Simulation of Ingotless Rolling-Extruding of Rods from Alloy of Al-Zr System and Investigating Into Their Properties

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Abstract. Computer simulation of the process of ingotless rolling-extruding (IRE) of aluminum alloy rods with a content of 0.15% zirconium in the Deform 3D software package performed. The temperature, speed and deformation parameters of the treatment of the investigated alloy determined under different process conditions. To check the adequacy of the models, rod samples were made on a CRE-200 laboratory unit at specified processing parameters. Using the Deform 3D software package, the forces acting on the rolls and the extruding die during the IRE determined and their comparison with tensometric experimental data presented. The mechanical properties, electrical resistivity of semi-finished products after processing by the method of ingotless rolling-extruding and for conditions of their heating to 230 °C investigated. Technological recommendations for the manufacture of deformed semi-finished products using the method of ingotless rolling-extruding are proposed.

Introduction

Recently, simultaneously with the growing demand for aluminum conductor products, the requirements for the quality of semi-finished products for its manufacture have been increasing. First of all, modern electrical engineering requires long rods of round cross section with a plasticity level that provides the possibility of subsequent cold processing without destruction, minimum weight, electrical resistance and strength level, which remains after heating the wires to 200 ºC [1-3].

Significant improvement of the strength, plastic properties and heat resistance of conductor semi-finished products allows alloying with zirconium alloys and their subsequent processing by the method of ingotless rolling-extruding (IRE), during which there is an additional form of alternating shear deformation of the metal, which increases the ultimate tensile strength and elongation to failure of the rods [4-13]. A good combination of the properties of extruded products is ensured by the processing of an aluminum alloy with a zirconium content of 0.15% and IRE parameters proposed by the authors in [14-16], however, in the early studies, the influence of the drawing coefficient when extruding metal from the die on the properties of the products did not evaluated.

The aim of this work is to simulate the process of IRE of an aluminum alloy with a content of 0.15% zirconium at different drawing coefficients to determine the temperature-speed, deformation and force parameters of the process, as well as to study the properties of rods made at specified parameters in the deformed state and after heating to temperature 230 ºC.

Methods of carrying out researches

The simulation was carried out in the Deform 3D program for the instrumental unit of the laboratory installation of combined processing CRE-200 [3, 4, 16], a computer model of which is shown in Fig. 1.

