HIGH-TEMPERATURE CHARACTERISTICS OF PLASTICITY OF MAGNESIUM ALLOYS

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Abstract

The development of deformable magnesium alloys and plastic forming methods has been strongly limited so far. Plastically worked magnesium alloys are very rarely used due to technological difficulties in plastic working and to high production costs. Alloys for plastic working are more and more promising, however, due to the elaboration of new ones and development of the technologies of processing them. A major drawback of magnesium and its alloys is their low deformability at ambient temperature, which is due to the type of crystallographic lattice. 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. The paper presents analysis of plasticity characteristics and microstructure of magnesium alloys for hot plastic treatment with different aluminium content (3 and 8%). Susceptibility of magnesium alloy to cracking in high temperatures was tested on Gleeble3800 simulator on which zero resistance temperature and zero plasticity were determined. Tests were conducted for assessment of susceptibility of tested alloys to hot plastic deformation. A tensile test was realized in temperature from 250 to 450 °C. On the basis of the results, ultimate tensile strength (UTS) and reduction of area (Z) were determined for samples. A varied plasticity of tested alloys was found depending on aluminium content. Tests results will be useful in development of forging technology of chosen construction elements which serve as light substitutes of currently used materials.

Keywords: magnesium alloy, research of plasticity, microstructure, mechanical properties, cracking.

1. INTRODUCTION

A popular group of magnesium alloys are those which contain aluminium with zinc and manganese addition [1, 2]. Those materials, due to the applied ingredients, are relatively cheap. They are characterised with beneficial set of mechanical properties. The most popular is alloy AZ31 which is characterised with good susceptibility to hot plastic treatment and can be shaped in conditions of rolling, extrusion or forging. Resistance of alloys from this group rises together with the increase of aluminium content in them [3]. For the elements which are required to be more resistant, the alloys marked as AZ61 and AZ80 are better because they contain 6% and 8% of aluminium respectively . Alloy AZ31 can reach the resistance of 230MPa and alloys AZ61 and AZ80 respectively 260 and 290MPa. Together with the increase of aluminium content the plasticity and susceptibility to plastic treatment in lower temperatures decreases. That is why those alloys are often used as casting materials [4]. In order to elaborate the technology of plastic forming for those materials it is necessary to determine precisely the properties and microstructure changes of those alloys.

The aim of the paper was to compare the plasticity and the microstructure changes of magnesium alloys AZ31 AZ61 and AZ80 with content of 3, 6,1 and 8% aluminium respectively with addition of zinc and manganese. Plasticity tests results of those alloys and their susceptibility to brittle cracking in high temperature on Gleeble simulator were presented. Plasticity characteristics of alloys were presented before in own papers [5-7]. The dependencies of flow stress and deformation from Zener-Hollomon parameter were determined in paper [8] base on equation presented in paper [9]. Achieved results will be used for preparation of forging construction elements technology for aviation industry Tests of fracture character were conducted with the use of scanning microscopy. On the basis of prepared characteristics the intervals of decreased plasticity were determined. After conducted tension test the changes of plasticity in temperatures from 250 to 450°C were determined. Such tests are crucial for preparing the plastic treatment technology for those alloys. Achieved results will provide data for computer simulation of hot forging process which is necessary to prepare forging technology of precise construction elements for aviation industry.

2. METHODOLOGY

Tests were conducted for magnesium alloys with varied content of aluminium and addition of zinc and manganese with chemical composition presented in **Table 1**.

Table 1 Chemical composition of investigated magnesium alloys AZ31, AZ61 and AZ80 type

Alloy ASTM	Chemical composition, [% mass.]									
	Al	**Zn**	**Mn**	**Si**	**Cu**	**Fe**	**Ni**	**Ca**	**Zr**	**other**
AZ31	3.0	0.71	0.20	0.02	<0.01	0.003	<0.001	0.01	<0.001	<0.30
AZ61	6.1	0.61	0.13	0.02	<0.01	0.003	<0.001	0.01	<0.001	<0.30
AZ80	8.2	0.34	0.13	0.02	<0.01	0.003	<0.001	0.01	<0.001	<0.30

