Computer simulation, analysis of force and temperature-speed parameters of the process of combined machining of Al-Mg-Sc alloys

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Abstract. The results of studies of the combined processing of alloys of the Al-Mg-Sc system with known rheological properties under various temperature-rate and deformation conditions are presented. A computer model of the combined machining process was created and the DEFORM 3D complex was used to analyze the metal flow, the distribution of the strain rate and the temperature of the metal over the cross section of the workpiece when receiving round bars of various diameters. The results of the research were used to develop the production technology of welding wire from alloys of the Al-Mg-Sc system.

Keywords: aluminum alloys, scandium, combined machining, rolling-extrusion, temperature, strain rate, drawing ratio, energy-power parameters, welding wire, longish semi-finished products.

1. Introduction

The modeling of metal forming processes has great scientific and applied importance, since the construction of a working model contributes to a better assessment and planning of the results of scientific activity. Preliminary modeling of the metal processing process allows reducing labor and energy costs in comparison with traditional methods of physical modeling. One of such programs is the DEFORM 3D complex of finite element modeling, which allows analyzing and calculating the parameters of combined machining processes to obtain longish deformed semi-finished products [1-3] and establish the patterns of the distribution of metal flow rates, moments and forces on the rolls, the force acting on the die, the temperature distribution in the deformation zone.

2. Experimental procedures

Studies have been performed for one of the alloys of the Al-Mg system doped with scandium. As it is known, scandium is an effective modifier of the cast structure of aluminum alloys. [4-11] and allows to obtain non-dendritic metal structure during the implementation of the method of continuous casting

[12]. In this regard, magnalia, economically doped with scandium, are considered the most promising alloys capable of providing a complex of high mechanical and performance properties.

To create a model used data of combined machining unit CRE-200 [3] and the parameters characterizing the shape of the gauge, the die, the workpiece and the press products are given in Table 1 and Figure 1. For the studied alloy of the Al-Mg-Sc system, the rheological properties were determined (Figure 1), tooling simulation for the combined rolling-extrusion process of metal in the SolidWorks package has been performed. Then, the resulting models and data on the material properties of the workpiece were imported into DEFORM -3D.

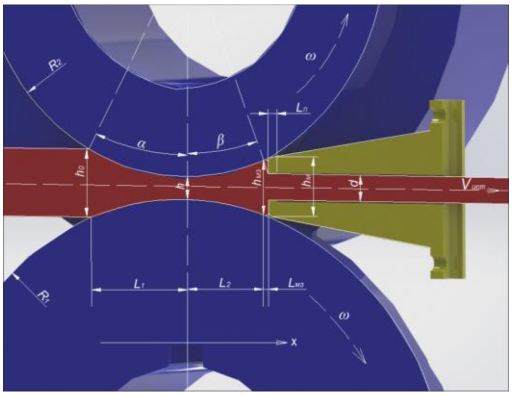

Figure 1. Geometric model of the combined machining process

Table 1. The parameters of the combined machining

Characteristic	Designation	Value
The diameter of the roll with a protrusion, mm	$2R_1$	214
The diameter of the roller with the groove, mm	$2R_2$	164
The average diameter of the rolls, mm	$2R$	189
Minimum height of caliber, mm	h	7
The width of the caliber, mm	b	15
Initial height of the workpiece, mm	h_0	14
Initial width of the workpiece, mm	b_0	14
The diameter of the gage hole of die, mm	d	9
Maximum allowable rolling force, kN	$P_{R.\max}$	1000
Maximum allowable extruding force, kN	$P_{D.\max}$	300

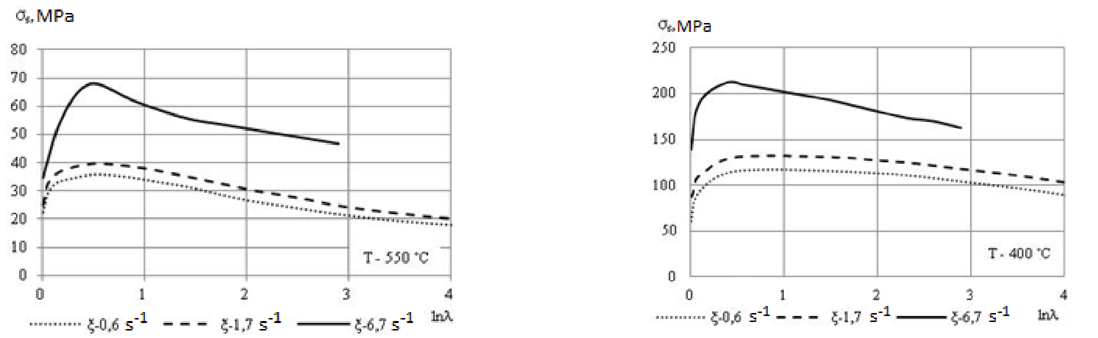

Figure 2. Deformation resistance dependence σ_S of investigated alloy from logarithmic degree of deformation lnλ at different temperatures T and strain rates ξ

