COMPUTER SIMULATION OF THE COMBINED ROLLING-EXTRUSION PROCESS FOR OBTAINING RODS FROM ALUMINIUM ALLOY 7075

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Received 27 January 2026
Accepted 17 March 2026
DOI: 10.59957/jctm.v61.i5.2026.17

ABSTRACT

This article presents the results of numerical modelling of the combined rolling-extrusion process for producing rods of various diameters from alloy 7075. A 7075 ingot with a cross section of 14×14 mm and a length of 200 mm was used as the initial billet. The processing temperature was 450°C, and the diameters of the resulting rods were 5 and 9 mm. The geometric parameters of the tool, as well as the choice of roll rotation speed (4 and 8 rpm), are analysed. An analysis of the temperature conditions of the process, deformation conditions, and trajectory-velocity conditions is performed. It was found that with an increase in the drawing ratio from 4.0 to 12.9, the temperature of the rod at the exit from the die increases by an average of 80 - 100°C. Also, with an increase in the roll rotation speed in the deformation zone, the temperature increases by an average of 60°C. The maximum flow rate for a drawing ratio of 4 was 125 mm s^{-1}, while for a drawing ratio of 12.9, the maximum flow rate was 399 mm s^{-1}. When using rolls with different rolling diameters and low drawing ratios, incomplete filling of the groove will occur. At drawing ratios greater than 10, the groove is filled.

Keywords: *aluminium alloy 7075, rolled wire, combined rolling-extrusion, computer modelling, FEM.*

INTRODUCTION

The development of modern industries such as aircraft manufacturing, aerospace, shipbuilding, transportation, and others is currently accompanied by an ever-increasing role for critical materials. One such material is 7075 aluminium alloy, products made from which are used as welding wire, rivets, and housing components in advanced technology [1]. This material possesses high mechanical and fatigue strength, yet is moderately susceptible to forming treatment, allowing it to be used to produce wire and other deformed semi-finished products.

The deformation behaviour of alloy 7075 was studied by Qingyu et al. and a fairly accurate model of compensated deformation was obtained [1]. The stress-strain curves over a wide range were studied in detail in the work of Zhang et al. [2]. This alloy also has good wear resistance, stability under thermal cycling and aggressive environments, good resistance to crack formation is characterized by good machinability, and satisfactory weldability [3 - 7]. Alloy 7075 is thermally hard enable and allows for an expansion of the range of strength properties of products obtained as a result of quenching [8 - 10]. Using various deformation and heat treatment schemes, it is possible to obtain products with strength of up to 600 MPa and higher [10 - 13].

However, classical metal forming methods do not always provide a balanced combination of mechanical and operational properties for rods made of difficult-to-deform alloys such as 7075. The equal-channel angular pressing (ECAP) method has a significant impact on the mechanical properties and structure. Currently, in the production of long-length deformed semi-finished products in the form of rods and wire, including those made of high-strength aluminium alloys, it is advisable to use combined processing methods that are characterized by high productivity, compactness, a favourable stress-strain state pattern, and rapid transition from one standard size to another [14]. One of these processes is combined rolling-extrusion (CRE), which can be used to produce rods of small cross-section from alloy 7075.

Another important factor is the process of producing the billets for subsequent deformation. Electromagnetic mold (EMM) technology offers several distinct advantages: a uniform ultra-granular structure, high strength, and preserved plastic properties [15 - 17].

The CRE method using an initial billet from an EMM has already proven itself in the production of rods from various aluminium alloys [17 - 20]. However, the development of production modes for 7075 alloy rods using the CRE method from a billet after an EMM requires additional research and computer modelling to establish the process parameters.

In this regard, the objective of this work was to conduct computer modelling of the process for the further development of CRE modes to produce rods from alloy 7075. Achieving this goal involved completing several tasks:

- Creation of a model of the elements of the working unit of the CRE installation.
- Analysis of temperature conditions during simulation.
- Analysis of deformation conditions during simulation.
- Analysis of trajectory-velocity conditions during simulation.