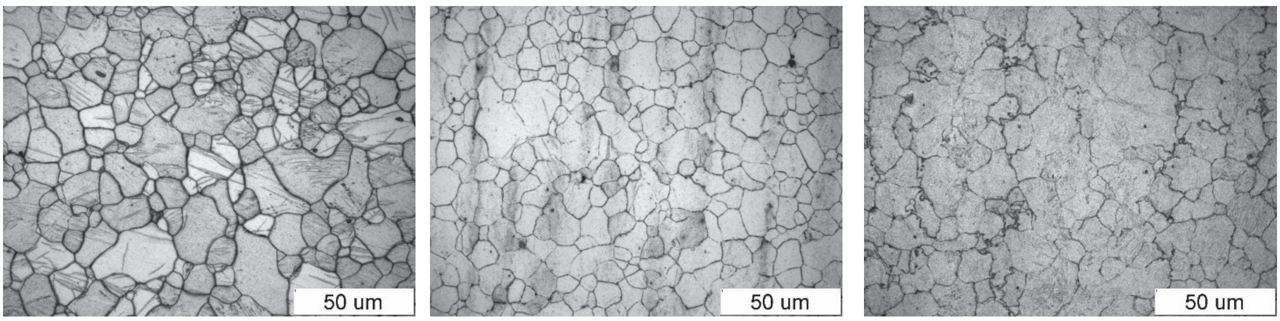
In order to determine the susceptibility of alloy to cracking in high temperature, the following aspects were determined with the use of Gleeble simulator:

- zero resistance temperature (NRT) which is temperature determined during heating and by which the resistance of sample drops to zero,
- zero plasticity temperature (NDT)which is temperature marked during heating in which the sample loses its ability to plastic deformation,
- after determination of plasticity recovery temperature some tension tests were conducted.

For samples after tension, the resistance to tension (R_m)□□ and reduction of area (Z) were determined. Character of fractures in tested samples was analysed with the use of scanning microscope Hitachi S-4200.

3. RESULTS

Microstructure of tested alloys in the initial condition and after annealing at temperature of 400 °C with soaking time of 40 minutes is shown in **Fig. 1**. Before deformation, tested alloys AZ31 are characterised with homogenous microstructure of solution α– Mg. In microstructure of alloy AZ61 and AZ80 the presence of small amount of intermetallic phase division γ - ($Mg_{17}Al_{12}$) was found which was confirmed in earlier X-ray tests [8].



a) b) c)

Fig. 1 Microstructure of investigated alloys in initial state after annealing at temperature of 400°C with holding time of 40 min. a - AZ31, b - AZ61 and c - AZ80

Zero resistance temperature was determined on the level of 580 °C for alloy AZ31. For alloy AZ61 the temperature is lower and equals 530°C. Tests to determine zero plasticity (TZP) were conducted in accordance with diagram presented in **Fig. 2**. First sample was heated to temperature 15 °C lower than the zero resistance temperature marked earlier. For the following tests the temperature was being decreased until the contraction in area was reached which is a proof of plasticity.

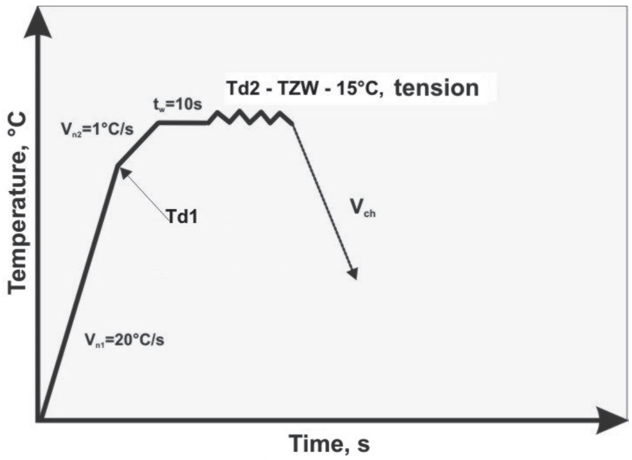


Fig. 2 Diagram of realized experiment for determining zero plasticity temperature (NDT)

Results of tests conducted to mark the zero plasticity are shown in **Fig. 3**. It is clearly visible there that in case of alloy AZ31 the temperature is higher than in alloys AZ61, AZ80 and equals 540 °C. In lower temperature the samples show reduction in area. For alloy AZ61 and AZ80 the temperature of zero plasticity is 505 °C and 490 °C respectively.

