HIGH-TEMPERATURE CHARACTERISTICS OF PLASTICITY OF MG-Y-RE-ZR ALLOY

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Abstract

The paper presents analysis of plasticity characteristics and microstructure of magnesium alloy type WE43 with yttrium, zirconium and rare earth elements. Susceptibility of magnesium alloy to cracking in high temperatures was tested on Gleeble3800 simulator. 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 performed in temperature range from 250 to 450°C. On the basis of the results, ultimate tensile strength and reduction of area were determined for tested samples. A varied plasticity of tested alloys was found depending on aluminium content. Tests results will be useful in development of forging technology for chosen construction elements which serve as light substitutes of currently used materials.

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

1. INTRODUCTION

Designing the technology of plastic processing for construction elements requires a precise determination of the influence of process parameters on the plasticity and microstructure of alloys. It is especially important in case of designing products made of magnesium alloys meant for construction elements for aviation industry which replace the currently applied conventional materials [1-3]. Alloy WE43 belongs to the group of magnesium alloys which includes rare earth elements, mainly Y, RE and Zr. This alloy is used as casting alloy and it is also shaped with the use of plastic processing. Alloy type WE43 has beneficial resistance properties and can be applied up to temperature of 300°C [4]. It is also characterised with better resistance to corrosion in comparison to classic alloys of magnesium with aluminium. Due to those factors it can be applied on such construction elements in aviation which are prepared with the use of forging or extrusion. However, plastic treatment is difficult because the alloy has low deformability. The paper presents tests of susceptibility to plastic forming of the tested alloy. In order to assess the susceptibility to plastic forming some plastometric tests were conducted with the use of hot compression method and tensile tests. Also the zero resistance temperature and zero plasticity temperature were determined on Gleeble3800 simulator. Tests of fracture character were conducted with application of scanning microscopy. On the basis of prepared characteristics the intervals of decreased plasticity were determined in which the alloy is susceptible to cracking. The assessment of microstructure of the alloy was also conducted. On the basis of conducted tension test the changes in plasticity were determined in temperatures from 250 to 450°C. Achieved results were compared with classic magnesium alloy AZ31. Such tests are vital in preparation of plastic treatment technology for this alloy with the use of hot forging method.

2. METHODOLOGY

Tests were conducted for magnesium alloys type WE43 [5] containing yttrium, zirconium and rare earth elements with chemical composition presented in Table 1. In order to determine the susceptibility of alloy to cracking in high temperatures, the Gleeble simulator was used to assess:

- the zero resistance temperature (NRT), which is the temperature determined through heating and where the resistance of sample drops to zero,
- the zero plasticity temperature (ZPT), which is the temperature marked during heating and by which the sample loses the ability to be plastically deformed

- after determination of zero plasticity temperature a tensile test was conducted.

For samples after tensile test the ultimate tensile stress was determined (UTS) as well as reduction in area (Z). Character of fractures of stretched samples was tested with the use of scanning microscope Hitachi S-4200.

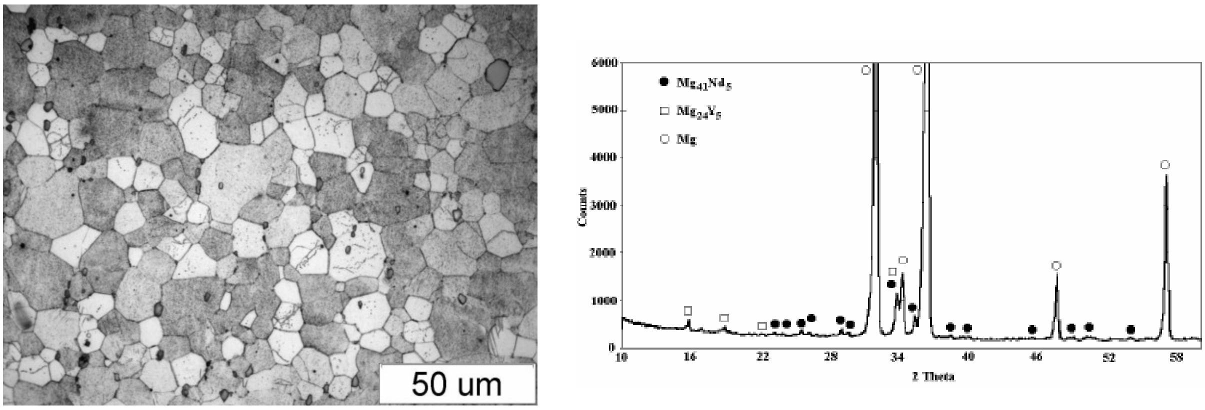
Table1. Chemical composition of WE43 alloy [% mass].

