Multi-Criteria Selection of Operational Parameters of Hydromechanical Extrusion

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Abstract. The paper presents results of the simulation modeling of the hydromechanical extrusion of bar stock from a material prone to sticking when being formed. The influence of operational parameters on the extrusion stress, deformation inhomogeneity, and damage of the material under deformation is studied by mathematical modeling and simulation exercise. A regression analysis of the results of the simulation exercise is performed. Semi-continuous hydromechanical extrusion of AMG5 aluminum alloy rods is studied using an expert system designed to optimize the plastic forming of hard-to-form metal materials.

INTRODUCTION

The work is aimed at improving the technology of forming of metals and alloys having the property of sticking to the tool, which increases the contact friction forces. It is known that more than 60% of the pressing force is spent on overcoming the friction forces. The effect of contact friction forces causes the high energy intensity of technological processes. The magnitude of the friction forces, their direction, and distribution over the contact surfaces of workpieces and metalworking tools determine the structural heterogeneity and mechanical properties of the product material [1, 2].

The purpose of the study is to implement mathematical and simulation modeling of the process of hydromechanical extrusion HME exemplified by investigating the aluminum alloy extrusion process and to determine the optimal parameters of the process using methods of multi-criteria optimization; the criteria are as follows: minimum extrusion stress, minimum damage of the material being deformed, and minimum inhomogeneity of the extruded workpieces.

RESEARCH METHODS

The technology under consideration allows us to produce precise shapes without heating the workpieces and with minimal friction of the workpiece surface against the container walls. Simulation modeling and exercise were used to improve the technological process.

Using a simulation exercise, it was necessary

- to investigate the effect of pressure on the workpiece side surface, friction, and elongation on the specific extrusion stress;
- to set the minimum pressure of the environment creating hydrostatic pressure (working agent) in order to implement the extrusion process;
- to study the influence of the operational parameters on the accumulation of damage during deformation;
- to perform a regression analysis of the results of the simulation exercise;
- to determine the optimal parameters of the HME process.

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The device for implementing the HME process is schematically shown in Fig. 1. The diagram shows the areas where the environment creating pressure (the working agent) has a deforming effect on the workpiece. A plastic medium with a low (relative to the deformable material) yield stress σ_{sp}=0.01...0.05 σ_s is taken as the working agent, where σ_s is the yield stress of the workpiece material. The application of the HME process gives grounds to assert that the semi-fluid friction mode is achieved when extruding hard-to-form materials [3].

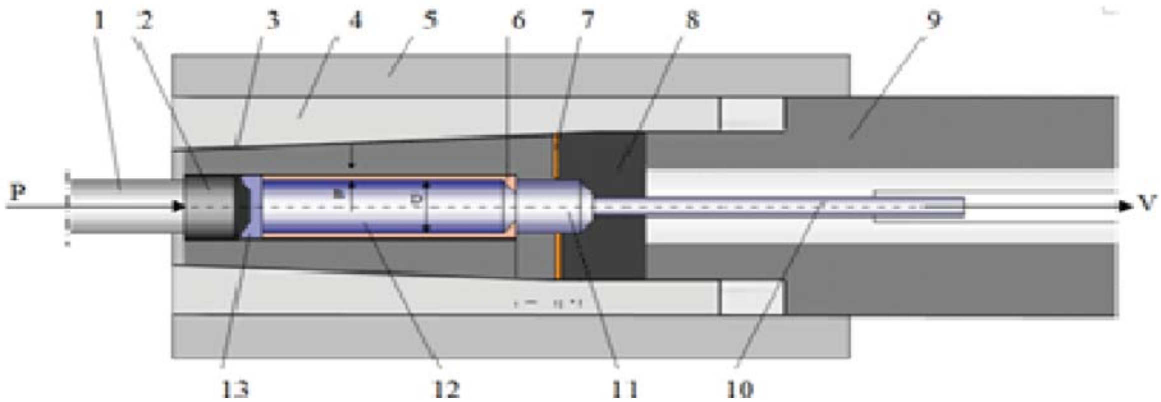

FIGURE 1. The diagram of the for implementing the HME process: 1 – punch; 2 – pressure pad; 3 – liner; 4 – cylinder; 5 – container; 6 – viscoplastic material; 7 – gasket; 8 – die; 9 – spacer; 10 – extruded part of the workpiece; 11 – extrusion discard; 12 – another workpiece; 13 – end of the workpiece