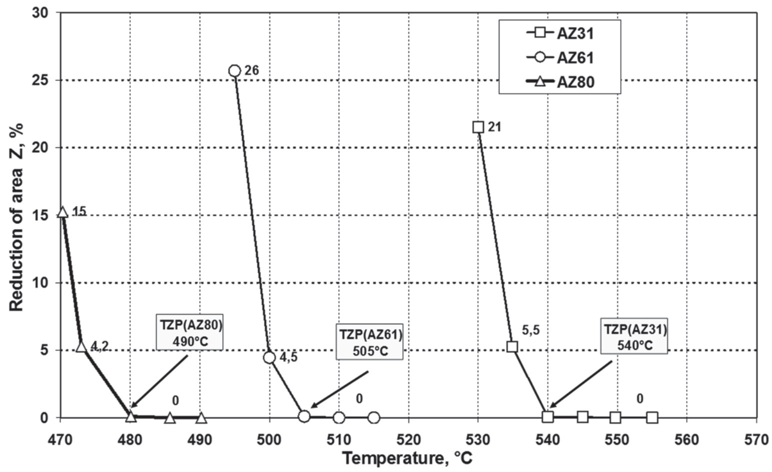
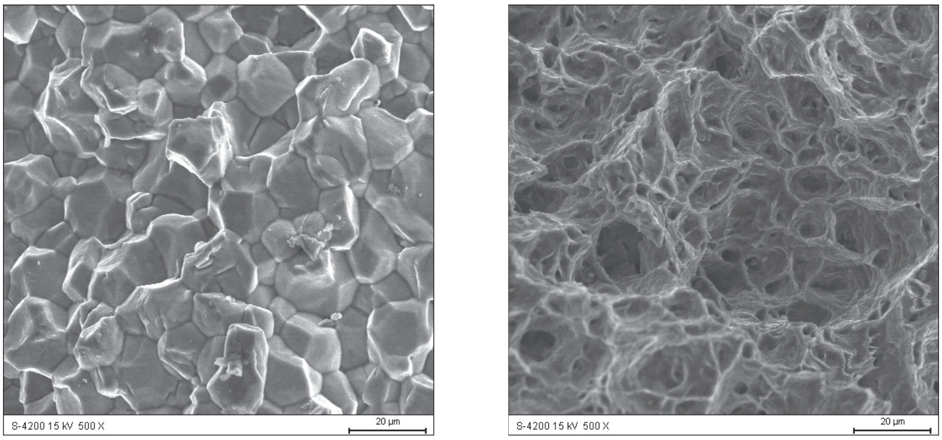


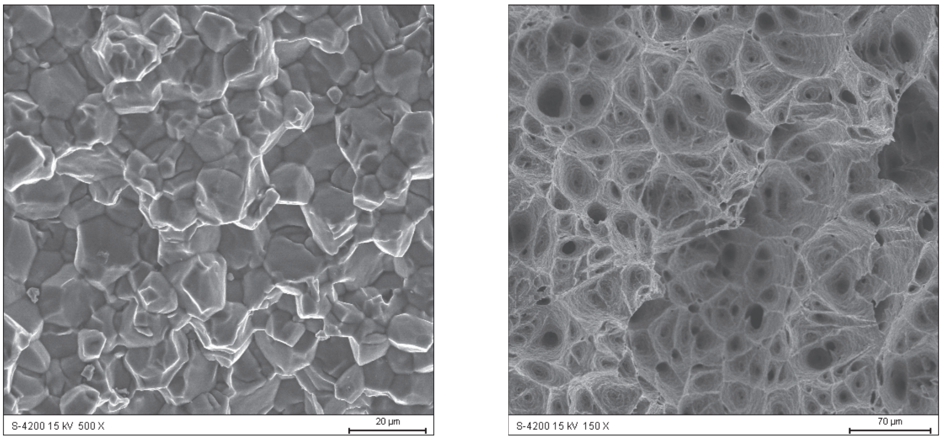
Fig. 3 Influence of temperature on reduction of area based on assumption presented on **Fig. 2** to determine zero plasticity temperature