When modeling the process used the following boundary conditions:

– workpiece material is isotropic;
– material of rolls and die is rigidly plastic;
– degree of deformation during rolling ε = 50 %;
– Zibel friction indicator when the metal moves along the die ψ_D=0,3;
– Ziebel friction index on the rolls and the calibrating belt of the die ψ_R=0,9;
– the number of finite elements into which the workpiece is divided, 32 thousand pcs.

In order to verify the possibility of implementing the process of combined processing of the investigated alloy, associated with restrictions on energy-power parameters, we calculated the forces acting on the die P_D and on the rolls P_R. It was believed that in the process of combined processing, the temperature of the metal of the workpiece coming into rolling may be equal to T = 450 °C when implementing the process of combined rolling-extrusion [3], either in the implementation of twin roll casting-extruding [2] can reach 550 °C, as this melt of the metal crystallizes in the rolls before the deformation.

3. Results and its discussion

Calculations of power parameters are given in table. 2. As follows from the table, the obtained values do not exceed the allowable values of the forces acting on the die and rolls (table 1). Analysis of the results also shows that with increasing metal temperature at the entrance to the deformation zone, the values of the forces on the rolls and the die decrease, which is associated with a decrease in the resistance of the metal to deformation. An increase in drawing ratio and strain rate leads to hardening of the metal and an increase in the force values, both on the rolls and on the die.

Table 2. Energy-power machining parameters of the investigated alloy on the unit CRE-200

Parameters		T = 450 °C		T = 550 °C	
		μ = 3.7	μ = 11.8	μ = 3.7	μ = 11.8
ξ_1 = 0.78 s^{-1}	P_D, kN	124	237	121	242
	P_R, kN	432	796	372	657
ξ_2 = 1.57 s^{-1}	P_D, kN	108	216	101	241
	P_R, kN	330	807	243	707

