COMPUTER SIMULATION OF THE CONTINUOUS EXTRUSION PROCESS OF WIRE FROM HIGH-STRENGTH ALUMINUM ALLOY 7075 ACCORDING TO THE CONFORM SCHEME

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ABSTRACT

This article presents the results of a finite element numerical simulation study of the 7075 alloy wire production process using the Conform method. A 12 mm diameter rod cast in an electromagnetic mold used as the starting material. A 3D assembly model of the tool and workpiece was developed and presented. During the simulation, the workpiece temperature, tool temperature, and wheel and roller speeds were varied, which made it possible to determine optimal Conform extruding conditions on the presented unit. The temperature, deformation, and trajectory-speed conditions of the extrusion process were analysed. The study established that the tool temperature should not exceed 400°C, and the wheel speed should be in the range of 2 to 4 rpm. Zones of difficult deformation were identified, as well as zones of intense deformation where the deformed metal meets the stationary tool.

Keywords: aluminium alloy 7075, rolled wire, conform method, computer simulation, FEM, trajectory-velocity and deformation parameters.

INTRODUCTION

Alloy 7075, due to its balanced combination of properties, occupies a niche in modern industry to produce advanced aviation, marine, and land-based equipment. It is characterized by high strength, achieved through a combination of deformation processing and artificial aging [1, 2]. Despite the extensive research into classical methods of plastic deformation for alloy 7075 to produce various semi-finished products, wire has recently become a significant area of research. Of particular interest are severe plastic deformation (SPD) processes [3, 4], as well as processes such as Conform [5].

Belov et al. previously conducted studies on the effect of thermomechanical treatment on the structure and strengthening of a workpiece made of this alloy obtained by casting in an electromagnetic mold [6], as well as by alloying a similar alloy with Zr and Sc [7]. Radial-shear rolling of similar alloys with the addition of calcium was studied in [8]. The Conform method allows processing other aluminium alloys, such as the Al-Mg-Si [9, 10], Al-Si [11] and Al-Fe [12] systems. It is possible to obtain rods from briquetted chips [13]. Since the Conform process is continuous, it uses a long workpiece [11]. Alternatively, it is possible to exclude a solid workpiece and use a metal melt [15 - 18].

The application of these approaches in rod production requires calculation of tool parameters [19] and process energy and force parameters [20, 21]. Modelling of the investigated process is of great importance for designing industrial plant components and processing modes for various alloys. Raab et al. investigated the stress-strain

state of the equal-channel angular pressing (ECAP) and Conform processes [14]. Skuratov et al. studied the heat transfer parameters and temperature state of the Conform process [15, 16]. Koshmin et al. [22] and Zinov'ev et al. [23] demonstrated the influence of the stress-strain state and Conform process parameters on the evolution of the microstructure and mechanical properties of M1 copper.

Despite the extensive research base of the 7075 alloy and combined processing methods, the issue of producing wire from this alloy using the Conform method is a pressing task that requires additional research and modelling of temperature-speed and deformation modes over a wide range.

In this regard, the objective of this work was to conduct computer modelling of the process for the further development of modes on the Conform installation for the production of wire from alloy 7075. To achieve this goal, it was necessary to solve several tasks:

- Creation of a model of the working unit elements of the Conform unit.
- Selection of ranges for workpiece and tool temperature variation, and tool rotation speed.
- Analysis of temperature and deformation conditions during the simulation.
- Analysis of trajectory and velocity conditions during the simulation.