Grade	Content of chemical elements, [mass %]							
	Y	RE+Nd	Zr	Mn	Cu	Ni	Zn	Mg
WE43	4	3.4	0.4	0.15	0.03	0.005	0.2	balance

Test results for marking the zero plasticity temperature (NDT) are shown in **Fig. 3**. It is clearly visible that in case of alloy WE43 the temperature is lower in comparison with alloy AZ31 and equals 515°C. In lower temperatures the samples show reduction in area.

3. RESULTS

Microstructure of tested alloy in initial state after annealing in temperature of 450°C with annealing time of 40 minutes is shown in **Fig.1**. Before deformation the tested alloy WE43 was characterised with microstructure of α-Mg solution. The presence of intermetallic phase division Mg-Y, Mg-Nd was also found in the microstructure of this alloy.



a) b)

Fig.1. Microstructure of investigated alloys in initial state after annealing at temperature 400°C with holding time 1 min. a – microstructure, b – X-ray diffraction.

Zero resistance temperature for alloy WE43 was determined at the temperature of 570°C. In comparison with classic alloy AZ31 the temperature is comparable is equals 580°C. Experiments to determine the zero plasticity temperature (TZP) were conducted in accordance with the model shown in **Fig. 2**. First sample was heated to a temperature 15°C lower than the zero resistance temperature marked earlier. For next set of samples the temperature was lowered in order to achieve reduction in area of samples which signified plasticity. Zero resistance temperature for alloy WE43 was determined at the temperature of 570°C. In comparison with classic alloy AZ31 the temperature is comparable is equals 580°C.

Results of fractographic tests are shown in **Fig.3**. Deformation of alloy WE43 samples in 515°C, in the experiment performed to determine the zero plasticity temperature, show cracking on grain boundaries with brittle transcrystalline fissile character (**Fig.4a**). In lower temperature crackings with intercrystalline ductile character are formed and in such temperature the sample shows reduction of area (**Fig.4b**).

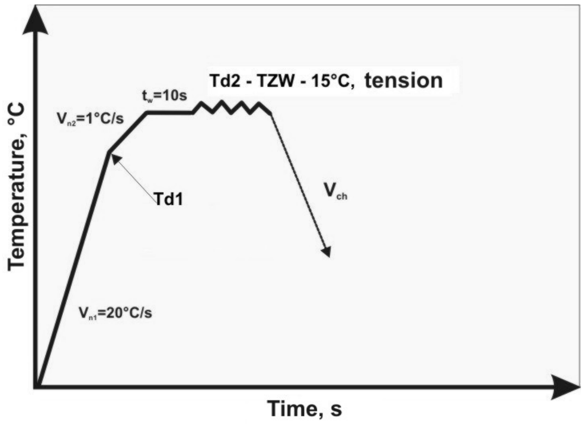


Fig.2. Diagram of realized experiment for determining zero plasticity temperature (NDT).

