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Modelling of temperature distribution during extrusion process

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The way of modelling of temperature distribution on the moulded hose during extrusion, have been presented in this article. The temperature distribution extrusion on the moulded hose and an empirical verification of obtained results was the aim of simulation.

1. INTRODUCTION

The carried research and obtained data will be the basis of modelling of blowing process. Make modelling used Polyfllow 3.9. program, which enables simulation flow viscous and viscoelastic fluid possible. This program use equations of conservation of mass, momentum and energy, and also of various rheological models describing material properties and behaviour during processing. The detailed description of programme potential is presented in the literature [1, 2, 3].

2. MODELLING METHODOLOGY WITH THE USE OF POLYFLOW PROGRAMME

The input of the following data to the program is essential in order to conduct the simulation:

- geometrical model with imposed FEM grid,
- definition of the problem and boundary conditions,
- characteristics and parameters of the material,
- conditions presented during phenomena [3].

2.1. The FEM (Finite Elements Method) model

The first stage of simulation is modelling of geometrical shape of the extrusion tube material. The definition of geometrical changes and temperature field of moulded hose, which is semi-finished product in the moulding process with blowing, was an aim of research in our case. Because the given problem is symmetrical in order to decrease in the number of finite elements, only one half of the tube was modelled (Fig. 1). The modelling has been conducted with the use of Gambit module, which is the integral part of the Fluent Inc. package. The net of finite elements has been imposed on the prepared geometrical model. The 2625 of 3-D elements have been used in rectangular shape (hexahedrons). So prepared the FEM model is ready to be exported to the Polydata module after checking the finite element net and defining the area borders.

2.2. The process conditions and the material properties

The second stage of the preparation of computer simulation of Barus effect is the definition of problem applying Polydata module, in which boundary conditions concerning equations of movement and energy are defined. The given problem has been defined as: 3D, no-isothermic and evolution. Two subdomains, limited by eight borders, on which five boundary conditions of flow and temperature (Fig. 1) were defined, were isolated in the considered task.

Table 1
The boundary conditions (see figure 1)

No. of boundary	Flow boundary conditions	Thermal boundary conditions
1	Inflow Q = 5×10 $^{-6}$ [m^3/s]	Temperature imposed T=200^{0}C
2	Outflow f_n=0 and V_s=0	Insulated boundary
3,4	Plane of symmetry	Symmetry insulated boundary
5,6	Walls of channel (V_n=0, V_s=0)	Temperature imposed T=200^{0}C
7,8	Free surface	Flux density imposed q= α(T- T_α), where: α = 20 W/m·K, T_α=20^{0}C, T= 200^{0}C

The selection of material rheological model, which will be used in the computer simulation, is the next essential step.

PE-HD material (Borealis firm) with BL-2571 symbol, adapted to the moulding process with blowing, was applied for modelling. The material was tested with the use of oscillatory and capillary rheometer to determine flow curves in a wide range of shear rate and to define the relationship of conservative and lossiness modules to the frequency of deformation change for four temperature values: 190, 210, 230, 250^0 C.

In this case it was assumed that viscosity depends on the shear rate and temperature (1):

$$\eta\left(\dot{\gamma},T\right)=F\left(\dot{\gamma}\right)H\left(T\right) \tag{1}$$

where $F(\dot{\gamma})$ and $H(T)$ represent the shear-rate and temperature dependence of viscosity, respectively.

Bird-Carreau Law's generalized Newtonian model (2), and Arrhenius Law's model (3) was applied to achieve this goal.

$$\eta=\eta_\infty+\left(\eta_0-\eta_\infty\right)\left(1+\lambda^2\dot{\gamma}^2\right)^{\frac{n-1}{2}} \tag{2}$$

where:
η - viscosity [Pa·s],
$\dot{\gamma}$– shear-rate [s^{-1}],
η_0 – zero-shear-rate viscosity = 36313 [Pa·s],
η_∞ – infinite-shear-rate viscosity = 0,000792 [Pa·s],
λ – natural time = 3,19 [s],
n – power-law index = 0,432.

$$H\left(T\right)=\boldsymbol{exp}\left[\alpha\left(\frac{1}{T-T_0}-\frac{1}{T_\alpha-T_0}\right)\right] \tag{3}$$

where:

α – ratio of the activation energy to the perfect gas constant = 1490,4,

T_α – reference temperature = 200^0C,
T_0 – non-absolute temperature = 0^0C.

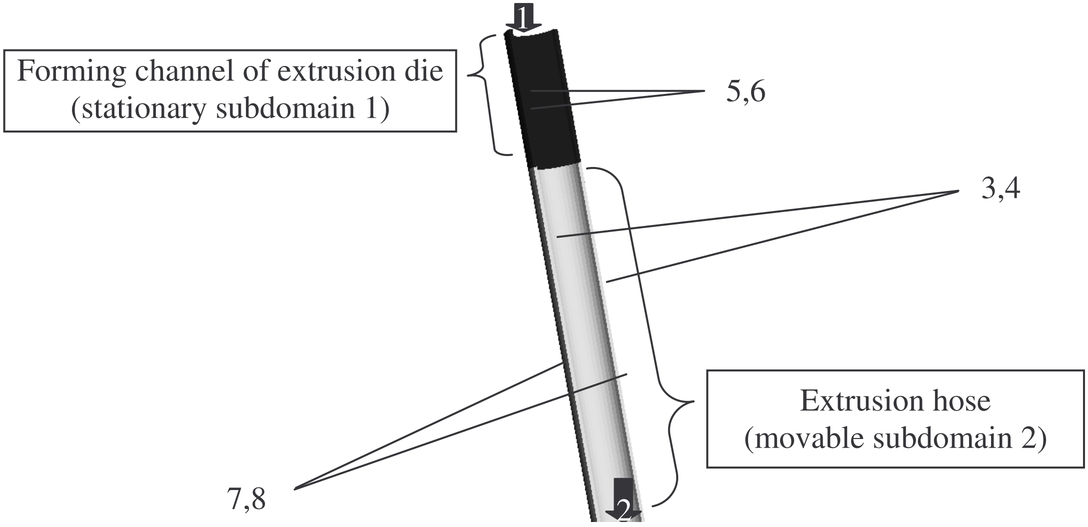

Figure 1. The geometrical model with pointed borders of domains

Parameters of equation were determined with the use of Polymat module on the basis of rheological research of material