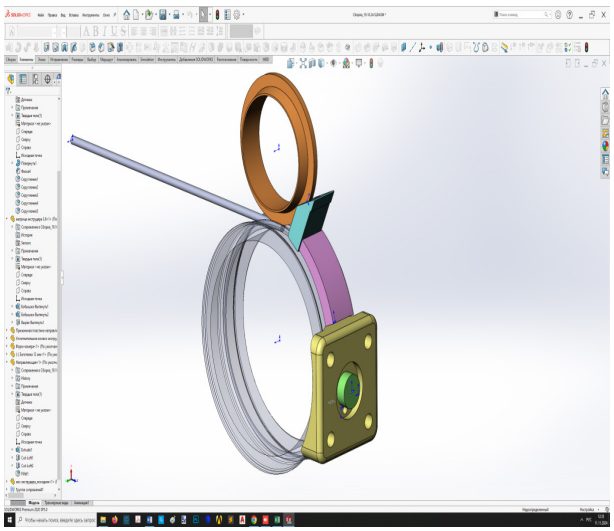
EXPERIMENTAL

The Conform process was simulated using the QForm 3D software package. A 12 mm diameter, 600 mm long 7075 aluminium alloy rods used as the initial workpiece for the simulation. A 3D model was created in SolidWorks for the simulation, including the workpiece and the main unit tool (Fig. 1).

The assembly model consists of an initial workpiece 1 in the form of a cylindrical rod, a working wheel 2, a setting roller 3, a pressure bar 4, a guide plate 5, a press-container 6, a die 7 and a stopper 8 (Fig. 2).

The calculation was performed by varying the key temperature and velocity parameters of the process (workpiece temperature, tool temperature, wheel and roller speed) to determine optimal extrusion conditions. The key parameters of the initial workpiece and tool are listed in Table 1.

The rheological properties of the original workpiece (Fig. 3), as well as the thermophysical properties of the workpiece and tool, are specified in the QForm materials



a)

b)

Fig. 1. General view of the assembly three-dimensional model of the tool and workpiece for modelling: (a) isometric view; (b) longitudinal section.

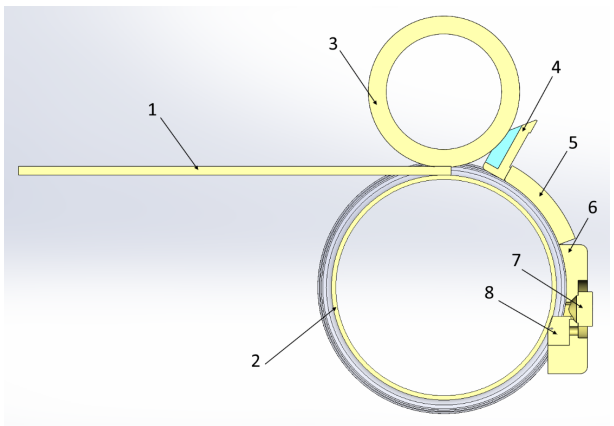
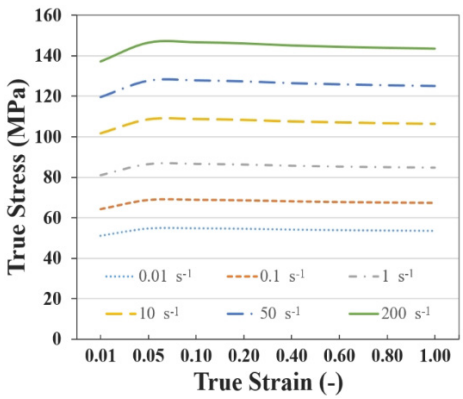


Fig. 2. The main elements of the working unit of the equipment for Conform extrusion: 1 - workpiece; 2 - working wheel; 3 - setting roller; 4 - pressure bar; 5 - guide plate; 6 - press-container; 7 - die; 8 - stopper.

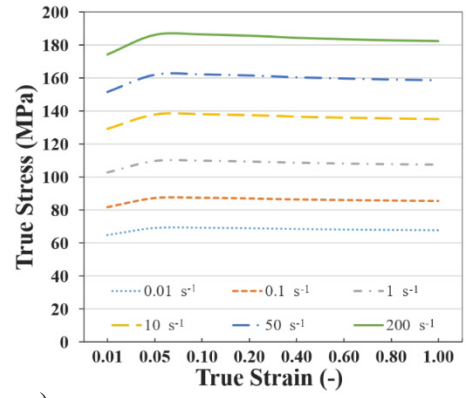
database.

Based on the simulation results, the temperature distribution in the mold chamber and at the outlet of the die channel, as well as the distribution fields of deformation and trajectory-velocity parameters, were analysed.

