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INFLUENCE OF TEMPERATURE AND METHODS OF PREPARATION ON STRUCTURE AND MECHANICAL PROPERTIES OF ALLOYS MG-AL WITH GRADUATED ALUMINIUM CONTENTS

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ABSTRACT
Magnesium alloys namely find wide use in aeronautics and automotive industries thanks to their advantageous properties given by combination of strength (160-365 MPa), elastic modulus (45 GPa) and low density (1740 kg/m^3).
Knowledge of elastic-plastic properties at high temperatures is often of utmost importance for complex evaluation of magnesium alloys. Objective of the work was focused on determination of changes of elastic-plastic properties of magnesium alloy AZ91 in dependence on method of its production, processing and graduated Al contents, including investigation of fracture characteristics with use of SEM. Impact of previous deformation after equal channel angular pressing by ECAP method on mechanical properties of selected alloys was considered as another important factor.
Keywords: Magnesium alloys, Mechanical Properties, Tensile test at elevated temperatures, Structure, Fracture Characteristics,

1. INTRODUCTION
Magnesium and magnesium alloys are primarily used in aeronautical and automotive marked in wide variety of structural characteristics because of their favorable combination of tensile strength 160 to 365 MPa, elastic modulus (45 GPa), and low density (1 740 kg/m^3).
Scope of utilisation of foundry magnesium alloys is continuously being extended, so if we want to operate as competitive producers, it is necessary to investigate very actively properties of individual alloys, optimise their chemical composition, study issues of their metallurgical preparation, including heat treatment. Recently, however, increases also utilisation of formed magnesium alloys [1-3].
Magnesium alloys are subjected to heat treatment mostly for the purpose of improvement of their mechanical properties or as an intermediary operation, to prepare the alloy to other specific treatment processes (for example the ECAP method) [4]. A change of the heat treatment basic parameters has an influence on a change of the properties. Annealing significantly decreases the mechanical properties and causes improvement of plastic properties, thus facilitating further treatment.
Complex evaluation of magnesium alloys requires very often knowledge of elastic-plastic properties at increased temperatures.

2. MATERIALS FOR TESTS AND PROCEDURES

Experimental investigation was made with use of cast plates (size 10x20x150 mm) of magnesium alloy AZ91 - Sample A, AZ61 - Sample B and AZ31 - Sample C (after ASTM Standard) in initial state as cast. Sample A1 - state after heat treatment: pre-heating 375°C/3h → 415°C/18h, cooling in air (T4-signed after ASTM Standard). Chemical composition of alloys is given in Table 1.

Table 1. Chemical composition of alloys

Alloy	***[%]***											
	Al	Zn	Mn	Si	Cu	Fe	Be	Zr	Sn	Ni	Pb	Ce
A-AZ91	**8,95**	0,76	0,21	0,041	0,003	0,008	0,0005	0,003	0,01	0,003	0,059	0,01
B-AZ61	**5,92**	0,49	0,15	0,037	0,003	0,007	0,0003	0,003	0,01	0,003	0,034	0,01
C-AZ31	**2,96**	0,23	0,09	0,029	0,002	0,006	0,0001	0,003	0,01	0,002	0,013	0,01

Testing of mechanical properties was made on tensile testing machine INOVA- TSM 20. Temperature range of the equipment is up to 800°C. Samples for tensile test in cast state had a form of bar with length 115 mm, diameter 6 mm, in central part the diameter was reduced to 4 mm in the length of 30 mm.

3. RESULTS OF TESTS AND THEIR ANALYSIS

Results of tensile test dependence on temperature of alloy AZ91 (samples A, A1) are summarised in the Figure 1, 2.

