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Structure and plasticity of the AZ31 magnesium alloy after hot deformation

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Materials

ABSTRACT

Purpose: The favourable properties of magnesium account for the fact that it is applied not only in cast structural components but also in those subjected to plastic working. Currently, intensive works are conducted to optimize the processes of plastic working of these alloys The following work concentrates on the analysis of microstructure and plasticity of magnesium alloy AZ31 type during hot plastic deformation process.
Design/methodology/approach: After rolling and annealing, alloy specimens were subjected to axial-symmetric compression in the Gleeble 3800 simulator at temperatures ranging from 200 to 450°C at 0.01 and 1.0 s^{-1} strain rates. In order to analyse the processes which take place during deformation, the specimens after deformation were intensely cooled with water. Structural examination was carried out using light microscopy.
Findings: The processes of structural reconstruction such as dynamic recrystallization, which take place during hot - deformation, have been detected.
Practical implications: The research carried out enabled the understanding of the phenomena taking place during deformation and annealing of the investigated AZ31 type alloy. The results will constitute the basis for modelling the structural changes.
Originality/value: The results obtained are vital for designing an effective thermo - mechanical processing technology for the investigated Fe_3Al-5Cr alloy.
Keywords: Metallic alloys; Plastic forming; Microstructure; Compression test

1. Introduction

The favourable properties of magnesium account for the fact that it is applied not only in cast structural components but also in those subjected to plastic working. Investigations of materials and production process of semi-finished products from magnesium alloys formed via plastic deformation methods are now in a phase of intensive development [1-3]. The chemical compositions of alloys intended for plastic working have been developed, obtaining enhancement of strength properties in relation to pure magnesium [1,2]. For the production of sheets in a hot rolling process, the magnesium alloys with aluminium content in the amount of 2.5-3.5% with zinc and manganese additions are used most often. Further enhancement of their mechanical properties is possible through improvement of thermal and plastic working processes or by unconventional processes of modelling the structure and properties [4-7]. These processes aim mainly at alloys' grain size reduction, thus leading to an increase of the yield point, which is shown by the Hall-Petch dependence, without worsening of plastic properties.

Currently, intensive works are conducted to optimize the processes of heat treatment and hot working of these alloys [8-14]. For the optimization of the technology of forming products from magnesium alloys, it is necessary to develop a physical and mathematical model of the structural changes that take place during plastic forming.

In the presented paper, research was undertaken aiming at an evaluation of the effect of hot plastic deformation on the structure of a magnesium alloy with a chemical composition corresponding to grade AZ31 (designation according to ASTM standards), which is used for metal sheet production by means of plastic deformation. The investigations on the influence of deformation on the structure were carried out with applying the hot compression method. The obtained preliminary results concerning plasticity characteristics and the structural changes taking place during continuous deformation will be used for the development of a complex mathematical model of structural changes in the AZ31 alloy during high-temperature deformation.

2. Research methodology

2.1. Research material

Bars of ϕ 15mm after hot rolling, made from alloy AZ31 (ASTM designation) constituted the research material. The chemical composition (in wt%) of AZ31 was: 2.83 %Al, 0.8%Zn, 0.37%Mn and 0.002%Cu.

2.2. Plastometric torsion test

The test was carried out on torsion plastometer, during testing, the methodology described in papers [15, 16] was applied. Due to the relatively low temperatures of deformation of magnesium alloys, the specimens were heated, soaked and subjected to torsion in a tubular chamber furnace. The specimens subjected to torsion had a measuring base of 12mm in length. The tests were carried out at 300, 400 and 450°C with a rotational speed of 65 rpm. Based on the data obtained from the plastometric torsion test, the yield stress σ_p, deformation ε and deformation rate $\dot{\varepsilon}$ were calculated.

2.3. Plastometric compression test

After annealing specimens for strength tests were made, which were subjected to an axisymmetrical hot compression test in a Gleeble 3800 simulator with concurrent structure freezing after deformation by quick water cooling. The specimens were cylinder-shaped and had the following dimensions: ϕ = 10 mm and h =12 mm. Compression tests were conducted in a temperature range of 200-450 °C at a strain rate $\dot{\varepsilon}$ =0.1 and 1.0 s^{-1}, up to deformation ε =1.2. Results of compression tests after processing in Matlab computer programme and spreadsheet allowed determining the flow curves in the stress (σ)-strain ε system. After the compression test, an analysis was made of the microstructure along the cross-section parallel to specimen axis with the application of light microscopy, with a bright field technique.

3. Results

The structure of alloy specimens after hot rolling and annealing at a temperature of 350°C for 60 minutes is shown in Fig. 1. The alloy is characterized by a single-phase structure with numerous deformation twins, which were formed during rolling. Soaking of the alloy at a temperature of 450°C for 10 minutes before plastic deformation leads to grain growth and a reduction of the amount of deformation twins.