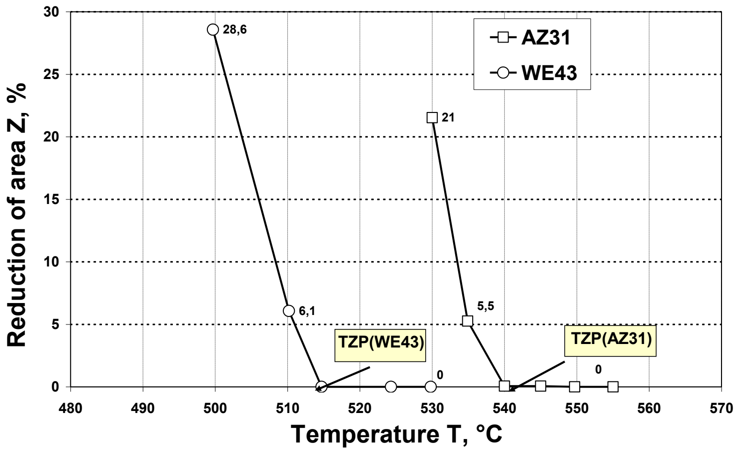
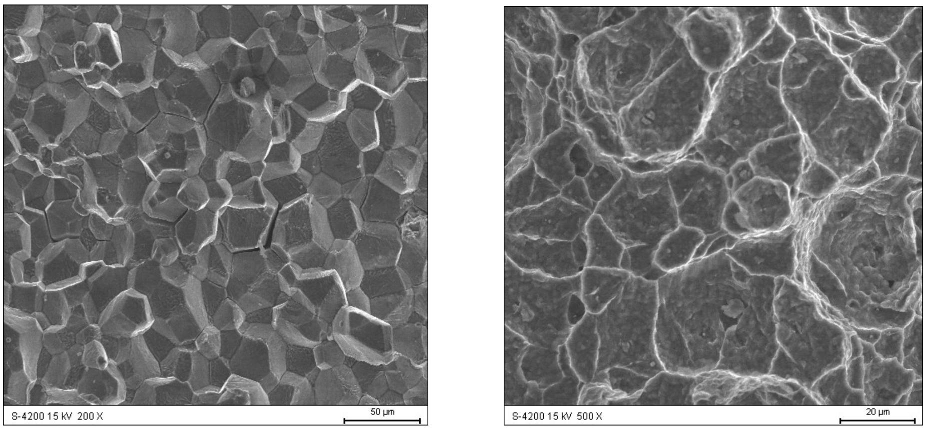


Fig.3. Influence of temperature on reduction of area (Z) based on assumption presented in **Fig.2** to determine zero plasticity temperature.

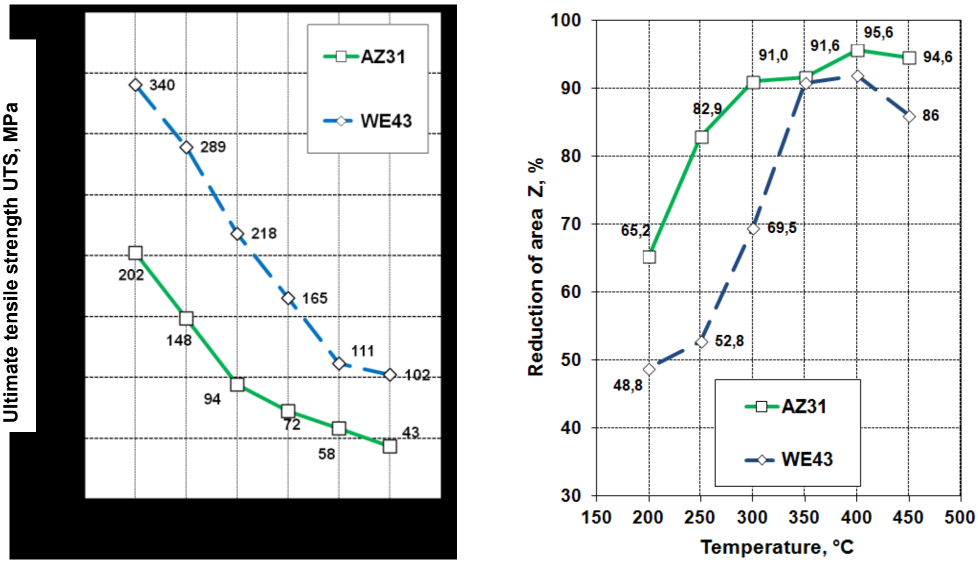
Results of fractographic tests are shown in **Fig.4**. Deformation of alloy WE43 samples in 515°C, in the experiment performed to determine the zero plasticity temperature, show cracking on grain boundaries with brittle transcrystalline fissile character (**Fig.4a**). In lower temperature crackings with intercrystalline ductile character are formed and in such temperature the sample shows reduction of area (**Fig.4b**).