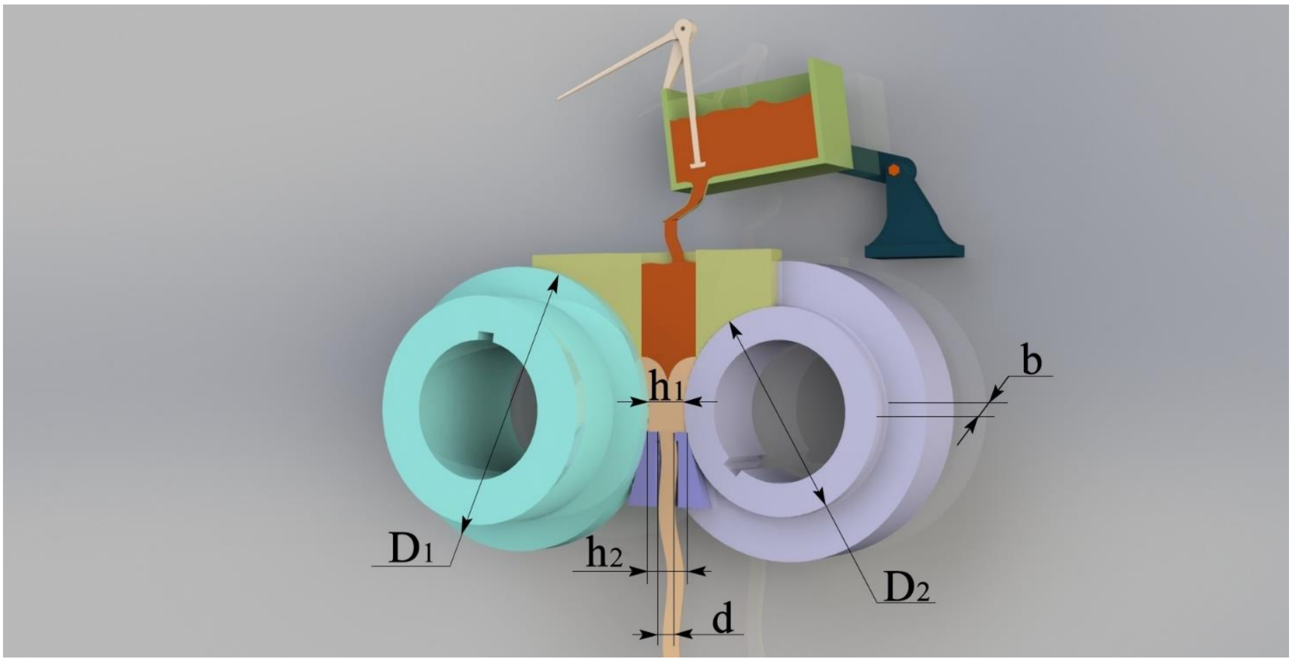


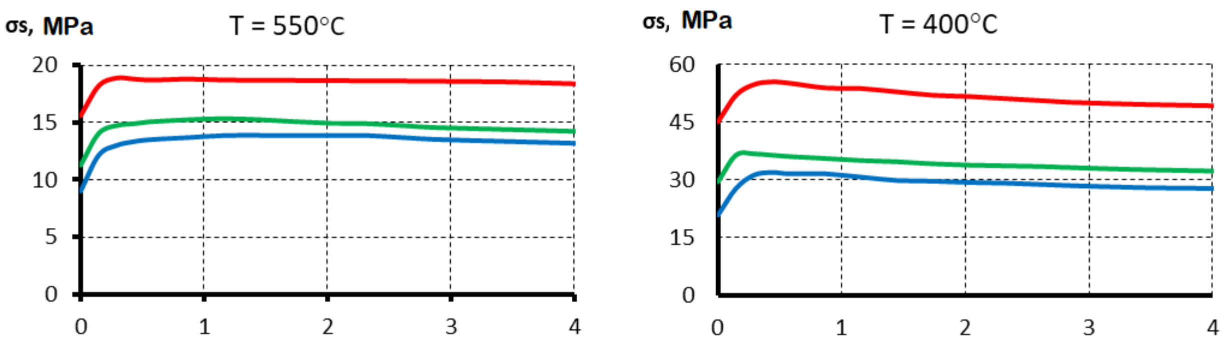
Fig. 1 Computer model of the combined processing unit CRE-200 [3, 4, 16]

The geometrical parameters of the roll tool with the roll diameters along the protrusion D_1 = 214 mm and the bottom of the caliber D_2 = 167 mm, the width of the caliber b = 14 mm, the minimum height of the caliber on the common axis of the rolls h_1 = 7 mm; the height of the die mirror h_2 = 20 mm and the diameter of the calibrating hole of the die d = 5, 7 and 9 mm.

The technological parameters were as follows: the temperature of the melt before pouring into the rolls was 800 °C; roll temperature 100 °C; roll rotation speed 4 rpm; the degree of deformation during rolling 50%; the extrusion coefficient during pressing was 4.4, 7.3, and 14.3 (the diameter of the rods was d = 9, 7, and 5 mm, respectively). The chemical composition according to the patent [5] is shown in Table 1. The hardening curves of the alloy were determined in [6] by the method of torsion of a conditionally hollow sample (Fig. 2).

Table 1 The chemical composition of the experimental alloy, % [13]

Al	Zr	Fe	Mg	Si	Cu	Zn	B	Σ Ti, V, Cr, Mn
99.277	0.15	0.35	0.01	0.15	0.01	0.02	0.003	0.030



