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PHYSICAL MODELLING OF METAL FORMING OF BARS MADE OF MAGNESIUM ALLOYS (AZ61)

FIZYCZNE MODELOWANIE WARUNKÓW PRZERÓBKI PLASTYCZNEJ PRĘTÓW ZE STOPÓW MAGNEZU (AZ61)

This study presents the results of physical modelling of the processes of metal forming of bars made of magnesium alloy (AZ61) obtained using two research methodologies. The study employed the Gleeble 3800 testing system for simulation of metallurgical processes and a torsion plastometer. Depending on the research methodology used, the examinations were carried out in the temperature range of 200 ÷ 400°C and strain rate of (0.1 – 10 s^{-1}). The results obtained in the study were used to determine the value of yield stress for AZ61 alloy for different strain procedures and different temperatures and strain ratios.

W pracy przedstawiono wyniki badań modelowania fizycznego procesów przeróbki plastycznej prętów ze stopu magnezu (AZ61) otrzymane przy zastosowaniu dwóch metod badawczych. Do badań zastosowano symulator procesów metalurgicznych Gleeble 3800 oraz plastomer skrętny. Badania przeprowadzono w zakresie temperatury 200 ÷ 400°C, przy zastosowaniu prędkości odkształcania (0,1 – 10 s^{-1}), w zależności od zastosowanej metody badawczej. Na podstawie otrzymanych wyników badań określono wartość naprężenia uplastyczniającego badanego stopu AZ61 dla różnych schematów odkształcenia oraz warunków temperaturowo-prędkościowych.

1. Introduction

Investigations of lightweight structural materials with good mechanical properties represent a research problem which has been the focus of interest of numerous research centers all over the world. In the last quarter of the century, the particular attention has been paid to magnesium alloys, which are characterized by the best strength-to-density ratio. It should be emphasized that, until the first half of the last century, products made of magnesium alloys were rare due to the complexity of the manufacturing process and, consequently, high costs of production. However, due to the specific properties such as high mechanical strength or good ductility, magnesium alloys have been extensively researched in terms of opportunities for application. Components obtained from magnesium alloys are used, among other things, as structural components in the aviation and automotive industries. Furthermore, good rigidity and improved capabilities of vibration damping increases the opportunities to use these alloys in the electronic industry [1-6]. Growing demand on products made of magnesium alloys causes the increase in the interest in manufacturing and processing technologies of this type of materials. Nowadays, some 90% of all the products based on magnesium belong to the group of cast products.

Therefore, it is justified to search for new solutions that lead to opening up new opportunities to use the products made of magnesium alloys. Only proper design of metal forming processes can allow for obtaining lightweight components with high mechanical properties, which represents a substantial benefit of modern structural materials. One solutions is offered by numerical modelling of conditions of metal forming, which are a very important factor from the standpoint of design of technological processes. The knowledge of characteristics that describe rheological properties of metals is also critical. The basic characteristic of materials for metal forming is yield stress σ_p. Determination of the value of σ_p for the material studied has essential effect on design of hot forming processes [7- 9]. Proper determination of the properties of AZ61 magnesium properties in the form of stress-strain curves with regard to the effect of temperature and strain rate ensures greater calculation accuracy during application of empirical formulae and during numerical calculations [10]. Due to their crystallographic structure, determination of conditions of formability for magnesium alloys, which are included in the group of hard-deformed materials, seems to be justified. Metal forming of magnesium alloys at room temperature is difficult due to their hexagonal compact crystallographic structure with c/a ratio close to the ideal value. Therefore, at room temperature, magnesium alloys are deformed through slipping on the base plane, which offers a limited number of

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deformation systems. Numerous studies on metal forming of these alloys (e.g. rolling, forging, extrusion) have been carried out at elevated temperatures [11, 12]. Forming AZ61 alloys is typically performed in the range of temperature of 250°C – 400°C and small strain rates, with operating deformation systems (slipping on the base plane and prism plane) allowing for achievement of adequate mechanical properties.

The main aim of this study is to determine the value of yield stress depending on the deformation process and to determine its effect on the microstructure of the magnesium alloy studied (AZ61).

2. Material and experimental procedure

The material used in the study was AZ61 magnesium alloy. AZ61 is a commercially available magnesium alloy which contains aluminium (nominal content 6%), zinc (nominal content 1%), and other trace elements.