Results of tensile test show that in tested range of tension parameters variability the resistance to tension in higher for alloy WE43 in comparison with alloy AZ31 (**Fig. 4a**). Ultimate tensile strength decreases almost 5×times together with the deformation temperature increase from 200°C to 450°C. In case of reduction of area Z, which is the measure of plasticity lower values were achieved for alloy WE43 for tested alloys during tension in tested deformation temperature variability (**Fig. 4b**). In the range from 350°C to 400°C the alloy has the best susceptibility to deformation and the reduction of area above 90%. Below the temperature of 350°C plasticity drops intensively. Above the temperature of 400°C the deformability decreases and in temperature of 450°C equals 86%.
Compression tests were conducted on heat-mechanical simulator Gleeble 3800 in temperatures of 200, 250, 300, 350, 400 and 450°C. Compression tests were conducted after heating the sample to 450°C with heating speed of 3°C/s, holding in this temperature for 300s and next cooling to deformation temperature with the speed of 5 °C/s. Holding time before deformation was 30s. The applied strain rates were 0.01, 0.1, 1.0 s^{-1}; strain equalled 1.0.



a) b)

Fig.4. Fractography of sample fractures WE43 alloy after tension of the samples at 515°C (a) and 510°C (b).



a) b)

Fig.4. 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).

Registered values of pressure force and displacement in time function were calculated into dependencies of stress to strain which for tested temperature and strain rate of 0.1s^{-1} are shown in **Fig. 5**. In temperature of 250°C alloy shows small deformability and cracks by deformation of ε = 0.3 in temperature of 250°C – also in temperature of 250°C the alloy presents low deformability. Some improvement of plasticity was observed after compression in temperature of 300°C. A significant increase of deformability occurs in temperature of 350°C. Similarly in higher temperatures: 400°C, 450°C the deformability is correct .

In order to describe the influence of process parameters on the properties the Zener-Hollomon parameter (Z) was calculated from the dependency:

$$Z = \dot{} \quad \left(\frac{Q}{R\cdot T}\right), \qquad (1)$$

on the basis of activation energy Q marked from constitutive equation [10]:

$$\dot{} \quad \left(-\frac{Q}{R\cdot T}\right)\times(\sinh(\alpha\sigma_{pp})^{n}, \qquad (2)$$

where: C, α, n – coefficients.

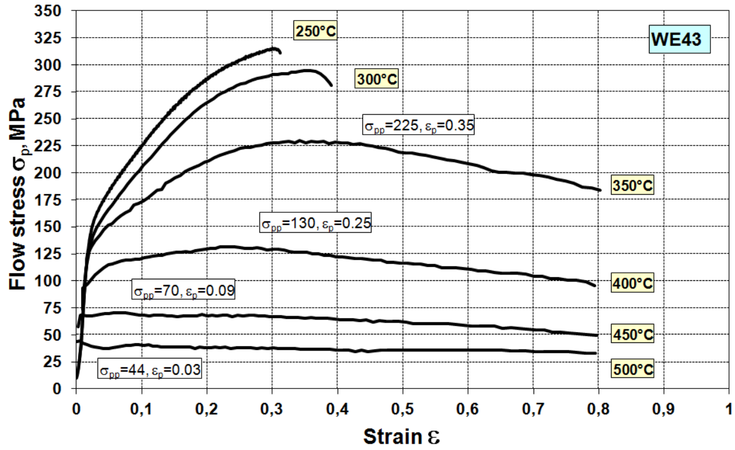


Fig. 5. Dependency of flow stress from strain for WE43 alloy at 250°C ÷ 450°C temperature with strain rate. of 0.1 s^{-1}

Activation energy was marked with application of program ENERGY 4.0. Maximum flow stress σ_{pp} in parameter Z function was calculated from transformed dependency (2):

$$\sigma_{pp} = \frac{1}{\alpha} \cdot arg\,sinh\left(\sqrt[n]{\frac{Z}{C}}\right) \tag{3}$$

Deformation ε_p which equals maximum yield stress in function of Z parameter was marked in exponential dependency [6]:

$$\varepsilon_p = U \cdot Z^W \tag{4}$$

where : U and W are material constants.