RESULTS

Simulation modelling of semi-continuous HME was performed the application of the finite element method. For the simulation modelling of the HME process, the following initial workpiece dimensions were assumed: D=9 mm, L_0=22 mm. The workpiece elongation $\lambda=D^2/d^2$ was varied from 2 to 8; the friction factor was varied from 0.1 to 0.4. The punch speed was V_0=0.03 mm/s.

The HME modelling was carried out for an axisymmetric process; the finite elements were polygons; the number of elements was 1000; the workpiece material before deformation was isotropic and homogeneous; the pressure on the workpiece side surface was varied from 50 to 400 MPa with an increment of 10 MPa.

Some results of the stress analysis and the strain analysis performed by DEFORM-2D are shown in Fig. 2.

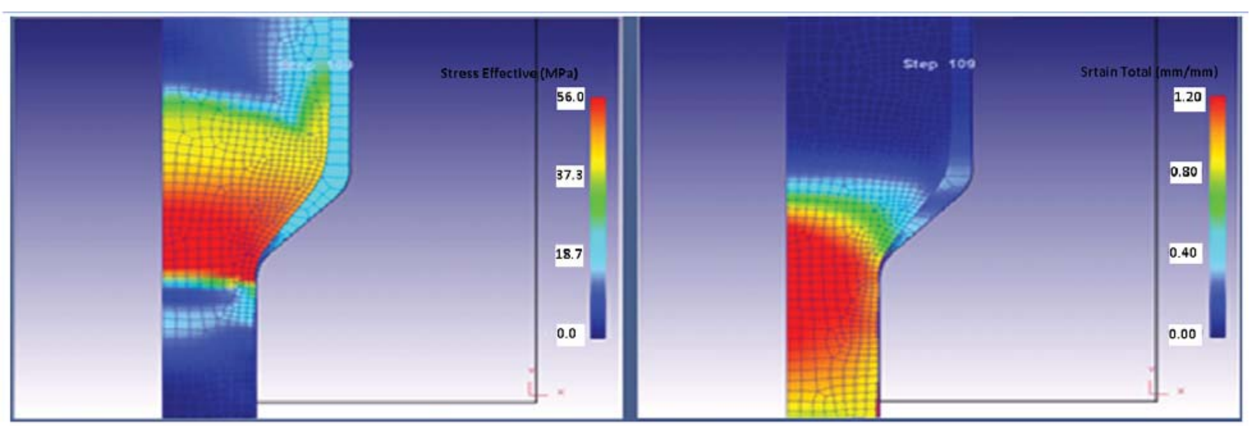

FIGURE 2. Some results of the stress analysis and the strain analysis performed by DEFORM-2D

Based on the HME modeling results for the AMG5 alloy, a series of 9 simulation exercises was performed in the DEFORM software package. The initial workpiece dimensions were as follows: diameter 9 mm and length 22 mm. The results of the simulation exercise are shown in Table 1.

TABLE 1. The results of the simulation exercise

No.	Variable factors			Quality criteria		
	Elongation	Die cone angle α, deg	Friction factor *f*	Pressing force $P*10^4$, N	Damage index ω	Deformation inhomogeneity η
	*X*1	*X*2	*X*3	*Y*1	*Y*2	*Y*3
1	2	50	0.3	2.57	0.27	2.95
2	4	55	0.3	5.04	0.18	2.19
3	6	60	0.3	6.13	0.17	2.12
4	8	60	0.4	7.6	0.18	1.96
5	2	60	0.1	2.62	0.31	3.89
6	4	60	0.2	4.92	0.31	2.44
7	8	50	0.2	6.34	0.17	1.66
8	6	50	0.1	5.29	0.15	1.77
9	8	55	0.1	6.1	0.18	1.79

The simulation exercise results were processed using an expert system [4].