The results of fractographic test are shown in **Fig. 4-6**. Deformations of alloy AZ31 samples in 540 °C, in the experiment aimed at determining zero plasticity temperature show the cracking on grain boundaries with trans-crystalline brittle character occurs (**Fig. 4a**). In lower temperature, the cracking of inter-crystalline ductile character appears and in such temperature the sample shows reduction of area (**Fig. 4b**).



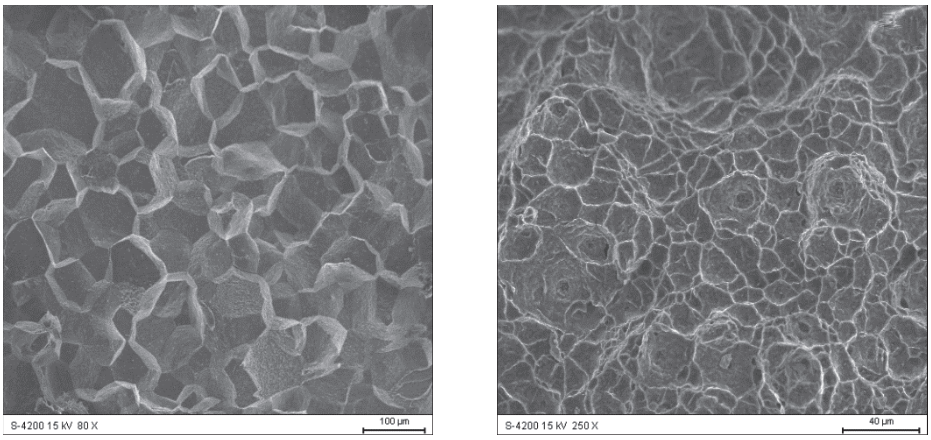
a) b)

Fig. 4 Fractography of sample fractures AZ31 alloy after tension of the samples at 540 °C (a) and 530 °C (b)



a) b)

Fig. 5 Fractography of sample fractures AZ61 alloy after tension of the samples at 505°C (a) and 495 °C (b)

