Modelling of wire extrusion process

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Abstract: *It is created computer model of wire extrusion process with Matlab. The model is verified by comparing the simulated results with experimental.*

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1. Description of wire extrusion process and definition of the model

The extrusion process is an essential method for the production of wires and rods (shown in Fig.1). Metal shavings, powder or granules are usually placed in a closed cylindrical container – matrix. Pressure from a tight-fitting rotation piston is applied. The piston rotates at a certain angular velocity. Due to the friction between the piston and the metal in the cylindrical container, heat is generated. Due to the heating and the applied pressure, plastic deformation occures in the metal raw material. The metal begins to come out through external channel in the piston, cools and crystallizes in the form of a wire or rod.

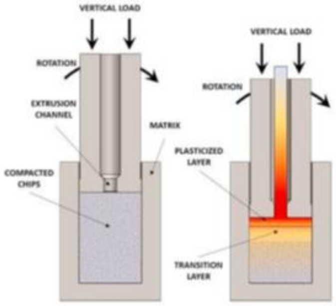

Fig. 1 *Principal structure of the wire extrusion process[1].*

The amount of generated heat in the extrusion process is determined according to:

$$Q = A = \vec{S_{sum}} x \vec{F_{fr}} = S_{sum} * \cos\alpha * F_{fr} = S_{sum} * F_{fr} \qquad (1)$$

Where S_{sum} is total contact area;

F_{fr} – friction force;

$\alpha = 90^o$ – angle between the piston surface and the metal in the cylindrical container

The total contact area is determined according to:

$$S_{sum} = n * S = \pi * r^2 * \omega * t \qquad (2)$$

Where $S=\pi r^2$ is the area of the piston;

r – radius of the piston;

$n=\omega * t$ – number of cycles the piston does;

ω – angular speed of the piston;

t – time of the extrusion process.

The friction force is determined according to:

$$F_{fr} = \mu * N \qquad (3)$$

Where N is the force applied by the piston;

μ – friction coefficient between the piston and the extruded metal.

By (1), (2) and (3) follows that the total amount of generated heat during the extrusion process is:

$$Q = \pi * \mu * \omega * N * r^2 * t \qquad (4)$$

To create the geometry of the model, the volume of the cylindrical container of the extruder is defined as the sum of elementary cubic cells along the X, Y and Z axes. These cells represent elementary volumes in each of which the given mathematical operations are performed.

The dimension of the created three-dimensional data array H (x, y, z) determines the size of the elementary volume for which the calculations are made and to which the value of the respective cell of this array is assigned. The size of this unit cell is determined according to:

$$d = \frac{D}{X} \qquad (5)$$

Where d is the size of the elemental cell;

D – the size of the element by the respective axis;

X – the dimension of the three-dimensional array along the respective axis.

The sampling time is determined by the number of steps. They are determined according to:

$$\Delta t = \frac{t_{extrusion}}{N_{steps}} \qquad (6)$$

Where Δt is the time of one sampling step;

$t_{extrusion}$ – the total amount of time of the extrusion process;

N_{steps} – the number of sampling steps.

Considering the generated heat energy for a single cell with extremely small dimensions and we have in mind (4) and (6), we have:

$$\Delta Q = \pi * \mu * \omega * N * r^2 * \Delta t = \pi * \mu * \omega * N * r^2 * \frac{t_{extrusion}}{N_{steps}} \qquad (7)$$

The increase in temperature depends on the amount of energy absorbed in the volume of the substance and is determined according to:

$$Q = cm\Delta T = c\rho_v V(T - T_0) \qquad (8)$$

Where c is specific heat capacity of the material;

m – the mass of the heated detail;

V – the volume of the heated part;

ρ_v – density of the material.

For elementary cell (8) is determined represented as:

$$\Delta Q = c\rho_v \Delta V(T - T_0) = c\rho_v d^3(T - T_0) \qquad (9)$$

The intensity of thermal conductivity is proportional to the temperature change in the considered direction. It is determined by Fourier's law:

$$Q = -\lambda S_x \frac{dT}{dx} \qquad (10)$$

Where Q is the full heat flow;

S_x – area of the heat flow conduction;

λ – thermal conductivity coefficient.

dT/dx – determines the rate of change of temperature in X axis (the direction in which the heat transfer is considered).

For elementary cell (10) is determined represented as:

$$\Delta Q = -\lambda d^2 * \frac{dT}{dx} \qquad (11)$$

The coefficient of thermal conductivity is a material constant that depends on temperature and is determined by:

$$\lambda = \lambda_0(1 + \alpha T) \qquad (12)$$

Where λ_0 is the coefficient of thermal conductivity at 0oC;

α – experimentally determined constant depending on the type of material.

The heat balance for each cell of the model is defined as the sum of the incoming heat transfer and the generated heat by friction on the one hand and the outgoing heat transfer and the accumulated heat in the cell on the other.

$$Q_{\text{incoming heat transfer}} + Q_{\text{generated heat by friction}} =$$

$$= Q_{\text{outgoing heat transfer}} + Q_{\text{accumulated heat in the cell}} \qquad (13)$$

2. Verification of the model

To create the computer model [2], the Matlab software product is chosen, which has very good computational and visualization capabilities, with the help of which the programming of the simulation model is greatly facilitated.

The verification of the model is performed by measuring the temperature of the extruded wire at the point where it comes out from the external in the piston channel. The extrusion is performed [3,4] using a hydraulic press for discrete extrusion ПХДЕ4000/ 1000, and the temperature measurement is non-contact – using an IL-92 pyrometer. The information is read via a USB interface from a laptop and processed in real time.

The process of extrusion is conducted with aluminium shavings. The coefficient of friction between aluminium and metal is considered to be 0.47. The applied pressure is 1000kN and the angular speed is 1rpm. The diameter of the extruded wire is 5mm. The temperature at the start of the extrusion process is T0 = 17oC.

Fig. 2 graphically presents the simulated and measured temperature. The temperatures reached by the extrusion process (simulated and measured) are below the melting point of aluminium, as this is the temperature to which the pyrometer has access to measure – the point at which the extruded wire exits the external in the piston channel.

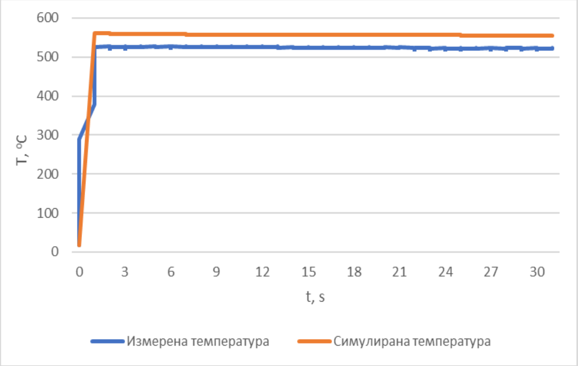

Fig.2 *Simulated and measured temperature reached in the extrusion process.*

Because of the nature of the process the piston moves inward into the cylindrical container, i.e. shifting the point at which the temperature is measured to a colder point of the wire. This displacement is not large and is relatively slow, as its effect is partially compensated by heating the piston, which leads to less heat loss in it.

The difference between the simulated and the measured temperatures is within 5-8%, as the simulated temperature is 30-35oC higher. The main reason is the simplification of the model and the complex definition of the influence of the piston.

3. Conclusions

It is created simulation model of the extrusion process from aluminium shavings. The model simulates temperature with 30-35oC higher than the measured.

The created model can be optimized by better defining of the influence of the piston of the extrusion press.

4. References

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