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NUMERICAL ANALYSIS OF AZ61 MAGNESIUM ALLOY EXTRUSION PROCESS BY MODIFIED EQUAL CHANNEL ANGULAR EXTRUSION (ECAE) METHOD

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The paper presents the results of numerical modelling of AZ61 magnesium alloy hot deformation using modified ECAE method. The temperature-velocity conditions were analysed using FEM. The extrusion process was realised using the die with modified angular channel containing horizontal contracting zone in the material exit direction. The channels were arranged at right angle relatively to each other. The main aim of the numerical research was to determine the most favourable parameters of the extrusion that allow obtaining the products with good mechanical properties. The final product is a round rod that could be used as a material charge to further plastic deformation process.

Key words: AZ61 magnesium alloy, modified ECAE method, FEM

INTRODUCTION

Constantly growing demand for products made from magnesium alloys increases interest in getting newer technologies of their plastic working. It can be seen that more than 90 % of all magnesium based products belong to the group of cast components. However, AZ series alloys because of their properties as e.g. high strength and good ductility are extensively analyzed for their plastic deformation. The elements from magnesium alloys are used to manufacture some constructional elements for aerospace and automotive industry. Good rigidity and high ability of vibration dumping result in their application in electronic industry [1 - 6].

Wrought alloys are less popular then those processed by casting but they are more promising and this is the reason of growing interests in plastic working of the AZ series magnesium alloys. Plastic forming of magnesium based alloys because of their crystallographic structure is conducted in higher temperatures and with low deformation velocities that allows obtaining the product with equivalent parameters. Moreover application of unconventional methods in plastic working as KOBO method or equal channel angular extrusion/pressing (ECAE, ECAP) gives possibility to obtain the material with fine-grained structure and advantageous mechanical properties that can be submit to further cold working [7 - 10].

The aim of the work is a numerical analysis of the conditions of AZ61 rods processing in modified ECAE method. Results of the numerical investigations allow determine the most advantageous parameters for plastic working that will lead to obtaining a product with good mechanical properties.

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TESTED MATERIAL AND TESTING METHODOLOGY

The material used for investigations was AZ61 magnesium alloy. This is a commercially available magnesium alloy which contains aluminum (nominally 6 %), zinc (nominally 1 %), and other trace elements.

For plastometric tests by the compression method using the Gleeble 3800 metallurgical process simulator, specimens of a working part diameter of 10 mm and a height of 12 mm were used.

The first stage of the study was conducting the compression tests in temperature range 250 ÷ 400 °C and deformation rates: 0,1 s^{-1}, 1 s^{-1} and 10 s^{-1}. Obtained results were used to determine rheology equation which describes tested material.

Determined coefficients of yield equation were applied to computer program Forge2008® based on FEM in order to make 3D numerical simulations of the extrusion process of AZ61 magnesium alloy rods in the die with modified angular channel as shown in Figure 1.

The modification of the die was based on the fact that the output horizontal channel was contracted to obtain the rod with smaller diameter which could be used for further plastic deformation. After one pass through the angular channel the reduction coefficient was λ = 2,7.

RESULTS AND DISCUSSION

On the basis of compression tests carried out in different temperatures the strain hardening curves were determined (Figures 2 - 4).

It can be seen that with increase of deformation rate the strain hardening of examined alloy grows, whereas temperature growth causes the lower level of yield stress in compression tests. The nature of the curves