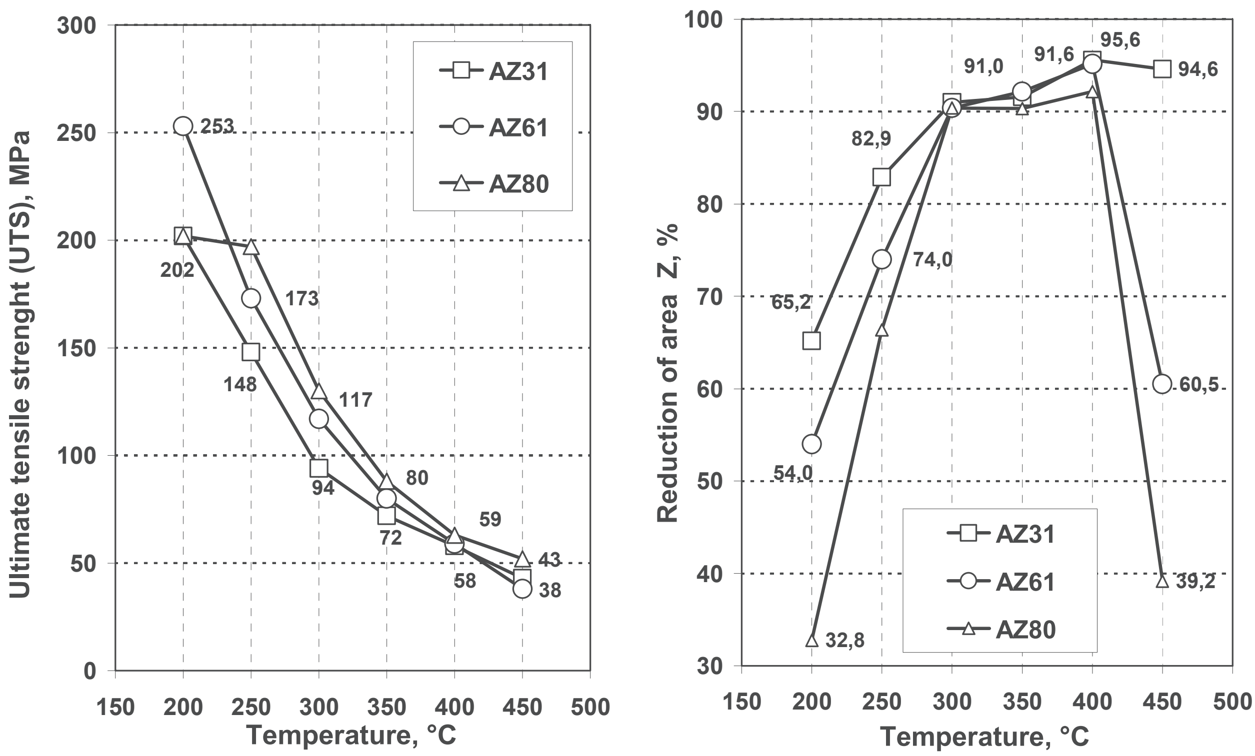


a) b)

Fig. 6 Fractography of sample fractures AZ80 alloy after tension of the samples at 480 °C (a) and 470 °C (b)

Similarly for alloys AZ61 and AZ80 the fracture for sample which did not show reduction of area had brittle character (**Fig. 5a, 6a**). Together with decrease of deformation temperature the increase of plasticity is observed and the fracture is characterised with ductile inter-crystalline character (**Fig 5b, 6b**).

Results of tension test show that, in the tested range of tension parameters variability, the resistance to tension is highly dependent on the content of aluminium and is bigger for alloy AZ80 (**Fig. 7a**). Resistance drops almost 5×times together with increase of deformation temperature from 200°C to 450 °C. In case of reduction of area Z, which is the measure for plasticity, similar values were achieved for tested alloys in temperatures of 300, 350 and 400 °C (**Fig. 6b**). In that range the most beneficial susceptibility to deformation of tested alloys can be observed (Z = 91.3÷ 95.6%). In temperature of 250°C and in lower ones, the plasticity decreases more intensively for alloy AZ61. In case of alloy AZ31 the deformability is also high in temperature of 450 °C, and for alloy AZ61 is significantly decreases in comparison to samples subject to tension in temperature of 400 °C.



a) b)

Fig. 7 Results of tensile test for investigated alloys in temperature range from 200 to 450°C, a - ultimate tensile strength (UTS), b - reduction of area (Z)

SUMMARY

Designing technologies of plastic processing for construction elements required precise determination of the influence of process parameters on the plasticity and microstructure of alloys. It is especially important in designing products made of magnesium alloys meant for construction elements for aviation industry which replace the currently used conventional materials. The benefits of magnesium are presented in many papers [1-4]. The method of plastic treatment can be used to prepare products with a set of better mechanical properties in comparison with those achieved with the use of casting. Achieved data proves that tested alloys can be formed with the use of methods of plastic processing. The most beneficial deformability described with the use of reduction of area Z in tested range of parameter change for deformation process can be found in alloy type AZ31 with smallest aluminium content (3%). Together with the increase of aluminium content the temperature interval is limited both at the beginning and the end of the process in which the plastic processing can be performed. Alloy type AZ61 has comparable deformability with alloy AZ31 in temperatures 300-400 °C, which is proved by similar value of reduction of area. Together with the temperature increase to above 450 °C the drop in deformability is observed which can be connected with the fact of gradual approaching to temperature of plasticity loss, because in alloys with bigger aluminium content low-melting eutectics are formed. Therefore, it requires a bigger discipline in conduction of the process so as not to lead to cracking of the product. For alloy AZ31 this range is bigger due to lower susceptibility to cracking. Conducted fractographic tests show that for tested alloys in deformation conditions in high temperature brittle cracking may appear. Achieved results provide data for designing processes of hot forging of precision construction elements for aviation industry.

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