EXPERIMENTAL

The combined rolling-extrusion (CRE) process for 7075 alloy was simulated using the QForm 3D software package. A 14×14 mm square billet of 7075 aluminium alloy, 200 mm long, was used as the initial workpiece for the simulation. A 3D model was created in Autodesk Inventor for the simulation, including the workpiece and the main tooling (Fig. 1).

The optimal extrusion temperature for alloy 7075 rod was set at 450°C, in accordance with the recommended processing parameters. The calculation was performed by varying the key process parameters (drawing ratio and roll speed) to determine optimal extrusion conditions. The key parameters of the starting material and tool are listed in Table 1.

The rheological and thermophysical properties of the alloy were taken from the QForm database. The extrusion drawing ratio λ and the roll speed n (rpm) were varied in the simulation (Table 2).

For comparative analysis, the distribution of temperature fields, accumulated degree of deformation, and flow vectors in the deformation zone were considered.

RESULTS AND DISCUSSION

The QForm calculation process considers changes in the workpiece temperature, considering its heat exchange with the environment and the tool. Fig. 2 shows the temperature distribution fields in the deformation zone for various process parameters for extruding 7075 alloy. For all simulation variants, the rod cools before the

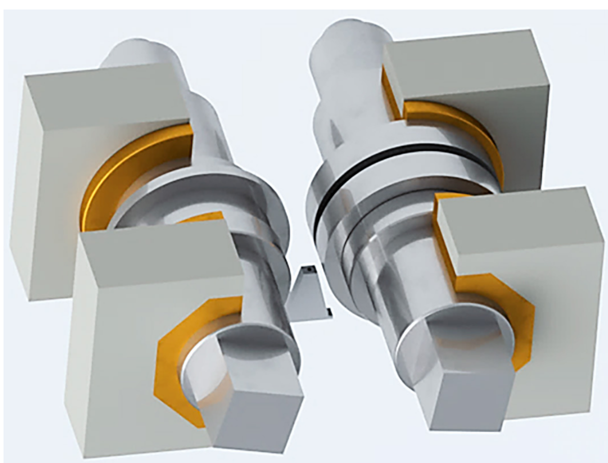

Fig. 1. View of the main elements of the working unit of the CRE-200 installation.

Table 1. Parameters of the original workpiece and tool.

Parameter	Designation	Units of measurement	Value
Workpiece			
Height × Width	$h \times b$	mm	14 × 14
Length	L_b	mm	200
Material	-	-	7075
Heating temperature	T_b	°C	450
Tool			
Material (rolls)	-	-	5135
Material (die)	-	-	H13
Die hole diameter	D_d	mm	5; 9
Roll diameter with protrusion	D_1	mm	214
Roll diameter with groove	D_2	mm	168
Groove width	b_c	mm	15
Die mirror height	h_d	mm	17
Number of die holes	-	pcs.	1
Roll rotation speed	N_r	rpm	4.0; 8.0
Tool temperature	T_t	°C	100

Table 2. Variable parameters during the simulation of the CRE process for alloy 7075.

Parameter	Variant number			
	1	2	3	4
Drawing ratio λ	4.0	12.9	4.0	12.9
n, rpm	4.0	4.0	8.0	8.0

initial pressing stage in the deformation zone, where its temperature increases by an average of 75°C. Increasing the drawing ratio from 4.0 to 12.9 increases the rod temperature at the die exit by an average of 80 - 100°C. Also, with increasing roll speed, the temperature in the deformation zone increases by an average of 60°C.

The maximum temperature was achieved in the fourth variant, with the maximum temperature at the die exit being 489°C.

At a drawing ratio of 4.0, uneven temperature distribution is observed in the deformation zone. Specifically, heat loss to the workpiece is greatest on the grooved roll side, as it has a larger contact surface with the workpiece. Furthermore, the mismatch in flow rates caused by the different rolling diameters of the rolls leads to a temperature increase of 10 - 15°C at the exit from the protruding roll side.

The conducted analysis of the workpiece temperature during the extrusion process using the CRE 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 deformation modes.