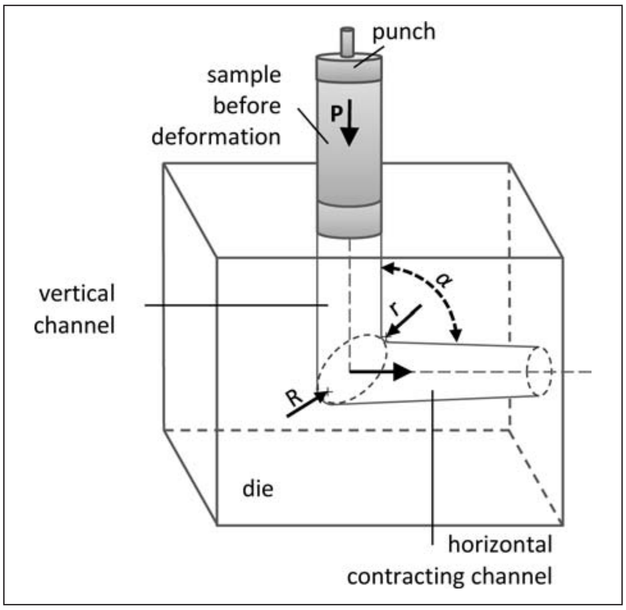

Figure 1 Scheme of modified ECAE process

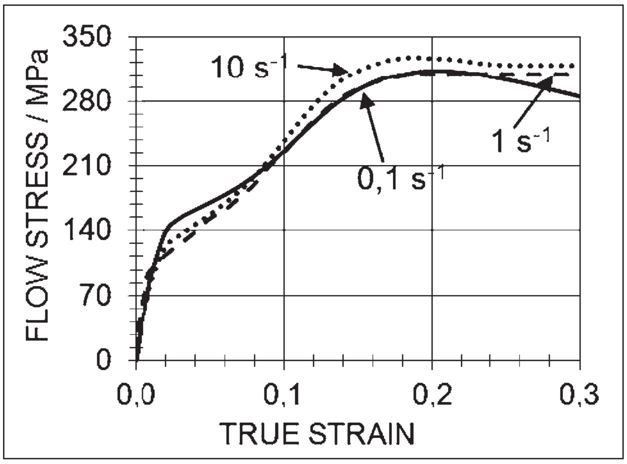

Figure 2 Strain hardening curves for AZ61 alloy obtained from compression tests on the Gleeble 3800 plastometer at temperature 250 °C

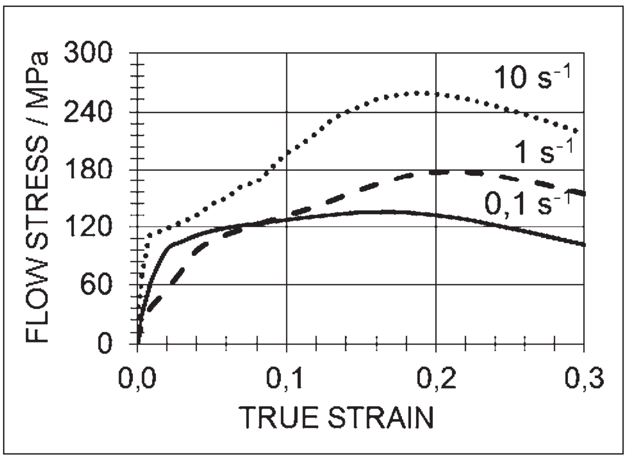

Figure 3 Strain hardening curves for AZ61 alloy obtained from compression tests on the Gleeble 3800 plastometer at temperature 300 °C

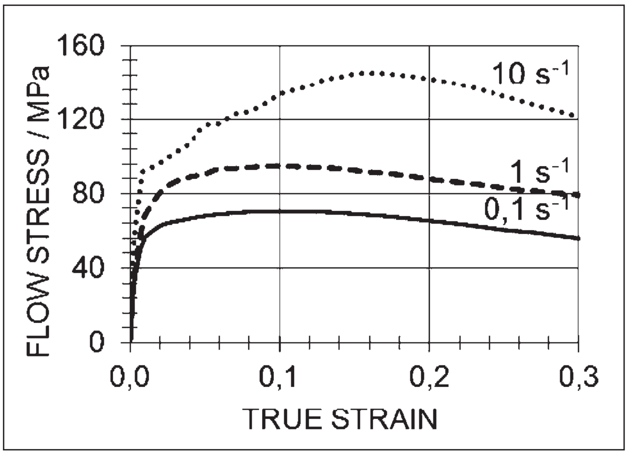

Figure 4 Strain hardening curves for AZ61 alloy obtained from compression tests on the Gleeble 3800 plastometer at temperature 400 °C

shows that recrystallization process takes place during plastic deformation of that kind of alloys.

For the numerical investigations the yield stress model of analyzed AZ61 magnesium alloy was needed. So, Hansel-Spittel equation was proposed:

$$\delta_p = A \cdot e^{m1 \cdot T} \cdot T^{m9} \cdot \varepsilon^{m2} e^{\frac{m4}{\varepsilon}} \cdot (1+\varepsilon)^{m5 \cdot T} \cdot e^{m7 \cdot \varepsilon} \cdot \dot{\varepsilon}^{m3} \cdot \dot{\varepsilon}^{m8 \cdot T}$$

where: A, $m_1 \div m_9$ – are the empirical coefficients.

To evaluate the empirical coefficients of the equation the results of earlier mentioned tests (the stress-strain curves were generated Figures 2 - 4) were used.

