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Mechanical properties of magnesium alloy AZ91 at elevated temperatures

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Properties

ABSTRACT

Purpose: Purpose of this article is to extend a complex evaluation of magnesium alloys which requires very often knowledge of elastic-plastic properties at elevated temperatures. These properties are connected with microstructure that is influenced by metallurgical and technological factors and conditions of exploitation.

Design/methodology/approach: Methodology Testing of magnesium alloys was based on tensile test in dependence on temperature. The methods of the light microscopy and SEM for metallographic and fracture analyses of alloys after testing were used.

Findings: Objective of this work consisted in determination of changes of elastic-plastic properties of magnesium alloy AZ91 in dependence on temperature, including investigation of fracture characteristics. It was confirmed that 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. Failure occurs practically at all temperatures basically by inter-crystalline splitting along the boundaries of original dendrites. At temperature testing near melting point of alloy the interdendrite areas melting were observed.

Research limitations/implications: The experiment was limited by occurrence a void in cast alloys.

Practical implications: The results may be utilized for a relation between plastic and strength properties of the investigated material in process of manufacturing.

Originality/value: These results contribute to complex evaluation of properties magnesium alloys at higher temperatures namely for explanation of fracture mechanism near the melting point.

Keywords: Mechanical properties; Magnesium alloys; Tensile test at elevated temperatures; Fracture characteristics

1. Introduction

Magnesium alloys has been used for a wide variety of applications, namely from the reason of their low density and high strength–to–weight ratio. Low inertia, which results from its low density, is advantageous in rapidly moving parts, for example automobile wheels and other automobile parts[1-4].

The basic magnesium alloys include ones which contain manganese, aluminium, zinc, zirconium and rare-earth elements which allow obtaining suitable properties. Manganese does not cause any increase of tensile strength, however, it does slightly increase the yield point. It also brings about an increase of resistance to the action of sea water. The quantity of manganese in magnesium alloys is limited by its relatively low solubility in magnesium.

Zirconium is added to alloys which contain zinc, rare-earth elements, thorium and their combinations, for the purpose of structure refinement. It should not be used in alloys containing aluminium and manganese, since it forms stable compounds with them which are removed from the solid solution. Rare-earth elements are added to manganese alloys as a mischmetal or didymium. Mischmetal contains cerium, lanthan and neodymium, whereas didymium is a mixture of neodymium and praseodymium. An addition of rare-earth elements enhances magnesium alloys' strength at a room temperature and what is more, it reduces porosity of casts [1].

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, verify experimentally their casting properties and conditions of successful casting of castings by individual methods, including heat treatment, forming and others specials methods of processing. The type of heat treatment depends namely on the chemical composition of the alloys [1, 5-11].

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 [12-14]. 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.

Objectives of the work are determination of changes of elastic-plastic properties of magnesium alloy AZ91 in dependence on temperature, including investigation of structure changing and fracture characteristics.

2. Used material and experimental technique

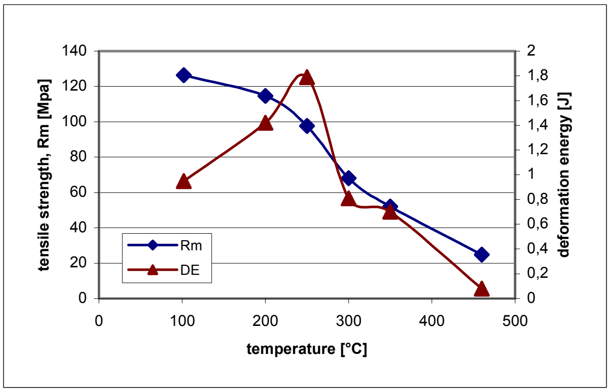
Experimental investigations were performed in commercial prepared magnesium alloy AZ91 with the following chemical composition (mass %): Al – 8.25; Zn – 0.63; Mn – 0.22; Si – 0.035; Cu – 0.003; Fe – 0.014; Be – 0.002; rest Mg.

Testing of mechanical properties were made on bursting equipment TSM 20 made by INOVA. Temperature range of the equipment is up to 800°C. Heating to the required temperature is realised in 3 stages in argon atmosphere.

Sample 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 discussion

Results of measurement of elastic-plastic properties by tensile test in dependence on temperature are summarised in the Figure 1.