In the expert system, the quality criteria for workpieces and products are reduced to a dimensionless form $\overline{Y1}$, $\overline{Y2}$, $\overline{Y3}$ and normalized so that they take values from 0 to 1; a generalized quality criterion is introduced,

$$F = \sqrt{k1\overline{Y1}^2 + k2\overline{Y2}^2 + k3\overline{Y3}^2}, \qquad (1)$$

where $k1$, $k2$, $k3$ are the weight coefficients.

The regression analysis method determines the dependence of the generalized criterion of the quality of the technological process functioning on the variable parameters ($X1$, $X1$, $X1$) of the technological system. Procedures of searching for the minimum value of the generalized process quality criterion are implemented:

$$F \; = min\, Z\left(X1, X2, X3\right). \qquad (2)$$

The use of the expert system has allowed us to determine the dependence of the generalized quality criterion of the HME process on the main HME operational parameters, which include: elongation λ, the die cone angle α and the medium of the viscoplastic coating of the extruded workpiece. Some results of the expert system are shown in Fig. 3.

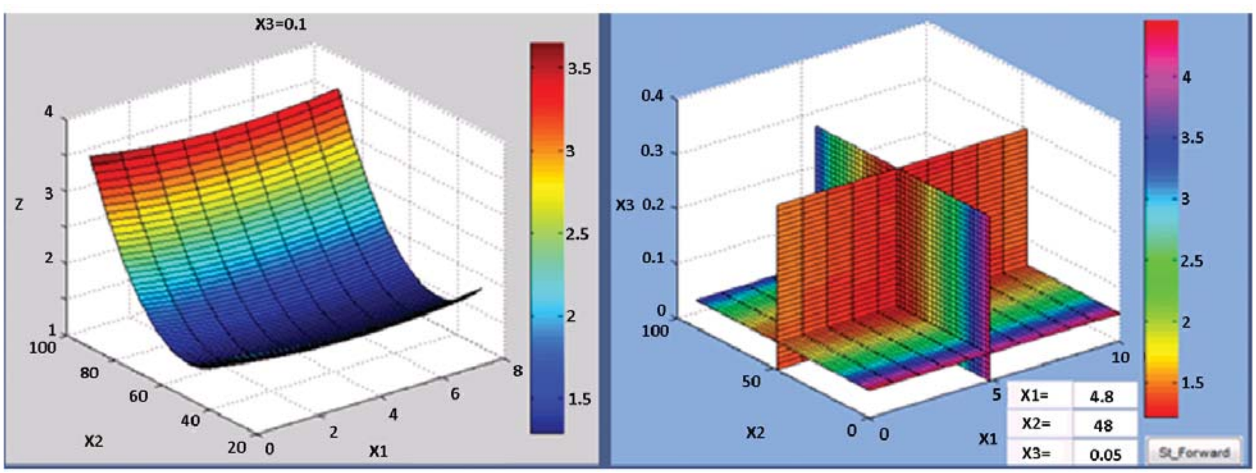

FIGURE 3. Some results of the expert system

The data in Fig. 3 allow us to recommend the following values of HME operational parameters: elongation λ=5.8; die cone angle α=52° Plastic paraffin can be used as the medium creating hydrostatic pressure in the die cavity.

CONCLUSION

A methodology for the multi-criteria choice of extrusion process parameters has been proposed. The methodology has been exemplified by the study of semi-continuous hydromechanical extrusion of a metal prone to sticking to the metal-forming tool, namely the AMG5 alloy. The expert system designed to improve the forming of hard-to-process metal materials has been used to achieve this goal.

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