The coefficients were determined using inverse approach with the least squares method. The appointed values of yield stress function are as follows: A_0 = 88899,384,

m_1 = 0,002638, m_2 = 0,505723,
m_3 = -0,072545, m_4 = -0,000138,
m_5 = -0,027881, m_6 = 0, m_7 = 4,382078,
m_8 = 0,000596, m_9 = -0,988923.

The coefficients were adopted to the numerical program Forge2008®. The geometry of initial material and tools was drawn in AutoCad2009® while the mesh of finite elements was generated using Preprocess module. The friction conditions were defined using Coulomb's friction model. Thermal conductivity between material and dies equals 2 000 W/m^{2}K. Viscous-plastic model of material flow described by Norton-Hoff equation was applied.

In order to select the appropriate conditions for the extrusion process in modified matrix ECAE a series of numerical studies were performed using several temperature-speed variants. Three extrusion speeds (punch feed rates) were used respectively: 1 mm/s, 10 mm/s and 20 mm/s. Also three different extrusion temperatures were adopted: 300 °C, 350 °C and 400 °C. One of assumptions made was the temperature of working tools. On each of analyzed variants whole tools were heated to the temperature of the extrusion process.

The results of numerical investigations carried out show that the temperature of deformed material strictly

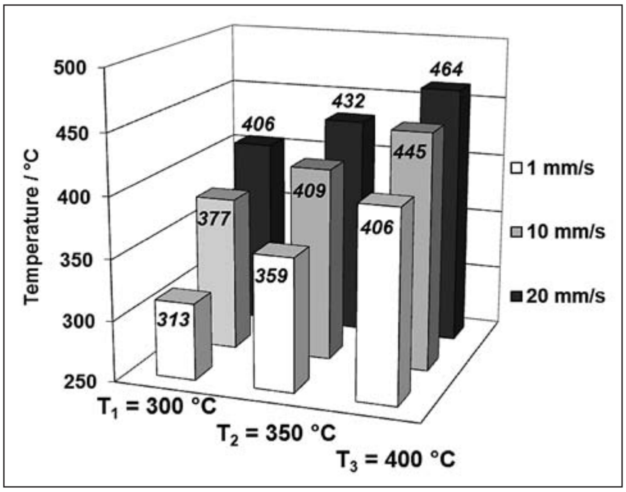

Figure 5 Relation of temperature distribution in material deformed by ECAE method at investigated extrusion temperature and punch feed rate range

depends on assumed temperature-speed conditions during modified ECAE method. Analyzing the results it can be observed that the biggest change in temperature distribution range appeared during the process realized with the highest of applied punch feed rates (Figure 5).

It should be noticed that extrusion deceleration causes stabilization in cross-section temperature distribution. Such a situation is produced by high accumulation of internal stresses that follow from the die construction and changes in material structure. Temperature of deformation process also has a significant influence on temperature distribution in the material. During the extrusion process with 10 mm/s punch feed rate there was observed the most proportional temperature rise in deformed material for each of analyzed extrusion temperatures.

The analysis of equivalent strain distribution in material during modified ECAE process shows that punch feed rate acceleration from 1 mm/s to 10 mm/s causes decrease of equivalent strain values in horizontal contracting channel. Character of analysed value distribution for 20 mm/s extrusion rate is similar to those obtained for 10 mm/s. The higher temperature of the process also results in equivalent strain decrease as shown in Figure 6. It should be noticed that the highest values of plastic strains were observed straight after the material pass through the angular channel and near the surface of the specimen in contracting zone, especially in the exit from the die. The most uniform distribution was obtained for the process temperature 350 °C (see Figure 6b)

Observation of flow stress distribution in deformed material shows the highest concentration of stresses also during the material passing through the angular channel, in shaping zone and exit from the die. The increase of extrusion speed doesn't cause loss of uniformity in stress distribution at deformed material. As can be seen in Figure 7, an increase of the process temperature from 300 °C up to 400 °C result in flow stress decrease and the most significant is for the lowest punch feed rate applied during the modified ECAE method. So it should be seen that the material (AZ61) has good plastic properties at temperature 350 °C and higher.