The flow curves obtained in compression tests at temperatures of 200, 300, 400 and 450 °C at a rate of 0.01 and 1 s^{-1}, respectively, are shown in subsequent Figures. 2,3. The indices characterizing technological plasticity of the investigated alloy during torsion and compression tests are juxtaposed in Table 2. The tested alloy is distinguished by increased threshold deformability with an increased torsion temperature in the range from ca. 1.2 at a torsion temperature of 300°C to ca. 5 at 450 (Table 1). The flow curves obtained based on torsion tests show a similar level of yield stress obtained for comparable deformation conditions in relation to the torsion curves (Table 1).

The values of deformation ε_p corresponding to stress σ_{pp} are several times higher for curves determined in the torsion tests (Table 1). The nature of the curves obtained based on the torsion tests shows intensive dynamic processes of the structure reconstruction occurring under deformation at a temperature of 300°C and higher for both deformation velocities applied (Figs. 2, 3).

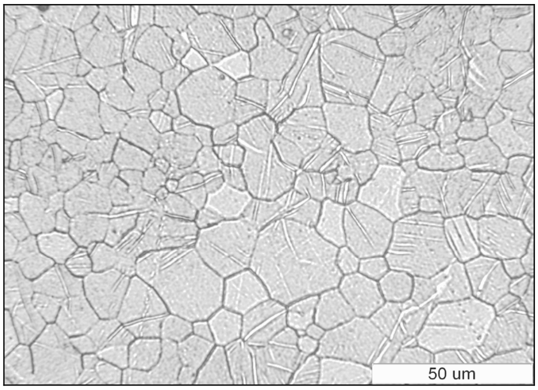

Fig. 1. Alloy structure after hot rolling and annealing at 350°C for 60 minutes with air-cooling

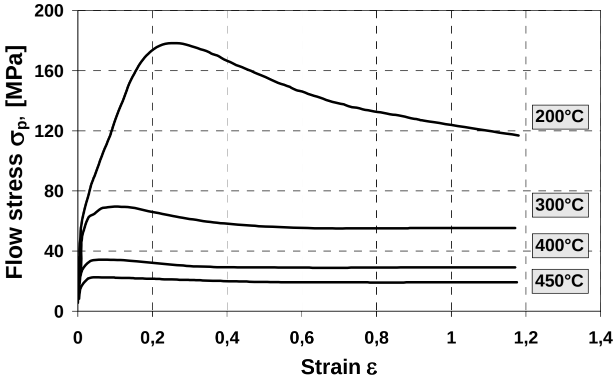

Fig. 2. Flow curves of the tested alloy after torsion at 200, 300, 400 and 450°C at a rate of 0.01s^{-1}

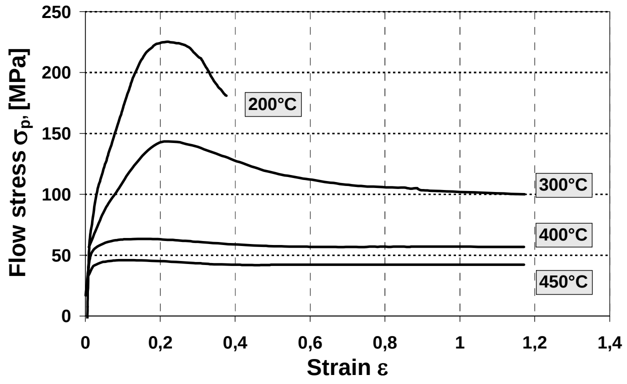

Fig. 3. Flow curves of the tested alloy after torsion at temperatures of 300, 400 and 450 C at a strain rate of $1s^{-1}$

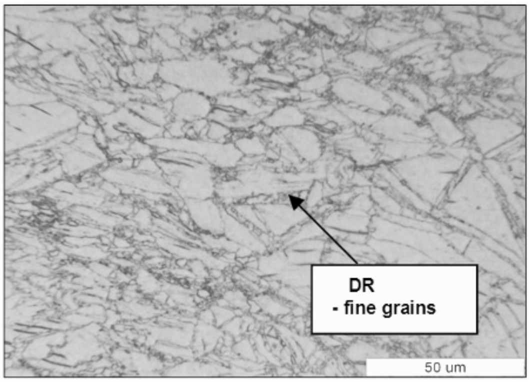

Fig. 4. Structure of the alloy after compression at 200°C at a rate of $1s^{-1}$

Table 1.
Indices characterizing technological plasticity of the investigated alloy during torsion and compression tests

Deformation temperature [°C]	Strain rate $[s^{-1}]$	σ_{pp} [MPa]	ε_p	ε_f
Plastometric torsion test				
300	1	123.8	0.60	1.2
400	1	65.8	0.52	2.8
450	1	51.5	0.55	5.1
Plastometric compression test				
200	0.01	178.2	0.26	-
	1	225.8	0.23	-
300	0.01	69.2	0.08	-
	1	143.4	0.22	-
400	0.01	34.1	0.07	-
	1	63.2	0.17	-
450	0.01	22.5	0.03	-
	1	45.2	0.13	-

The alloy structures after deformation by means of hot compression at 200, 300, 400 and 450°C at a rate of 0.01 and $1\ s^{-1}$, respectively, are shown in Figures 4-7. After compression at a temperature of 200°C for both rates applied for deformation 1.2, a structure of primary elongated and ultrafine dynamically recrystallized grain has been observed on primary boundaries and twinnings (Fig. 4).