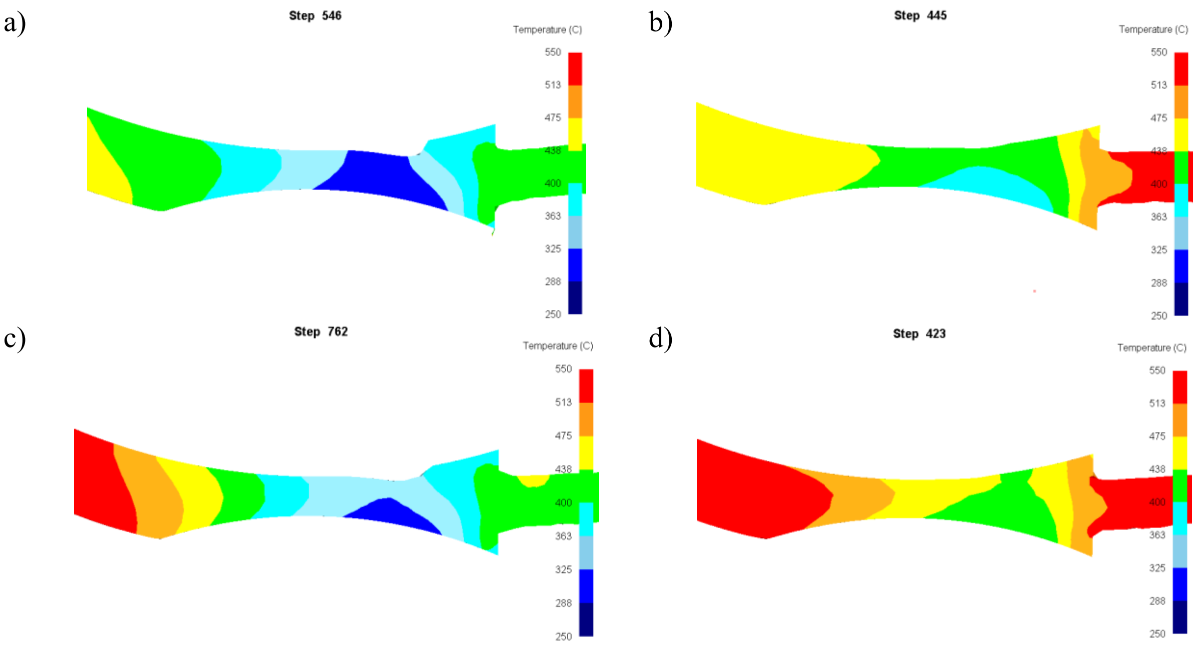

Figure 3. The temperature change in the deformation zone for the studied alloy at drawing ratio $\mu = 3.7$: a, b – $T = 450$ °C; c, d – $T = 550$ °C; a, c – $\xi_1 = 0.78$ s^{-1}; b, d – $\xi_2 = 1.57$ s^{-1}

The variable factors in the simulation were the temperature of the workpiece ($T = 450$ °C and 550 °C), rolling strain rate ($\xi = 0.78$ s^{-1} and 1.57 s^{-1}) and the drawing ratio during extruding to obtain bars with a diameter of 9 and 5 mm ($\mu = 3.7$ and 11.8). By changing the values of the selected parameters, we simulated various technological modes of combined machining.

Figure 3 shows the nature of the forming metal in the process of combined machining and the temperature distribution in the deformation zone.

Earlier studies of the formation of metal in the machining of combined methods on the unit CRE-200 [1-3] suggest that the deformation zone consists of zones of capture and rolling of metal, repressing and extrusion (pressing). At the time of capture of the workpiece by the rolls, it bends toward the roll with a larger diameter (with a protrusion), and after passing the rolling zone, it begins to bend toward the roll with a smaller diameter (with a groove), bounding it. Next, the workpiece reaches the die and begins the process of repressing the metal in the working part of the caliber formed by the rolls and the die. After full filling of the gauge in front of the die, the process of metal outflow begins with the formation of a press product according to the shape and dimensions of the corresponding calibrating hole of die. This sequence of combined machining is confirmed by the simulation data (figure 3, 4). The peculiarity of the change in the investigated alloy is that when drawing ratio $\mu = 3.7$ and strain ratio $\xi_1 = 0.78$ s^{-1} the steady extruding process takes place without completely filling the deformation zone from the side of the roll with a protrusion (figure 3, a, c).

As a result, there is no cooling of the workpiece from the contactless area and the temperature of the workpiece from the side of the roll with a protrusion is higher than from the side of the roll with a groove.