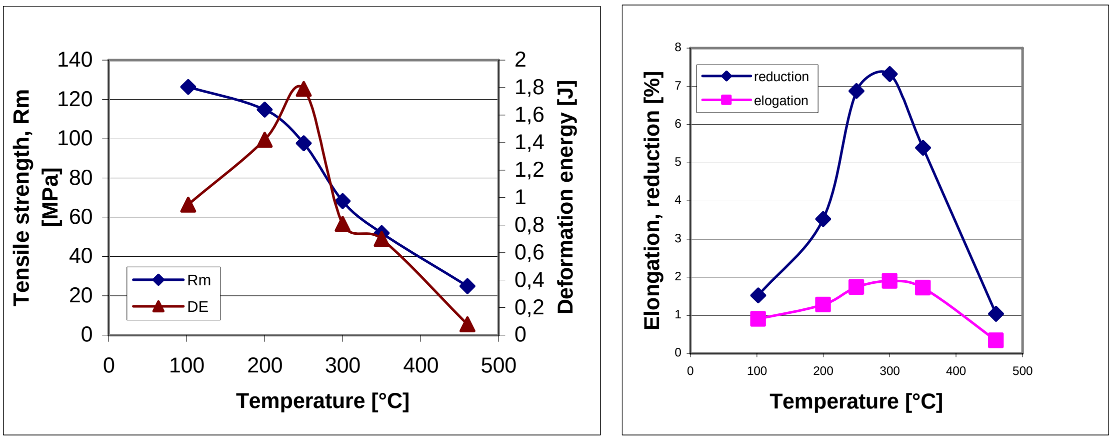

Figure 1. Temperature dependence of mechanical properties alloy AZ91- A

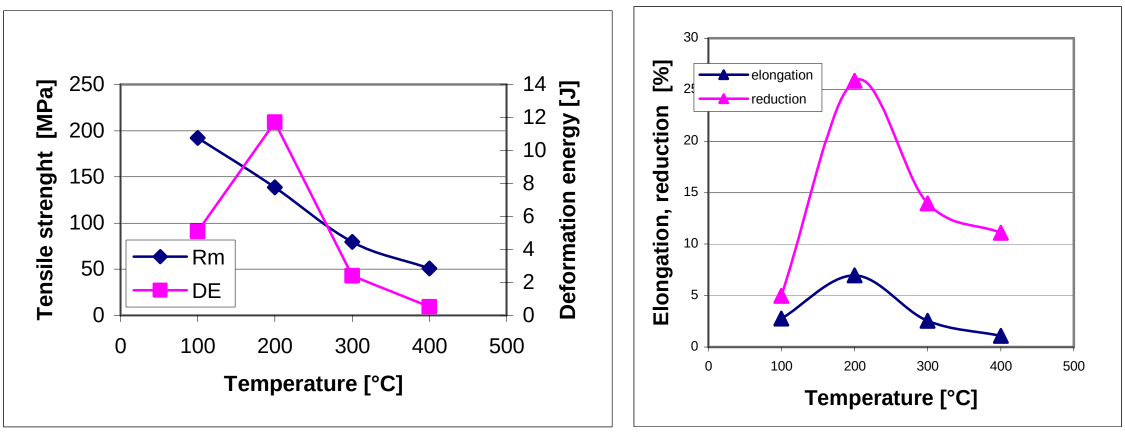

Figure 2. Temperature dependence of mechanical properties alloy AZ91- A1

As it is seen in Figure 1 (sample A) values of R_m swiftly decrease with increasing temperature of the test. In other measured values there was registered initial growth with indistinctive maximum in temperature zone of approx. 250°C for work to rupture, and approx. 300^0C for elongation and reduction. After achieving of the maximum there follows sharp fall, at the highest temperatures the achieved values are mostly lower than the values at the temperature of 20^0C.
In order to complete the obtained results and to clarify dependencies in the figure 1 an evaluation of microstructure and character of fracture was performed in the relevant samples.
Microstructure in initial as cast state is formed by crystals of matrix on the basis of magnesium, surrounded by minority phases of the type $Mg_{17}Al_{12}$ in almost continuous formations in interdendritic areas, which represent places of initiation and propagation of failure at tensile test.
Microstructure near of fracture surface after testing at selected temperature 250°C in the cutting plane of the sample parallel with its axis is shown in the figure 3.