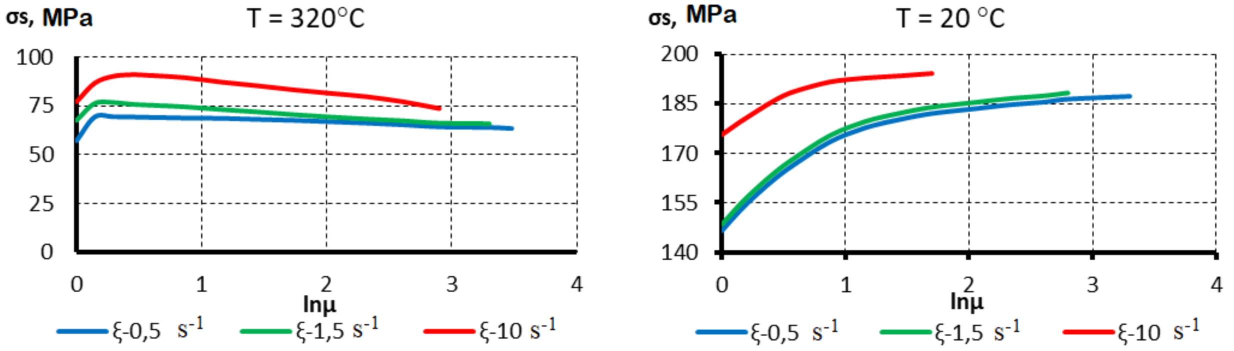


Fig. 2 Experimental alloy hardening curves [6]:
σ_s – plastic deformation resistance, MPa; T –temperature of test, °C; lnμ – true strain; ξ – strain rate, s^{-1}

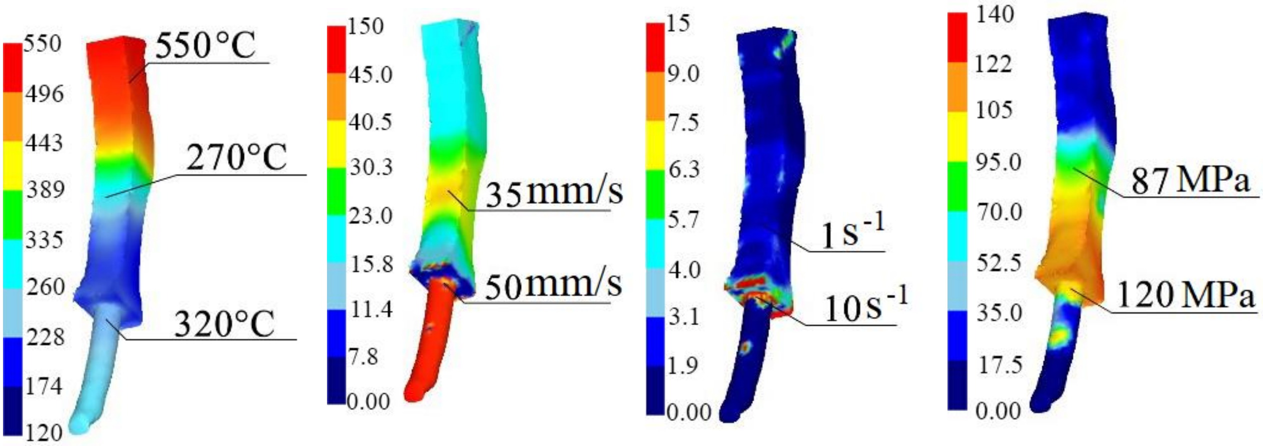
Modeling was carried out under the following assumptions: material of rolls and matrix is rigid; the workpiece material is isotropic, rigid plastic; the values of friction during hot processing on rolls 0.9 and a matrix of 0.5 were taken according to previous studies in discounts [15, 16]; friction at the contact of the rolls and the matrix was not taken into account; the number of crystallized ingot elements of grid was 23629.

To verify the simulation results, experiments were carried out on the production of rods by the method of ingotless rolling-extruding of the alloy on the CRE-200 unit for given initial parameters, during which the force arising on the rolls P_1 and matrix P_2 was measured using ZetLAB strain gauges, CWW-50tf and CWW-100tf from Dacell Co. Ltd.

The study of the properties of the samples was carried out in a deformed state after IRE and heating for 1 hour at a temperature of 230 °C to assess the change in properties. The ultimate tensile strength R_m and the elongation to failure A determined by the tensile method on a Walter Bai AG LFM 20 machine, the electrical resistivity ρ of the rods was measured on samples with a design length of 1 meter on a “VITOK” milliohmeter.