Analysis of deformation conditions

Fig. 3 shows the distribution fields of the accumulated strain in the deformation zone for various temperature and velocity parameters of extruding 7075 alloy. A similar distribution pattern of the accumulated strain is observed for all variants. As the roll speed increases, an increase in accumulated strain is observed on the side of the roll with the protrusion. At the exit from the die channel, the wire has accumulated strain values from 4 to 8.9.

For the CRE process, an analysis of the trajectory-velocity conditions of deformation is also of interest. Fig. 4 - 5 show the distribution fields of the flow velocity vectors in the deformation zone for various temperature-velocity parameters of 7075 alloy extrusion. In this case,

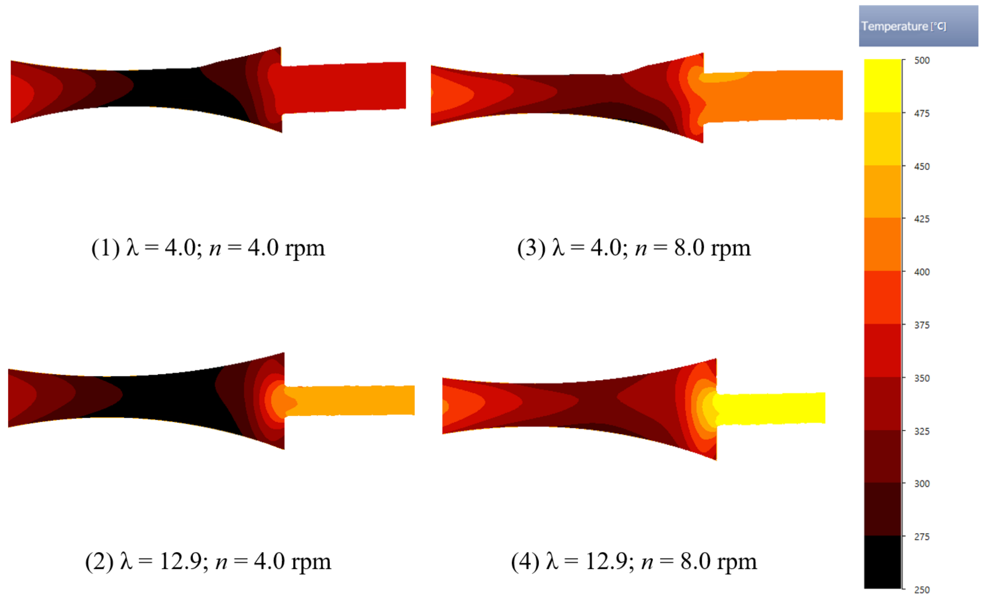

Fig. 2. Temperature distribution fields in the cross-section of the deformation zone at different temperature-velocity parameters of CRE process for alloy 7075.