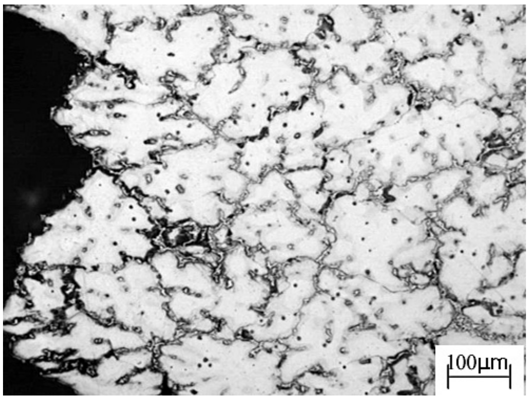

Figure 3. Microstructures of samples after tensile test at 250°C – A

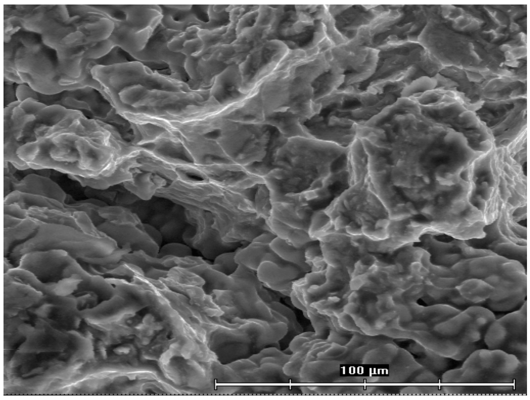

Figure 4. Analysis of fracture areas at temperature 250°C – state A with use of SEM (electron microscope JEOL 50A, the same samples as in the figure 3)

At temperatures from 100^0C to 460^0C there occurs partial dissolution of dispersion precipitate, and at temperatures above 300^0C there occurs even coagulation and partial dissolution of the massive phase. These processes are accompanied by forming of micro-pores in interdendritic areas contributing also to initiation of crack propagation along the phase boundary [5].
It can be seen that the fracture line runs mostly along diminished dendrite boundaries and sub-surface cracks are located in the same areas. The maximum of plastic properties at temperatures (250^0C - 300^0C) can be connected, among others, with a significant dissolution of dispersion precipitate, decline of strength (and plastic) values at the temperature of 460^0C is related evidently mainly with formation of continuous non-integrities at the places of massive phase and partly growth of matrix grain.
Interdendritic character of failure was demonstrated on fracture surfaces at all temperatures. Fracture areas at selected temperature 250°C is shown in figure 4.
Similar temperature dependence of mechanical properties of alloy AZ91- A1 (Figure 2) was observed, but mechanical properties reach more high values.
Results of tensile test of alloys AZ61 and AZ31 (samples B,C) are shown in Table 2.

Table 2. Results of tensile test of alloys AZ61 and AZ31 (samples B,C) at ambient temperature

Alloy	**R_p0,2 [MPa]**	**R_m [MPa]**	**A [%]**
A-AZ91	117,546	175	5,7
B-AZ61	109,403	177	7,3
C-AZ31	67,382	199	24,9

As it is seen from Table 1 at ambient temperature Proof strength is falls with increasing content of Aluminium in alloys while Tensile strength and Percentage elongation are increased.

4. CONCLUSIONS

The following conclusions can be drawn from results of evaluation of mechanical properties, structural and fracture characteristics of the magnesium alloy AZ91 - state A at increased temperatures:

- Microstructure of the alloy in initial state is formed by solid solution and by minority phases $Mg_{17}(Al,Zn)_{12}$ in massive and dispersion form.
- Microstructure has dendritic character, minority phases are comparatively continuously distributed in interdendritic areas, which represent suitable places for initiation and propagation of cracks under load.
- During heating at chosen temperatures there occurs partial dissolution of minority phases. Homogenisation of microstructure is, however, accompanied by simultaneous forming of inter-granular non-integrities, which is unfavourable from the viewpoint of strength and plastic properties, especially at higher temperatures.
- These structural changes can be connected with increasing of values of tensile strength with increasing test temperatures, as well as with observed changes of plastic properties in the mentioned temperature interval.
- During increasing of plastic properties in the temperature interval from 250 to 300^0C some role is played, among others, also by certain homogenisation of microstructure, their decrease at the temperature above 300^0C can be connected with formation of continuous non-integrities, or with melting of residues (of eutectic) phase in interdendritic areas.
- Failure occurs practically at all temperatures basically by inter-crystalline splitting along the boundaries of original dendrites.
- Trans-crystalline plastic character of fracture in small areas at 300°C was occurred.

Similar temperature dependence of mechanical properties of alloy AZ91- state A1 was observed, but mechanical properties reach more high values.
Results of tensile test of alloys AZ91, AZ61 and AZ31 at ambient temperature show:

- Proof strength is falls with icreasing content of Aluminium in alloys while Tensile strength and Percentage elongation are increased.

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