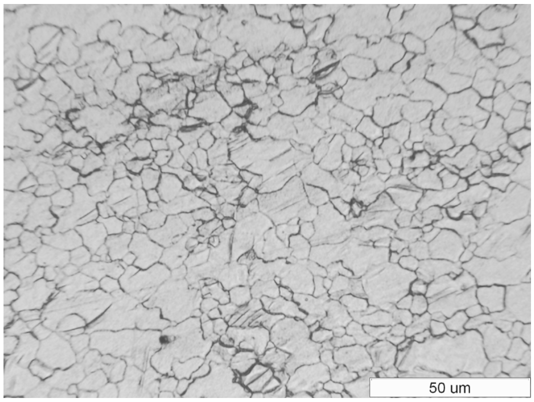

Fig. 5. Structure of the alloy after compression at 300°C at a rate of $0.01s^{-1}$. Fine grains structure

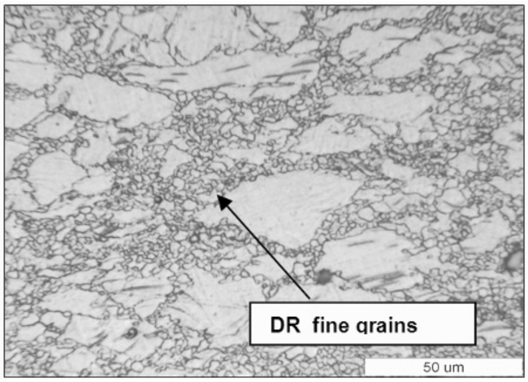

Fig. 6. Structure of the alloy after compression at 300°C at a rate of $1s^{-1}$. Partially dynamic recrystallization structure

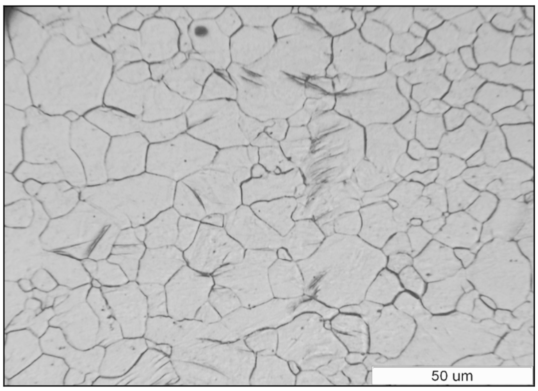

Fig. 7. Structure of the alloy after compression at 450°C at a rate of $1s^{-1}$. Growth of dynamically recrystallization grains

The specimens subject to deformation at a lower strain rate are distinguished by a more advanced recrystallization process, where the recrystallized grain is observed on both the boundaries and within primary grain areas. After deformation at a temperature of 300°C at a rate of 0.01 s^{-1} the microstructure consists of fine dynamically recrystallized grains (Fig. 5), whereas for a higher rate, little chains of recrystallized grain are observed on boundaries of the deformed primary grain. (Fig.6.)

An increase of compression temperature up to 400 and 450°C intensifies the recrystallization and grain growth; also, not numerous deformation twins become visible (Fig. 7).

4. Conclusions

The magnesium alloy is characterized by a single-phase structure with numerous deformation twins formed during rolling. Soaking of the alloy before plastic deformation leads to a grain growth and a decrease of the number of deformation twins. The obtained torsion test results show good alloy deformability after hot rolling. The tests of the structure after hot compression show a tendency of the Mg-Al-Zn alloy to dynamic recrystallization.

The alloy deformation at a temperature of 200°C for both the deformation velocities applied and at a temperature of 300 °C at a rate of $1s^{-1}$ leads to partial dynamic recrystallization. The dynamic structure reconstruction processes taking place, have asignificant influence on a decrease in flow resistance of the alloy tested. A fine-grained recrystallized structure is obtained after compression at a temperature of 300 at a rate of $0.01s^{-1}$. An increase of the deformation temperature leads to a growth of the recrystallized grain. In consequence, after deformation at a temperature of 450°C the grain size is significantly larger than before the deformation.The directions of further research are the following: a quantitative evaluation of the structure of tested alloy, investigations of the mechanisms of plastic deformation of an alloy with the application of electron microscopy, the development of crystallographic orientation maps with the application of scanning microscopy by EBSD method.

The research will be used for the development of mathematical models taking account of the structural changes taking place during dynamic and static recrystallization of alloy AZ31 in high-temperature deformation conditions.

Acknowledgements

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