica materialelor plastice, vol. 2, Ed. Tehnică, Bucureşti, 1979.

[2] Mihail, R., Ştefan, AL, Simularea proceselor de prelucrare a polimerilor, Ed. Tehnică, Bucureşti, 1989.

[3] Durbacă, I., Contribuții teoretice şi experimentale ladezvoltarea agregatelor de injecție a materialelor polimerice din industria de încălțăminte, Teza de Doctorat, UPB, 1999.

[4] Blumenfeld, M., Introducere în metoda elementelor finite, Ed. Tehnică, Bucureşti, 1995.

[5] Ionescu, M., ş.a., Proiectarea matrițelor pentru produse injectate din materiale plastice, Ed. Tehnică, Bucureşti, 1987.