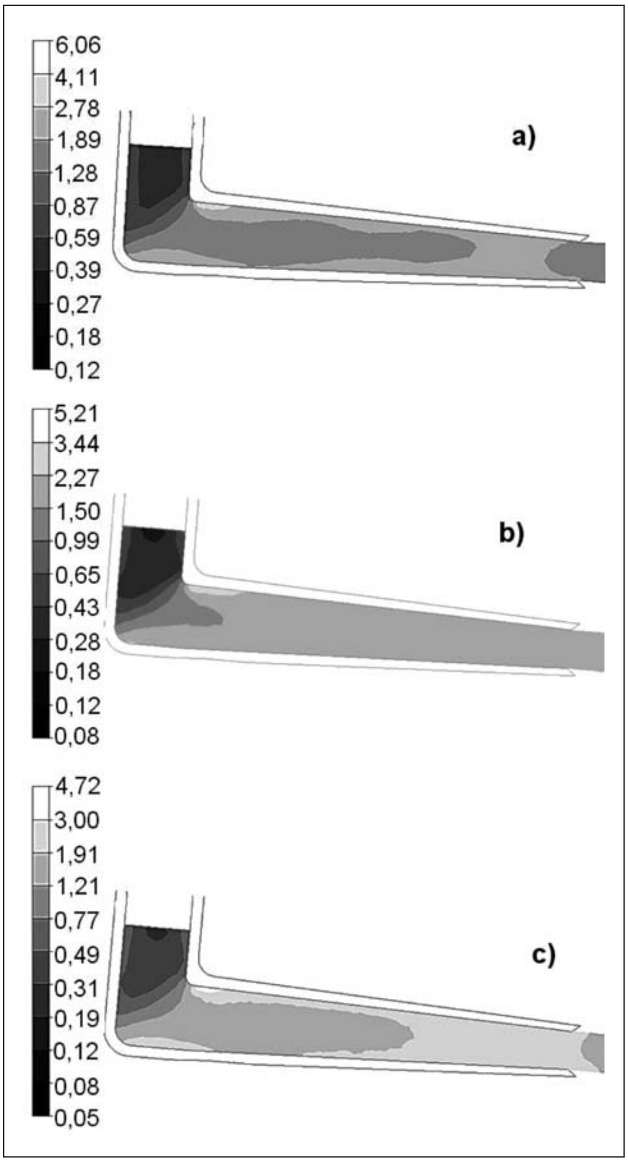

Figure 6 Equivalent strain distribution in material during ECAE process with 10 mm/s punch feed rate at temperatures: a) 300 °C, b) 350 °C and c) 400 °C

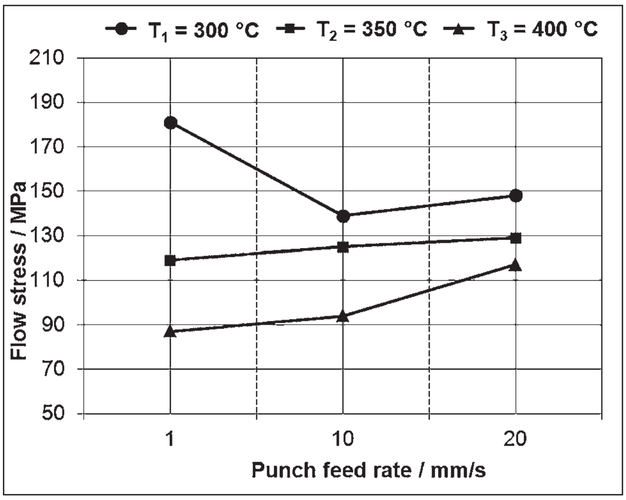

Figure 7 Relation of the flow stress in material deformed by modified ECAE method vs. punch feed rate

SUMMARY

The investigations carried out enable the following observation to be made and conclusions to be drawn.

Application of modified ECAE method to extrusion of AZ61 rods gives a product with good reserve of plasticity.

When the extrusion process was conducted there weren't observed any discontinuities and cracks in the material during transition through the modified angular channel, so it means that the research methodology was appropriate.

The increase of extrusion rate causes higher level of temperature decomposition and higher stress concentration inside deformed material. Observed increase of stress concentration is justified and results from a strong grid reconstruction inside of the material. Acceleration of extrusion speed has an important influence on the temperature level of the process, which is associated with accumulation of energy in deformed material.

Application of at least 350 °C temperature and 10 mm/s extrusion speed allows to obtain a product with an uniform flow stress distribution on longitudinal section. On the basis of the numerical study results can be noticed that using contracted horizontal channel in angular die allows obtaining the material suitable for further processing.

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Note: Jasińska J. is responsible for English language, Czestochowa, Poland