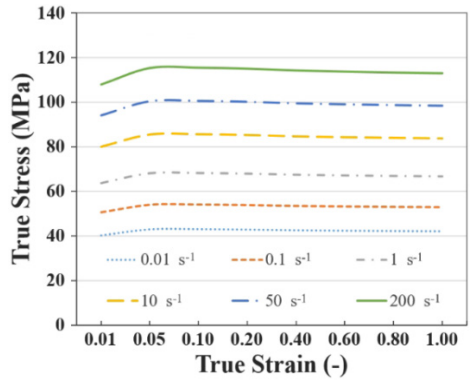
Calculating this process is quite time-consuming. A single calculation, until the mold chamber is filled and the rod exits the die channels, takes on average 80 - 100 h.



b)



a)



c)

Fig. 3. Stress-strain curves of alloy 7075 at different strain rates and temperatures: (a) 400°C, (b) 450°C and (c) 500°C.

Table 1. Parameters of the original workpiece and tool.

Parameter	Designation	Units	Value
Workpiece			
Diameter	D_w	mm	12
Length	L_w	mm	600
Material		-	7075
Heating temperature	T_0	°C	400/420/450/480/500
Instrument			
Material (wheel, roller, bar, guide, stopper, press-container)		-	5135
Material (die)		-	H13
Diameter of die holes	D_d	mm	3.8
Number of die holes		pcs.	2
Temperature: - wheel, roller, bar, guide - stopper, press-container, die	 T_{wh}, T_r, T_b, T_{gp} T_s, T_{p-c}, T_d	 °C °C	 25 400/450/500
Wheel rotation frequency	N_{wh}	rpm	2.6/4.0/6.0
Roller rotation frequency	N_r	rpm	4.16/6.4/9.6

RESULTS AND DISCUSSION

Analysis of temperature conditions

During the simulation process in QForm, the change in workpiece temperature is calculated, considering its heat exchange with the environment and the tool. For the tool, the specified temperature is constant when interacting with the environment, and heat exchange occurs when it encounters the workpiece. Since previously obtained results indicate that the preheating temperature is 500°C, but there is no data on the time interval from the end of the preheating to the beginning of contact with the workpiece, the calculation assumed a tool heating temperature varying between 400 - 500°C.

The initial heating temperature for the workpiece is selected based on the alloy's chemical composition and deformation method. For alloy 7075, 480°C is the upper limit, and 300°C is the lower limit (the deformation resistance at this temperature exceeds 200-220 MPa). Based on these criteria, five simulations were run with varying workpiece temperatures, tool temperatures, and rod feed rates (wheel and roller speeds) (Table 2).

Fig. 4 shows the temperature distribution fields in the cross-section of the mold chamber and die channel for various temperature and speed parameters of extrusion 7075 alloy. For all simulation variants, the rod temperature decreases as it moves along the wheel groove due to contact with the cold tool (T_{wh} = 25°C). Subsequently, as the form chamber is filled, the temperature begins to increase rapidly and reaches a maximum in the contact zone with the die when the chamber is filled.

For the first option, at maximum workpiece and tool temperatures, the workpiece heating temperature reaches 530°C at the die entry, which is unacceptable for this alloy. The wire temperature at the die exit also exceeds 500°C.

When the workpiece heating temperature is reduced to 450°C, the preheating temperature decreases slightly, but the temperature in the form chamber and at the die channel exit is still too high (500 - 506°C), due to the high tool temperature. The third option, where the workpiece temperature is reduced to 420°C but the wheel speed is increased by 2.3 times, also results in intense heating to 505 - 540°C due to the increased strain rate.

These temperature and velocity conditions of extrusion can lead to metal over burning, instability of the extrusion process, wire breakage at the exit of the channels or other defects.