The process of physical modelling of conditions of metal forming was carried out using two research methods: upsetting and torsion upsetting.

Upsetting tests were carried out using Gleeble 3800 testing system for simulation of metallurgical processes in the range of temperatures of 250 – 400°C and strain rates of: $0.1s^{-1}$, $1s^{-1}$ and $10s^{-1}$. The dimensions of the specimens used for upsetting tests were 10 mm (diameter) and 12 mm (height). It's a device that enables conducting physical simulations for processes such as: continuous casting of steel, rolling, drawing, forging, extrusion, and welding. The system also allows to conduct research on plastic properties of materials for plastic working processes, and to determine material characteristics. The basic technical parameters of the device: sample are: heating rate: 10000 °C/s, max. pressure force: 100kN and max. speed of the mobile jaw: 1000 mm/s.

The second research methodology concerned processes in complex states of strain i.e. simultaneous upsetting and torsion, and consecutive upsetting and torsion. The examinations were carried out using STD 812 torsion plastometer. This device offers broad testing capabilities since it allows for performing free-torsion testing and non-free-torsion testing.

The examinations on torsion plastometer were carried out at temperatures of 300°C and 400°C and for two strain rates: $1s^{-1}$ and $1.5s^{-1}$. Specimens for tests carried out using torsion plastometer were prepared as shown in Fig. 1.

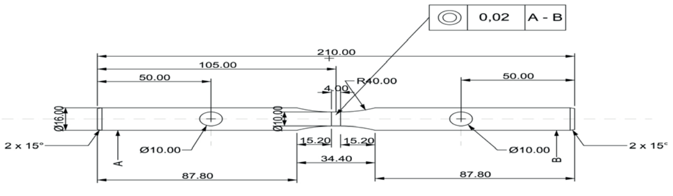

Fig. 1. Dimensions of the specimen prepared for testing on STD torsion plastometer

3. Experimental results

Strain hardening curves were obtained based on the upsetting tests carried out in different conditions of temperature and strain rate, illustrated in Fig. 2.

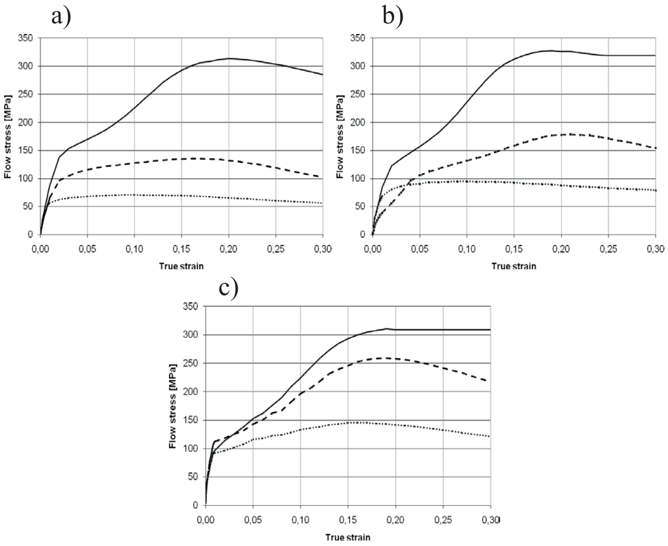

Fig. 2. Strain hardening curves for AZ61 alloy obtained from compression tests on the Gleeble 3800 plastometer at strain rate $\dot{\varepsilon}$ of a) 0.1 s^{-1}, b) 1 s^{-1}, c) 10 s^{-1}

The yield stress values obtained during deformation with the strain rate of $\dot{\varepsilon}$ = $0.1s^{-1}$ (Fig 2a) are the lowest. For the temperature of T = 300 and 400°C and $\dot{\varepsilon}$ = $0.1s^{-1}$, yield stress was σ = 95 MPa and σ = 60 MPa, respectively. For the lowest strain rate at temperatures of 300°C and 400°C, strain hardening curves, after reaching a specific level of stress, are deformed homogeneously (see Fig. 2 a, b). The character of the curves shows that the dominant process of changes that occurred in the structure during deformation at the temperature of 400°C was recovery. A reduction in temperature and an increase in strain rate causes that the dominant mechanism behind the decay of hardening is dynamic recrystallization, which is reflected by the shape of curves presented in Fig. 2.