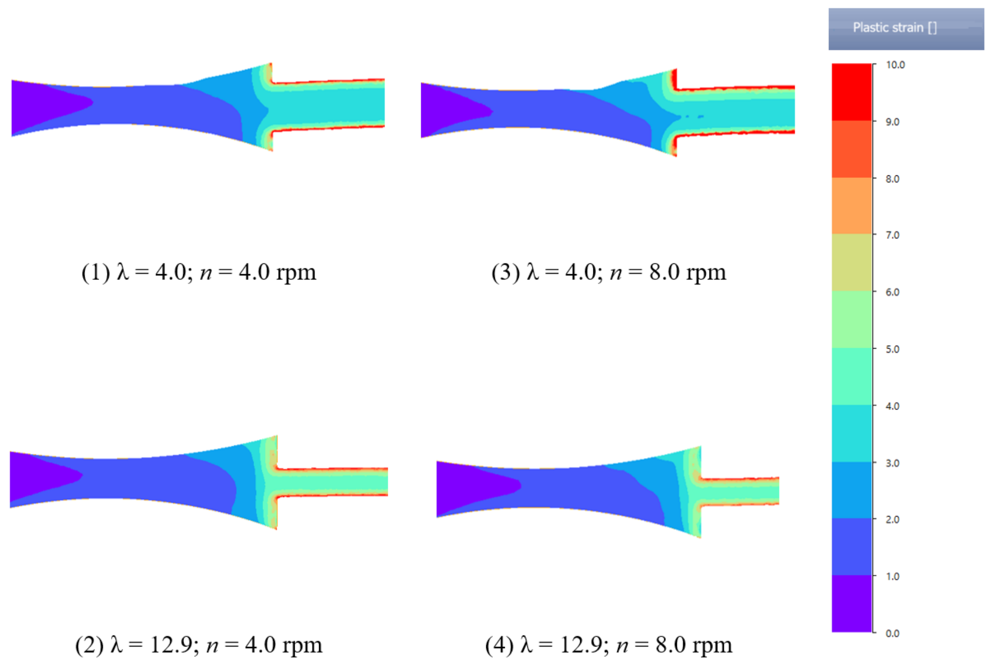

Fig. 3. Distribution fields of the accumulated strain in the deformation zone at different temperature and velocity parameters of CRE process for alloy 7075.

the metal flow intensity, expressed as the flow velocity and direction, will depend both on the tool geometry and, to a significant extent, on the friction conditions at the workpiece-tool interface. During workpiece deformation at the rolling stage, the velocity vector of each point is tangential to the radius of the roll, relative to which the workpiece is oriented, and its value depends on the roll rotation frequency. During the compression stage, the velocity primarily depends on the drawing ratio achieved during the extrusion process. Furthermore,

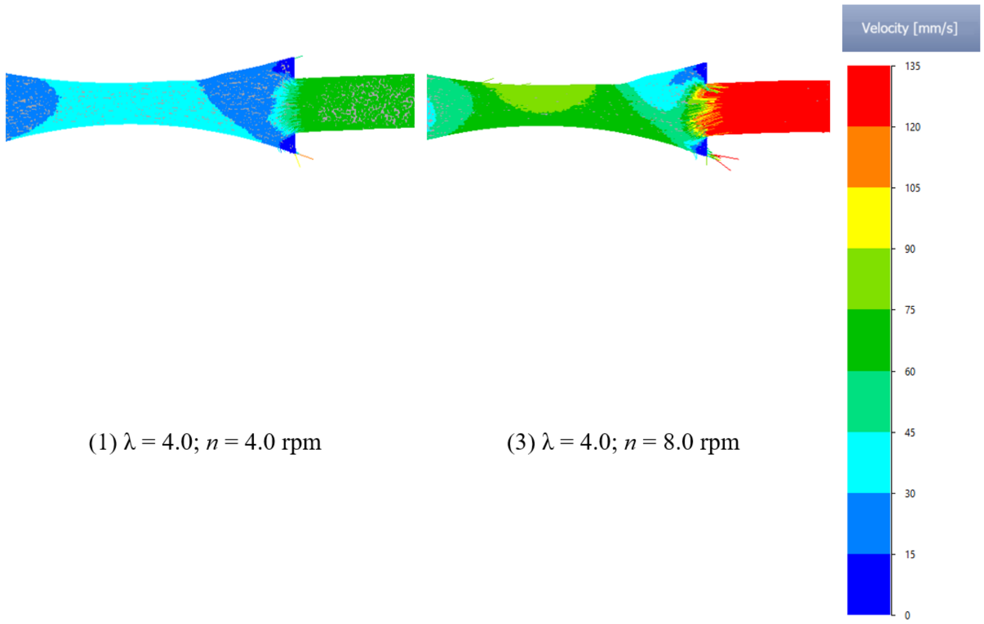

Fig. 4. Fields of distribution of flow velocity vectors in the deformation zone at different temperature-speed parameters of CRE process for alloy 7075 (up to 135°C).