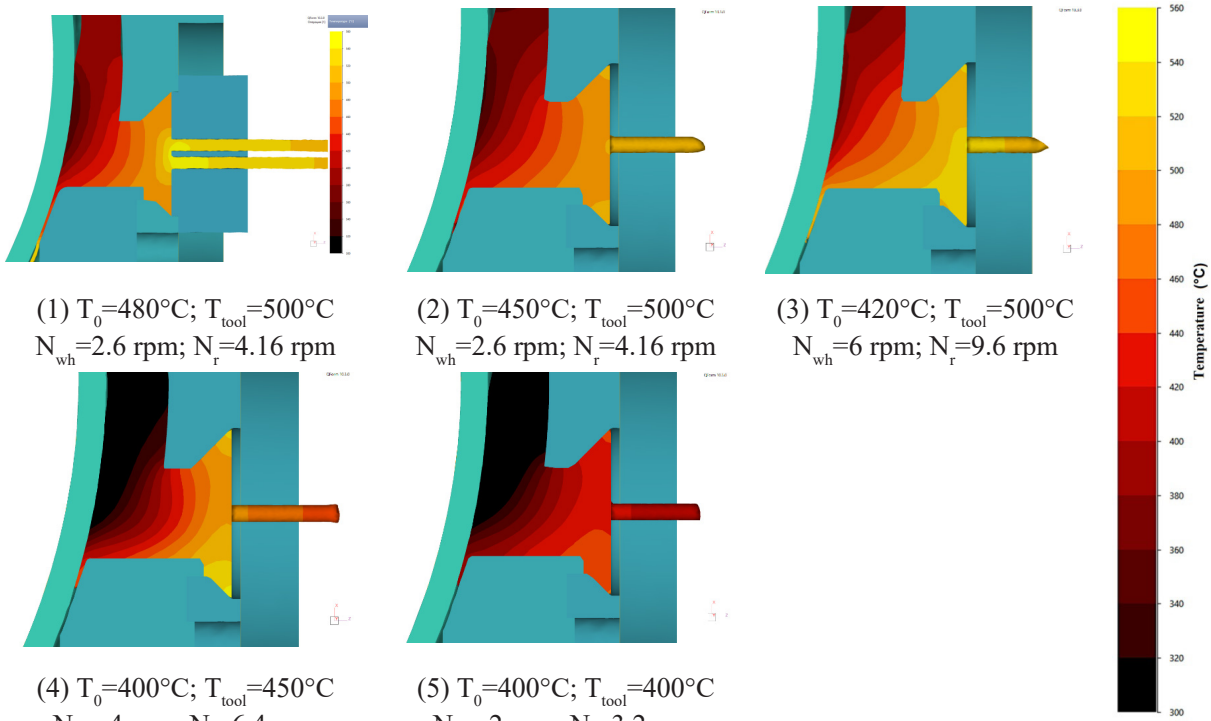
In the actual process, the tool cools gradually (unless additional heating equipment, such as an inductor, is used). At T_0 = 400°C and T_{tool} = 450°C (option 4), a decrease in die exit temperature can be observed, on average, to 460°C. However, in the form chamber, overheating of the annular region of the workpiece, reaching 520 - 540°C, is observed in the area where the die is inserted into the press-container.

For the fifth option, with equal workpiece and tool temperatures (400°C) and a low extrusion speed, the maximum temperature in the form chamber reaches 450°C, and the die exit temperature is 410 - 420°C, which is the standard hot deformation temperature for 7075 alloy. It is worth noting a significant decrease in the rod temperature at the form chamber entrance to 300°C for the last two options. However, during the initial stage of the Conform process, no significant deformation of the workpiece occurs (only its bending along the wheel radius), so this should not affect the quality of the final wire and is acceptable.

The conducted analysis of the workpiece temperature during the Conform extrusion process showed that both the workpiece and tool temperature and the choice of extrusion speed are significant factors in the design of the modes.

Table 2. Conform process simulation mode options parameters for 7075 alloy.