The deformation that uses combined procedures of deformation has a substantial effect on the shape of strain hardening curves and, consequently, the level of the stress measured. Figure 3 illustrates curves for two different similar deformation procedures that included the upsetting and torsion processes performed simultaneously (Fig. 3a) and one after another (Fig. 3b). The curves presented in Fig. 3 were obtained in the process of deformation at the strain rate of $\dot{\varepsilon}$=$1s^{-1}$ for the torsion and upsetting test. The tests were performed for two temperatures: 300°C and 400°C.

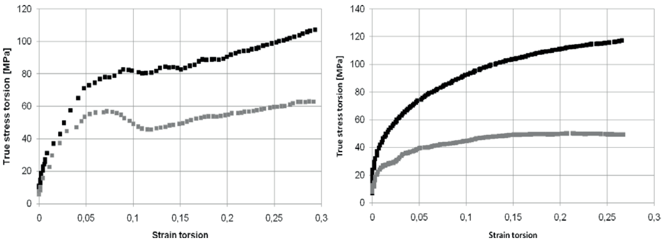

Fig 3. Dependency of true torsional stress on torsional strain for the process (a) performed simultaneously and (b) performed one after another

Analysis of the shape of the curve for torsional stress with respect to torsional strain reveals that simultaneous process of upsetting and torsion is reflected by higher values of yield stress. In the case of performing the process one after another, torsional stress is increasing monotonically with the increase in strain.

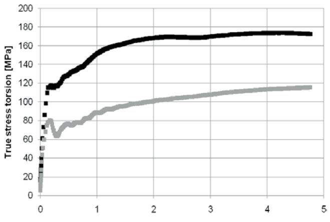

Fig. 4. Relationships between true torsional stress and torsional strain for the process performed simultaneously at the strain equal 2.5 for the upsetting process and 2.5 for the torsion process

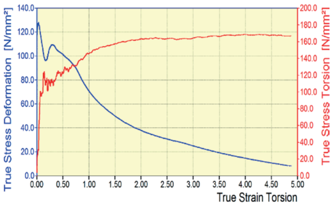

Fig. 5. Dependency of true torsional stress and true stress deformation on torsional strain for the process performed simultaneously at the strain equal 2.5 for the upsetting process and 2.5 for the torsion process at the temperature of 300°C

In order to evaluate the effect of the strain in the process of simultaneous upsetting and torsion, the stabilization of the level of torsional stress is noticeable in both research temperatures. The increase in the strain rate during the process of torsion to the value of 1.5s-1 while maintaining the strain rate for the upsetting process of 1s-1 causes the increase in the value of yield stress by 20 MPa for both research temperatures. After achievement of the torsional strain of 2, stabilization in the value of torsional stress can be observed at the level of 175 MPa for the process carried out at the temperature of 300°C and 118 MPa for the process carried out at the temperature of 400°C. In order to demonstrate the importance of the research procedure used in the study, Figure 4 presents comparison of stress-strain curves for the combined process of upsetting and torsion for the same strain and strain rate conditions at the temperature of 300°C. In the initial range of strain, the value of upsetting stress is 130MPa and starts to decline gradually, while in the same range of strain, the value of torsional stress measured was 75 MPa. An increase in the value of torsional stress to the level of 85 MPa is then noticeable, causing a decrease in the value of upsetting stress to 95MPa. Further increase in strain (ε=0.25) results in the increase in the value of deformation stress (110MPa), followed by its monotonic decline simultaneous with the increase in torsional stress. Undoubtedly, this combination is connected with the increase in the number of torsions during torsion test and starting the mechanisms of deformation in the form of shear bands.

The observation of changes that occur in the structure of the deformed AZ61 alloy was also carried out. Selected photographs of microstructures were presented in Figs. 6, 7 and 8. The specimens for observations using Nikon Eclipse MA-200 optical microscope were etched using the mixture of acetic acid, picric acid and ethanol. The longitudinal sections were analysed in the area of the greatest strain.