Results and its discussion

The simulation results of the ingotless rolling-extruding process presented in Fig. 3 and Table 2. The calculation showed that an increase in the drawing coefficient from 4.4 to 14.3 leads to an increase in the temperature at the bar exit from the matrix from 320 to 365 ºC, and the extruding speed from 50 to 140 mm/s and strain rates from 10 to 14 s^{-1}.



a *b* *c* *d*

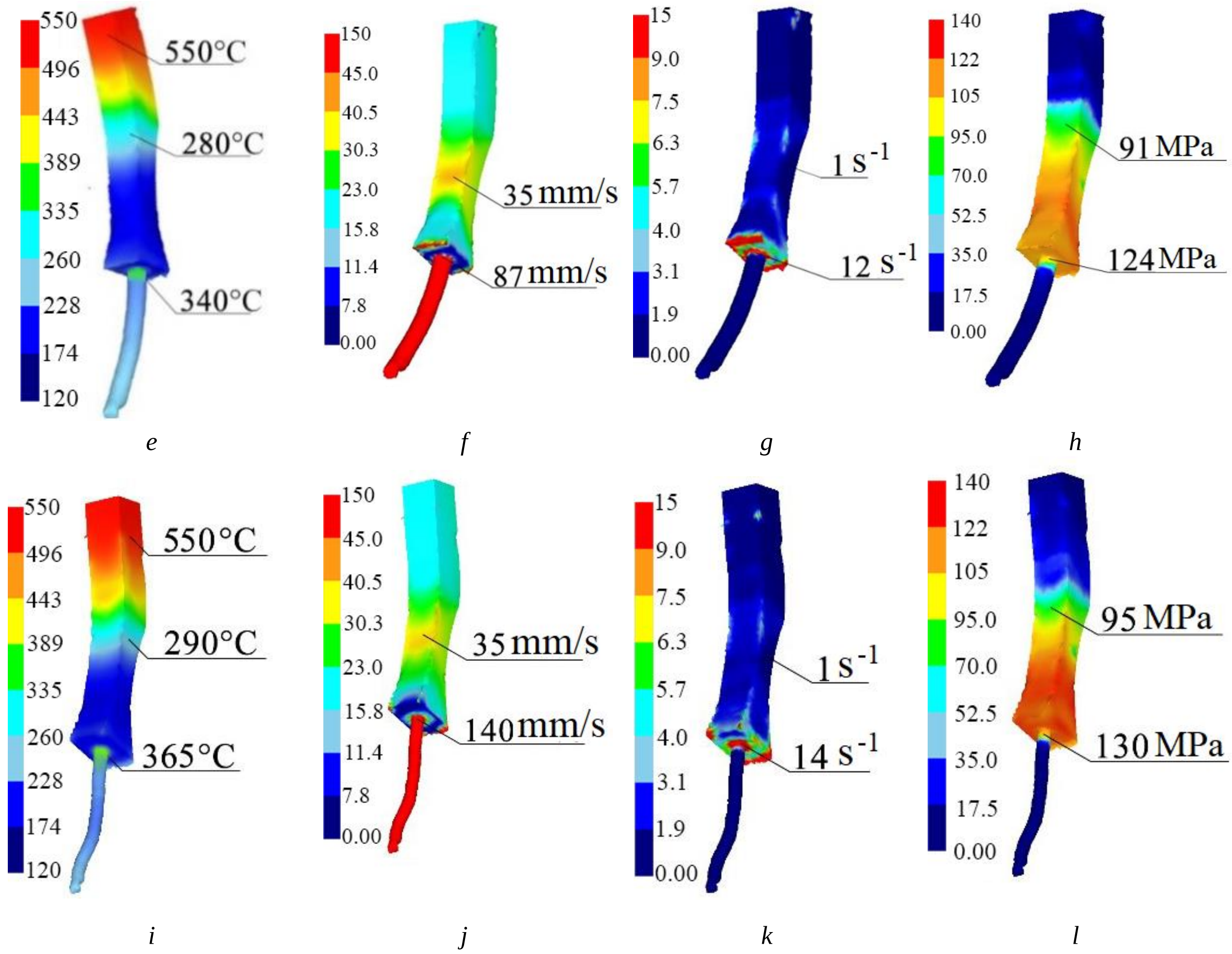


Fig. 3 Process simulation results: *a, b, c, d* – μ = 4.4; *e, f, g, h* – μ = 7.3; *i, j, k, l* – μ = 14.3; *a, e, i* – temperature distribution, ºC; *b, f, j* – distribution of metal moving speeds, mm/s; *c, g, k* – strain rate distribution, s^{-1}; *d, h, l* – stress intensity, MPa

The stress intensity in the rolling-extruding zone depends on the drawing ratio during extruding, namely: an increase in μ to 14.3 leads to an increase in intensity from 87 to 95 MPa. The stress values in the extruding zone increase to 130 MPa with increasing coefficient μ.