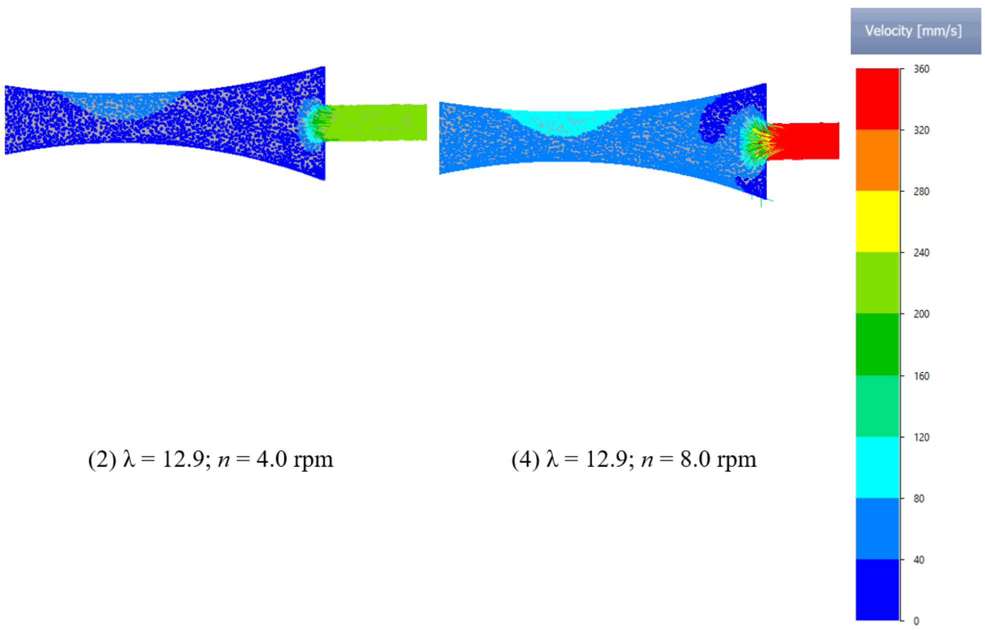

Fig. 5. Fields of distribution of flow velocity vectors in the deformation zone at different temperature-speed parameters of CRE process for alloy 7075 (up to 360°C).

variants with a drawing factor of 4.0 are characterized by an asymmetrical velocity distribution, since the larger diameter of the roll with the protrusion results in a higher peripheral velocity, resulting in incomplete filling of the groove and a shift in the metal flow vector in the deformation zone. For variants with a 12.9 draw, this feature is not typical, since the caliber is filled.

The maximum flow velocity for a drawing ratio value of 4 was 125 mm s^{-1}, and for a drawing ratio value of 12.9, the maximum flow velocity was 399 mm s^{-1}.

CONCLUSIONS

As part of the work, an analysis of the temperature, deformation and velocity parameters of the combined rolling-extrusion process of 7075 aluminium alloy was carried out using computer simulation with the finite element method. The conducted analysis of the workpiece temperature during extrusion using the CRE method showed that the geometric parameters of the tool, as well as the choice of the rotation speed of the rolls, are significant factors in the design of processing modes. The obtained velocity vector distribution fields show that when using rolls with different rolling diameters and low drawing ratios, incomplete filling of the groove will occur, which affects the uniformity of metal flow in the deformation zone; this effect is more pronounced with increasing rotational speed of the rolls. At an elongation ratio greater than 10, complete filling of the groove occurs. A slight shift in the field of increasing values of the accumulated strain can be noted on the side of the roll with the protrusion. With an increase in the drawing ratio, the accumulated deformation in the extrusion zone increases.

Acknowledgments

The research was supported by a grant from the Russian Science Foundation No. 22-19-00128-П, https://rscf.ru/en/project/22-19-00128/.

Authors' contributions

A.P.: investigation, methodology, writing - original draft, data curation, visualization, validation, software; D.V.: investigation, writing - original draft, writing - review & editing; M.M.: supervision, funding acquisition, investigation, resources, data curation; A.D.: investigation, writing - original draft, validation; S.S.: conceptualization, methodology; E.P.: methodology, writing - review & editing, visualization, formal analysis; I.K.: investigation, resources; M.V. project administration, writing - review & editing, formal analysis; O.N.: investigation, software; D.S. visualization, validation; D.G.: investigation.

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