Parameter	Variant No.				
	1	2	3	4	5
T_0, °C	480	450	420	400	400
T_{tool}, °C	500	500	500	450	400
N_{wh}, rpm	2.6	2.6	6.0	4.0	2.0
N_r, rpm	4.16	4.16	9.6	6.4	3.2



(1) T_0=480°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

(2) T_0=450°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

(3) T_0=420°C; T_{tool}=500°C
N_{wh}=6 rpm; N_r=9.6 rpm

(4) T_0=400°C; T_{tool}=450°C
N_{wh}=4 rpm; N_r=6,4 rpm

(5) T_0=400°C; T_{tool}=400°C
N_{wh}=2 rpm; N_r=3,2 rpm

Fig. 4. Temperature distribution fields in the cross-section of the mold chamber and the die channel at different temperature-velocity parameters of extrusion alloy 7075.

To reduce the risk of overheating and burning of the metal during the extrusion process, as well as the formation of defects in the wire, the tool temperature should not exceed 400°C. The workpiece heating temperature can be 400 - 420°C, with the wheel rotating at 2 to 4 rpm.

Analysis of deformation conditions

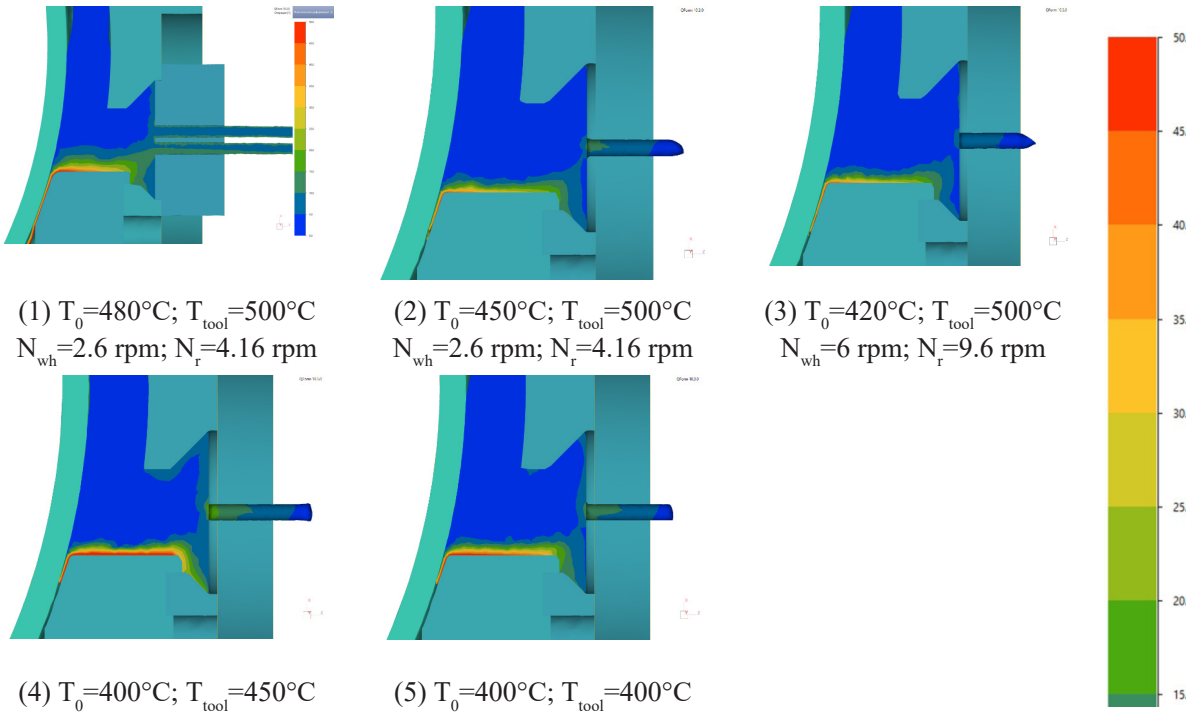
Fig. 5 shows the distribution fields of the accumulated strain in the cross-section of the form chamber and the die channel at different temperature and velocity parameters of extrusion alloy 7075.

A similar distribution pattern of cumulative deformation is observed for all variants. At the point where the rod meets the stop, a zone of intense deformation forms, where equivalent deformation values reach 40 - 50, due to the abrupt 90° change in the metal flow path upon encountering the stationary tool. A slight increase in cumulative deformation values can be observed as the workpiece temperature decreases.