3. EXPERIMENTAL VERIFICATION

Determination of errors occurring during modelling, caused by simplifications introduced into mathematical model and numerical algorithm, was an aim of the verification. Experimental studies were investigated on the extrusion machine adapted for packing production by blow moulding method. The range of research enclosed recording of temperature distribution on moulded hose (Fig. 3) with the use of ThermaCam PM 590 thermovision camera (produced by American firm FLIR) [4].

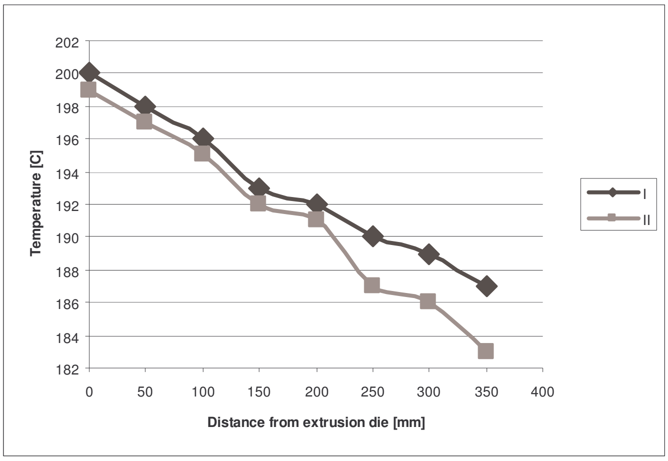

Figure 2. Diagrams of temperature distribution along moulded hose: I - obtained during modelling, II - recording by thermovision camera

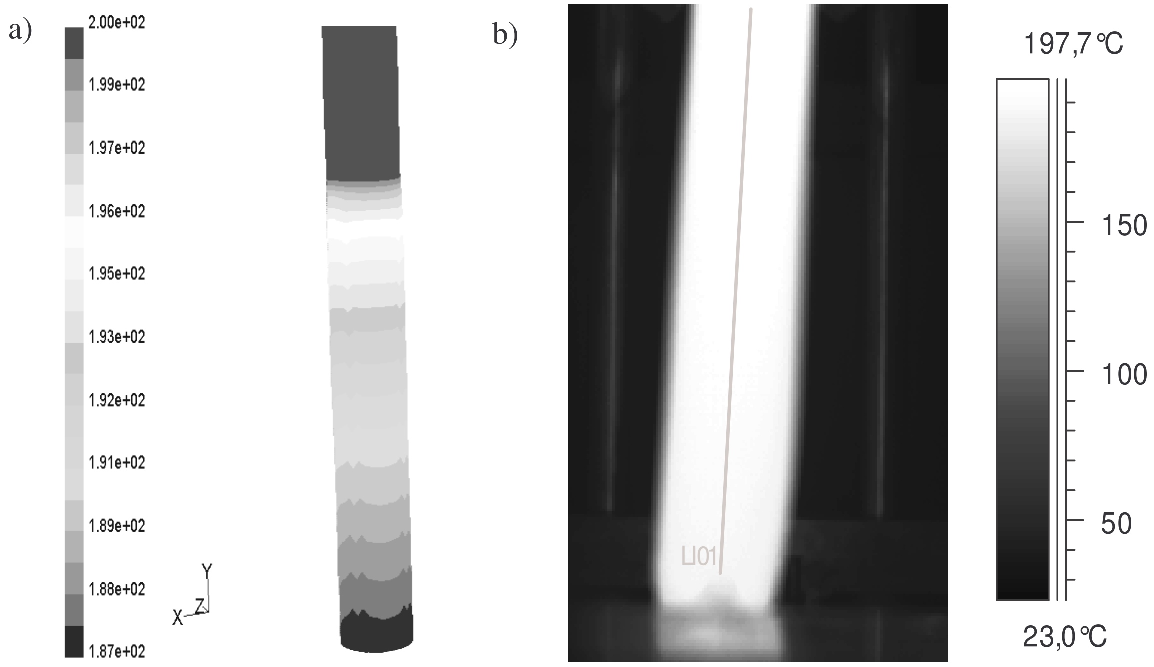

Figure. 3. The distribution of temperature a) obtained during modelling, b) recording by thermovision camera

4. CONCLUSIONS

The carried out experimental verification confirmed high accuracy of obtained during computer simulation final data (Fig. 2.). The research and computer simulations pointed that an exact representation of reality (e.g. selection of rheological model, determination of this model parameters) has an influence on an accuracy of obtained results.

The modelling of such the phenomenon, taking into account viscoelasticity of polymer with the use of integral and differential rheological equations, is the task set for the future scientific work. The carried out research is preliminary for modelling of moulding process with blowing, which character is double-stage. The modelling of stream expansion phenomenon is one of the stage of the whole process. The obtained data will be the basis of modelling of blowing process.

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