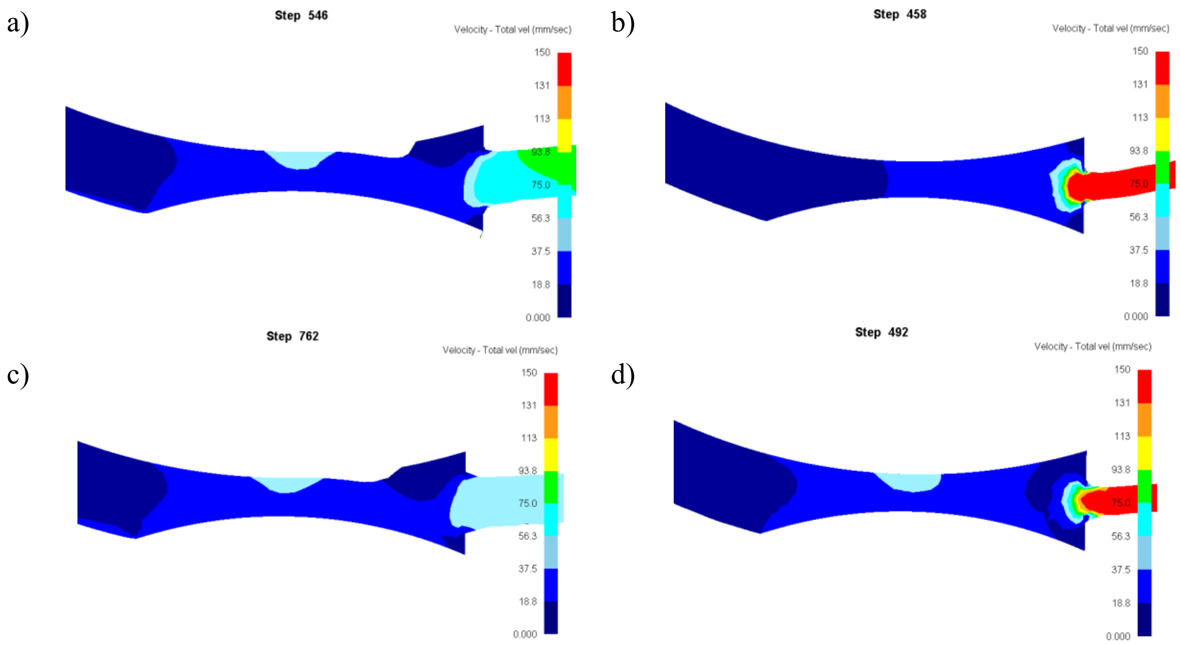

Figure 4. Distribution of strain rate over the cross section of the workpiece for the investigated alloy: a, b – $T = 450$ °C; c, d – $T = 550$ °C; a, c – $\mu = 3.7$; b, d – $\mu = 11.8$

An increase in drawing ratio (figure 4) or strain rate leads to a decrease in the contactless zone or to its absence, which is typical for alloys with high strain resistance. The workpiece is cooled unevenly, and a more intense heat sink is carried out in the lower part of the workpiece from the side of the roll with a groove. Throughout the entire length of the deformation zone, the inner layers of the workpiece have a higher temperature.

Increased drawing ratio is characterized by complete contact of the metal with the roll and a more uniform temperature distribution on the metal surface. In the "dead" zones of the metal in front of the die, there is a slight decrease in temperature (figure 3, c, d), and the bar at the exit from the gauge of the die is heated evenly.

The analysis of the data obtained showed that with an increase in the strain rate, the temperature of the semi-finished product at the exit from the die increases, which is associated with an increase in the strain resistance and the amount of heat released. At the same time, the heat transfer time between the workpiece metal and the tool is reduced, thereby increasing the temperature of the workpiece in the rolling and repressing zone. An increase in the drawing ratio from 3.7 to 11.8 leads to an increase in the strain rate in the extruding zone (figure 4).

These patterns of change in the parameters of combined machining are confirmed by experimental data [1] for the preparation of welding wire from alloys Al-Mg-Sc system.

4. Conclusion

Thus, as a result of the research it was confirmed that the process of combined machining of Al-Mg-Sc system alloys with known rheological properties under various temperature-speed and deformation conditions is realizable, since the limitations on the energy load of the equipment are fulfilled. With the help of modeling in the DEFORM 3D package, the laws of the distribution of metal temperature and strain rate over the cross section of the workpiece with combined rolling-pressing of round bars with a diameter of 5 – 9 mm were established.

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References

[1] Vladimir Baranov, Sergey Sidelnikov, Evgeniy Zenkin, Olga Yakivyuk 2018 *Materials Science Forum* **918** 54–62

[2] Sidelnikov S.B., Lopatina E.S., Dovzhenko N.N. 2015 *Features of structure formation and properties of a metal during high-speed crystallization-deformation and modification of aluminum alloys: a collective monograph* (Krasnoyarsk: SibFU) p 179

[3] Sidelnikov S.B., Dovzhenko N.N., Zagirov N.N. 2005 *Combined and complex methods of processing non-ferrous metals and alloys* (M.: MAKS Press) p 344

[4] S. Malopheyev, V. Kulitskiy, R. Kaibyshev 2017 *Journal of Alloys and Compounds* **698** 957–966

[5] Pedro Henrique R. Pereiraa, Ying Chun Wang, Yi Huang, Terence G. Langdon 2017 *Materials Science & Engineering* **A685** 367–376

[6] M. Li, Q. Pan, Y. Shi, X. Sun, H. Xiang 2017 *Materials Science & Engineering* **A687** 298–305

[7] W. Kang, H.Y. Li, S.X. Zhao, Y. Han, C.L. Yang, G. Ma 2017 *Journal of Alloys and Compounds* **704** 683–692

[8] Anthony De Luca, David C. Dunand, David N. Seidman 2016 *Acta Materialia* **119** 35–42

[9] Zhemchuzhnikova D., Kaibyshev R. 2014 *Advanced Materials Research* **922** 862–867

[10] Zhemchuzhnikova D., Kaibyshev R. 2014 *Materials Science Forum* **794-796** 331–336

[11] D. Zhemchuzhnikova, A. Mogucheva, R. Kaibyshev 2013 *Materials Science & Engineering A* **565** 132–141

[12] Dobatkin V.I., Eskin G.I. 1991 *Non-ferrous metals* **12** 64–67