In the form chamber, under conditions of elevated temperature and intense deformation, significant changes in the structure of the workpiece occur, associated with dynamic recrystallization, polygonization, changes in grain size, substructure formation, fragmentation of phase particles, etc. At the exit of the die channels, the wire has deformation values from 5 to 10.

Analysis of trajectory-velocity conditions

For the Conform process, an analysis of the deformation trajectory and velocity conditions is also of interest. Fig. 6 shows the flow velocity vector distribution fields in the cross-section of the form chamber and die channel for various temperature and velocity parameters of 7075 alloy extrusion. In this case, the metal flow rate, expressed as the flow velocity and direction, will depend not only on the feed rate of the rod into the form chamber and the tool geometry, but also, to a significant extent, on the friction conditions at the contact interface between the workpiece and the tool. The Conform process utilizes multiple tools, including stationary and rotating ones, creating a complex combination of friction conditions. As the feedstock rod is fed by a roller and wheel, the velocity vector of each point is tangential to the wheel radius, and its value depends on the wheel rotation speed. When the leading end of



(1) T_0=480°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

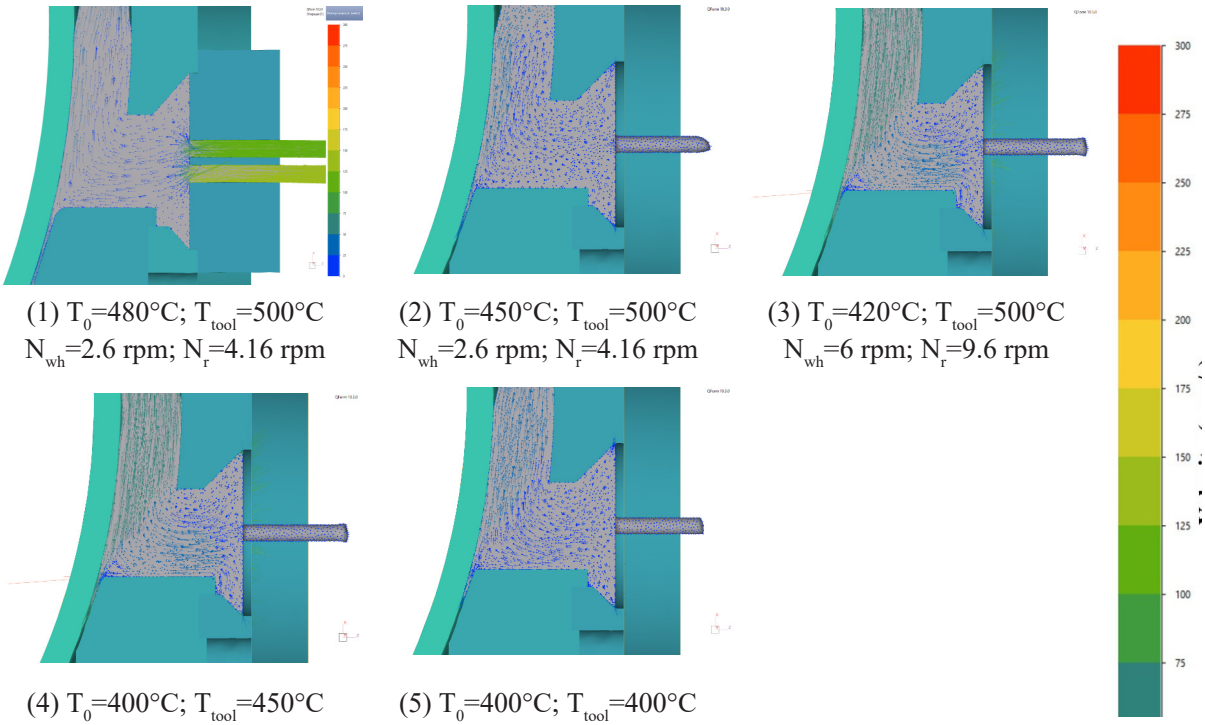
(2) T_0=450°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

(3) T_0=420°C; T_{tool}=500°C
N_{wh}=6 rpm; N_r=9.6 rpm

(4) T_0=400°C; T_{tool}=450°C
N_{wh}=4 rpm; N_r=6,4 rpm

(5) T_0=400°C; T_{tool}=400°C
N_{wh}=2 rpm; N_r=3,2 rpm

Fig. 5. Distribution fields of the accumulated strain in the cross-section of the form chamber and the die channel at different temperature and velocity parameters of extrusion alloy 7075.