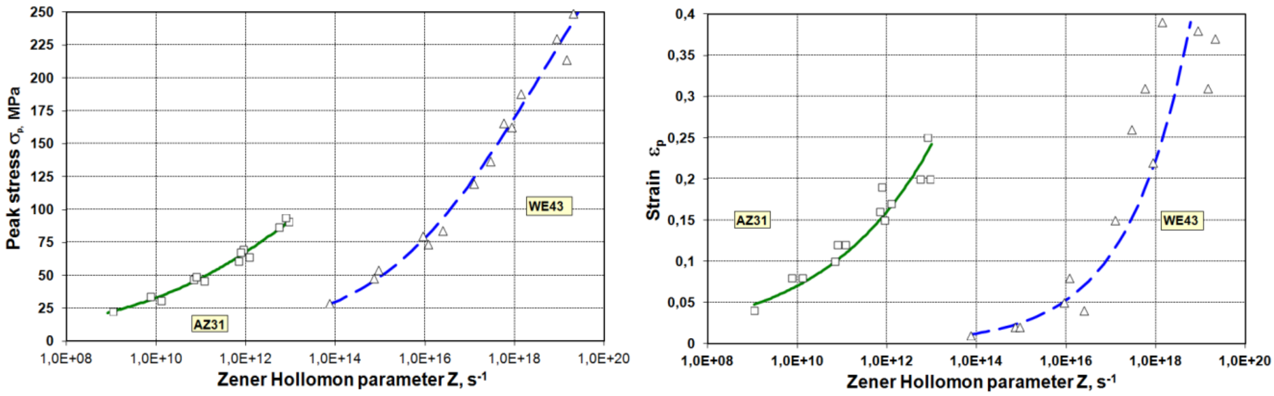
Marked values of activation energy Q and material constants are shown in table 2. Presented values indicate that tested alloy WE43 has higher activation energy of plastic deformation in comparison with classic magnesium alloy AZ31 [7,8]. A good correspondence of calculated values on the basis of equations (3) and (4) with experimental data was confirmed (**Fig.6**).

Table 2. Material constants of investigated alloy determined in Energy 4.0 computer program

Alloy	AZ31	WE43
Q [kJ·mol^{-1}]	153.1	237.71
n [-]	5.67	4.44
α [MPa^{-1}]	0.013	0.0087
C [s^{-1}]	$1.04\cdot10^{12}$	$3.86\cdot10^{16}$
U [-]	0.0011	0.00057
W [-]	0.18	0.31

CONCLUSION

Designing the technology of plastic processing of construction elements requires a precise determination of the influence of process parameters on the plasticity and microstructure of alloys. It has significant importance in designing the products from magnesium alloys meant for construction elements for aviation industry which replace the currently applied conventionally used materials. Advantages of magnesium are presented in a number of papers [1-4]. By plastic processing the products with better set of mechanical properties can be achieved in comparison with the ones achieved in casting method. The gathered data indicate that the tested alloy can be shaped with the use of plastic processing.



a) b)

Fig. 6. Influence of Zener – Hollomon parameter (Z) on peak stress σ_{pp} (a) and strain ε_p (b) for investigated alloys; points – experimental values, lines – calculated.

The most beneficial deformability for alloy type WE43, described with the use of reduction of area Z in tested range of parameter variability in deformation process is gained in range from 350 to 450°C, but the deformability is lower in comparison to alloy AZ31. Together with the temperature increase above 400°C the drop in deformability is observed. Conducted fractographic tests show that for tested alloys brittle cracking can occur in strain conditions in high temperature. Marked temperature of zero plasticity (515°C) is connected with the fact of presence of intermetallic phases in the alloy which melt in lower temperatures.
It requires bigger discipline in conduction of the process in order not to lead to cracking of product. Locally, during deformation, the temperature should not exceed 500°C. For alloy AZ31 the range is bigger due to lower susceptibility to cracking. Properties marked in compression test, for the range of plastic processing which is 350-400°C that is the maximum flow stress σ_{pp} and corresponding deformation ε_p can be described with the use of mathematical functions. Achieved results provide data for designing the process of hot forging of precise construction elements for aviation industry.

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