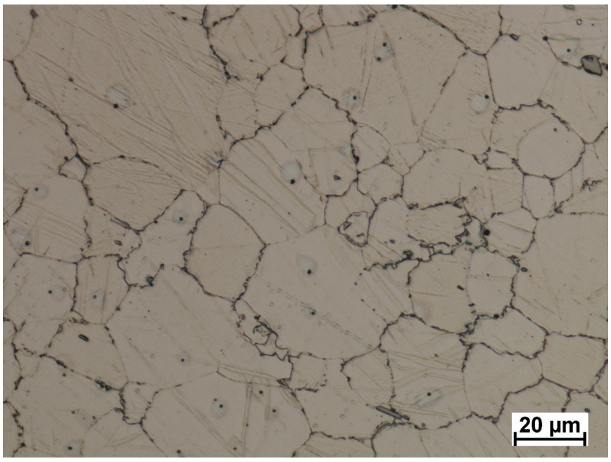

Fig. 6. Microstructure of AZ61 magnesium alloy used as a research material

Fig. 6 presents initial microstruture for the research material. The microstructure shows noticeable big grains with the size of even 80m surrounded with smaller grains with the size of ca. 20mm.

Fig. 7 illustrates photographs of the microstructures obtained during the process of simultaneous upsetting and torsion at the temperature of 300°C (Fig. 7a) and 400°C (Fig. 7b). The strain rate used for the process of upsetting and torsion was $\dot{\varepsilon} = 1$

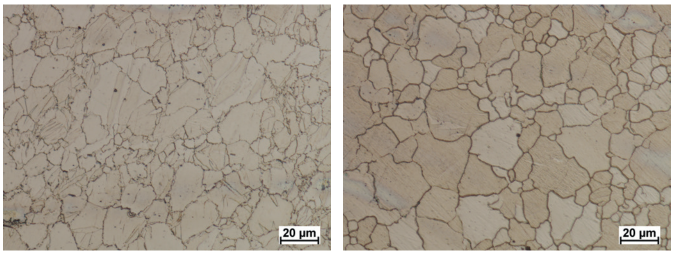

Fig. 7. Microstructure of AZ61 magnesium alloy deformed at the strain rate of $\dot{\varepsilon} = 1 s^{-1}$ for the processes of upsetting and torsion performed simultaneously at the temperature of (a) 300°C and (b) 400°C

The use of the strain temperature of 400°C demonstrated the occurrence of the process of recovery, whereas performing the process of deformation at the temperature of 300°C stimulates the process of dynamic recrystallization. The increase in the level of strain has a substantial effect on grain fragmentation, which is illustrated in Fig. 8. Stability of the material studied was not lost in any of the cases during the deformation process.

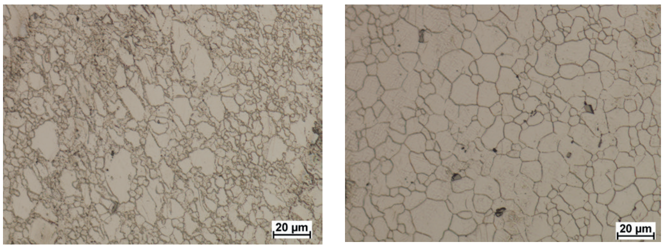

Fig. 8. Microstructure of AZ61 magnesium alloy deformed at strain rate of $\dot{\varepsilon} = 1 s^{-1}$ for the process of upsetting and $\dot{\varepsilon} = 1.5 s^{-1}$ for the process of torsion carried out simultaneously at the temperature of (a) 300°C and (b) 400°C, for fixed strain for each process of $\varepsilon = 2.5$

Deformation at the temperature of 300°C causes the occurrence of extended grains that form a band structure (Fig. 8 a) Simultaneous process of upsetting and torsion at the temperature of 300°C reveals, in the initial period, the occurrence of a dislocation substructure inside big grains, whereas for greater values of strain, it shows noticeable fragmentation. The use of the temperature of 400°C allows for obtaining the material with homogeneous grain without noticeable band structure. The increase in strain significantly affects fragmentation of the microstructure of the AZ61 alloy studied.

4. Summary

The empirical examinations carried out in the study lead to the conclusion that combination of two procedures of plastic deformation of upsetting and torsion causes an increase in accumulation of the deformation effects and formation of the strain state which is particularly conducive to grain fragmentation.

Combination of two procedures of plastic deformation (upsetting and torsion) causes a reduction in the value of yield stress by 20 MPa, which allows for the increase in the value of strain in the alloy studied in one technological operation.

The process of deformation of AZ61 magnesium alloy at the temperature of 400°C is connected with the decay of hardening in all the cases analysed in the study due to the recovery process.

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