(1) T_0=480°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

(2) T_0=450°C; T_{tool}=500°C
N_{wh}=2.6 rpm; N_r=4.16 rpm

(3) T_0=420°C; T_{tool}=500°C
N_{wh}=6 rpm; N_r=9.6 rpm

(4) T_0=400°C; T_{tool}=450°C
N_{wh}=4 rpm; N_r=6,4 rpm

(5) T_0=400°C; T_{tool}=400°C
N_{wh}=2 rpm; N_r=3,2 rpm

Fig. 6. Distribution fields of flow velocity vectors in the cross-section of the form chamber and the die channel at different temperature and velocity parameters of extrusion of 7075 alloy.

the rod encounters the stop, the metal flow trajectory changes sharply with a 90-degree rotation angle, resulting in high values of accumulated deformation at the contact interface with the stopper (Fig. 5). Next, when the form chamber is filled, the metal is distributed towards the free zones and fills the space, after which it begins to flow into the die channels.

The resulting velocity vector distribution patterns reveal several zones of difficult deformation, where the metal's velocity is close to zero. These zones are the annular zone of the form chamber and the region of the die between the channels. The die has no cone angle at the channel entrance and no reverse cone or rounding radii at the exit, which would prevent possible undercutting of the wire or a reduction in extrusion force and a reduction in the difficult extruding zone at the entrance.

CONCLUSIONS

As part of the work, an analysis of the temperature, deformation and velocity parameters of the process of extrusion Conform high-strength aluminium alloy 7075 was carried out using computer modelling using the finite element method.

- The conducted analysis of the workpiece temperature during the extrusion process using the Conform method showed that both the temperature of the workpiece and the tool, and the choice of extrusion speed are significant factors in the design of modes.
- Heating the tool to 500°C (provided its temperature is maintained) and heating the workpiece above 450°C leads to the formation of unacceptably high temperatures (500 - 506°C) in the mold chamber and at the outlet of the die channels. For the variant where the workpiece temperature is reduced to 420°C, but the wheel speed is increased by 2.3 times, intensive heating to 505 - 540°C also occurs due to the increased strain rate. These temperature and velocity conditions of extrusion can lead to metal burnout, instability of the extrusion process, wire breakage at the outlet of the channels, or other defects.
- To reduce the possibility of overheating and burning of the metal during the extrusion process and the formation of wire defects, the temperature of the tool should not exceed 400°C. The heating temperature of the workpiece can be 400-420°C, with a wheel rotation speed of 2 to 4 rpm.
- Several zones of difficult deformation can be identified in the obtained velocity vector distribution patterns, where the metal has a velocity value close to zero. These are the annular zone of the form chamber and the section of the die between the channels. It is recommended that the die be given a cone angle at the channel entrance and a reverse cone or rounding radius at the exit, which would prevent possible undercutting of the wire or a reduction in extrusion force and a reduction in the difficult extruding zone at the entrance.
- A similar distribution pattern of accumulated deformation is observed for all variants. At the point where the rod meets the stop, a zone of intense deformation forms, where equivalent deformation values reach 40 - 50, due to a sharp 90° change in the metal flow trajectory upon encountering the stationary tool. In the form chamber, under conditions of elevated temperature and intense deformation, significant changes in the workpiece structure occur, associated with dynamic recrystallization, polygonization, changes in grain size, etc.

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Authors' contributions

Y.G.: investigation, methodology, writing - original draft, data curation, visualization, validation, resources, software; N.B.: investigation, methodology; S.Ch.: investigation, software; M.M.: supervision, project administration, funding acquisition, investigation, resources; D.V.: writing - original draft, writing - review & editing, formal analysis; S.L.: writing - review & editing, formal analysis.

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