The results of measuring the forces during established process of ingotless rolling-extruding are shown in Table 2. An analysis of the data showed that an increase in μ from 4.4 to 14.3 leads to an increase in the force P_1 acting on the rolls from 220 to 310 kN and the force P_2 on the die from 115 to 157 kN. The deviation of the calculated parameters from tensometric measurements does not exceed 7%, which confirms the correctness of the computer model of the process.

Table 2 Power load on the tool in the process IRE

Parameter	*d*, mm	μ	Estimated data in Deform 3D	Tensometric measurements	Deviation, %
P_1, kN	9	4.4	210	220	4.5
	7	7.3	260	280	7.0
	5	14.3	290	310	6.5
P_2, kN	9	4.4	110	115	4.4
	7	7.3	120	125	4.0
	5	14.3	145	156	7.0

Table 3 summarizes the results of the study of the properties of the samples after IRE and heating. According to the data in the Table 3, it can be seen that with an increase in the drawing coefficient μ, the ultimate tensile strength R_m increases from 121 to 135 MPa, the elongation to failure A decreases from 25 to 18%, and the electrical resistivity ρ increases from 0.0298 to 0.0310 Ohm·mm^2/m.

Table 3 Properties of the test samples

Type of processing	After IRE			After heating up to 230°C		
d, mm	9	7	5	9	7	5
μ	4.4	7.3	14.3	4.4	7.3	14.3
R_m, MPa	121	123	135	114	119	126
R_p, MPa	84	91	98	82	88	96
A, %	25	20	18	30	28	26
ρ, Ohm·mm^2/m	0.0298	0.0305	0.0310	0.0289	0.0290	0.0295

After heating 230 °C and holding for 1 hour, the strength of the rods is reduced by no more than 7%, and the electrical resistivity is 3-5%, which confirms the stability of the properties after heating.

Conclusion

As a result of the simulation, a computer model of the process of ingotless rolling-extruding of the investigated alloy was developed, which allows evaluating the rationality of the technological parameters of the manufacture of longish deformed semi-finished products. Using the model, it was determined that an increase in the drawing coefficient up to 14.3 will provide ultimate tensile strength of the rods at the level of 130 MPa, an increase in the extruding speed by more than 2 times, and the maximum forces of 310 and 156 kN acting on the rolls and the extruding die will not exceed the permissible installation load of CRE-200 unit. The study of the properties of the experimental batch of rods showed that the ultimate tensile strength after IRE with a draw ratio of 14.3 is 135 MPa, the elongation to failure is 18%, and the electrical resistivity is 0.0310 Ohm·mm^2/m. After holding the rods at a temperature of 230 °C for 1 hour, the ultimate tensile strength is 126 MPa, the elongation to failure is 26%, and the electrical resistivity is 0.0295 Ohm·mm^2/m. Thus, the processing of the investigated alloy by the method of ingotless rolling-extruding with a higher drawing ratio allows improving the level of properties of the rods and increasing the productivity of their manufacture.

Nomenclature

D_1	roll diameter with protrusion, [mm]
D_2	roll diameter with groove, [mm]
h_1	width of the caliber, [mm]
h_2	height of the die mirror, [mm]
d	calibrating hole diameter of the die, [mm]
σ_s	plastic deformation resistance, [MPa]
T	temperature, [ºC]
μ	drawing coefficient, [-]
ξ	strain rate, [s^{-1}]
R_m	ultimate tensile strength, [MPa]
R_p	yield strength, [MPa]
A	elongation to failure, [%]
ρ	electrical resistivity, [Ohm·mm^2/m]

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