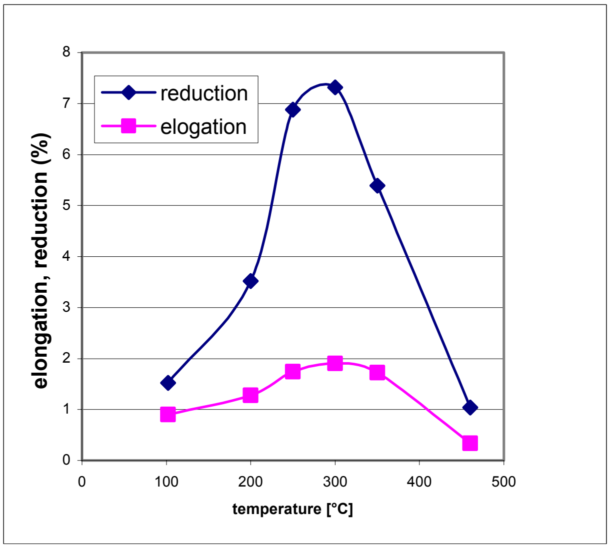


Fig. 1. Temperature dependence of mechanical properties alloy AZ91

As it is seen in this figure 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°C 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°C.

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 $Mg_{17}Al_{12}$, or possibly $Mg_{17}(Al, Zn)_{12}$ [6,7,15].

Microstructure has distinctly dendritic character, massive phases form 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 elevated temperatures in the cutting plane of the sample parallel with its axis is shown in the figure 2, 3.

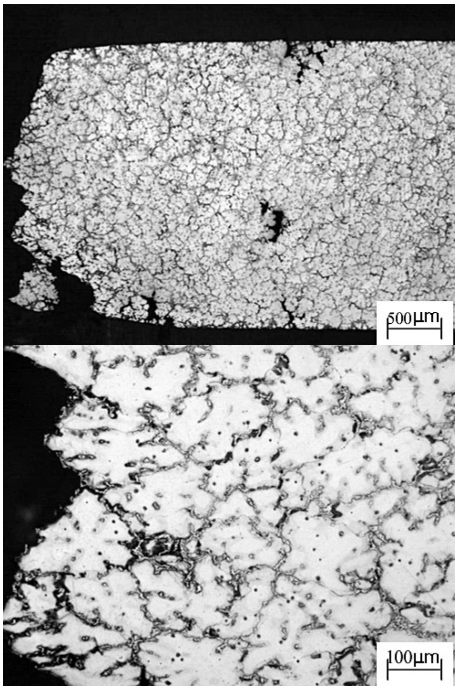


Fig. 2. Microstructures of samples after tensile test at 250°C

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.

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 – figure 3.

Interdendritic character of failure was demonstrated on fracture surfaces at all temperatures. Fracture areas at selected temperatures are shown in figure 4.

4. Conclusions

The following conclusions can be drawn from results of evaluation of mechanical properties, structural and fracture characteristics of the magnesium alloy AZ 91 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.

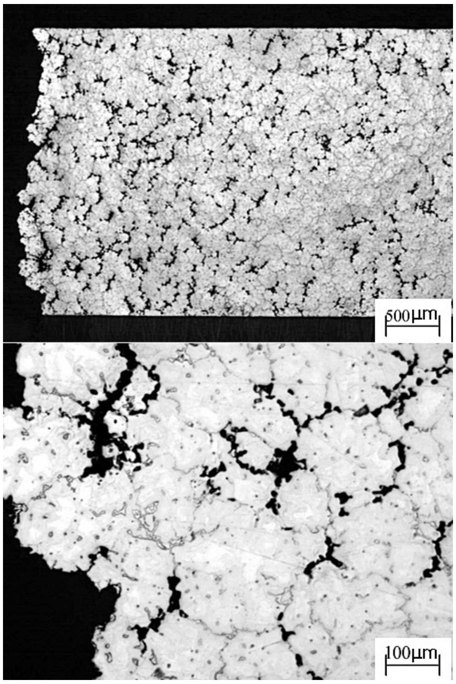
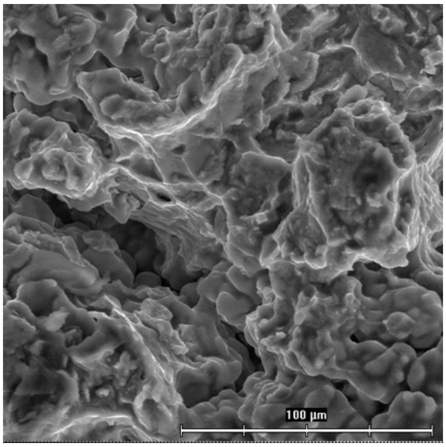
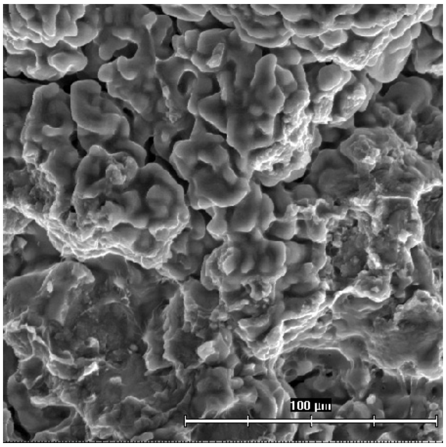


Fig. 3. Microstructures of samples after tensile test at 460°C



250°C



460°C

Fig. 4. Analysis of fracture areas at selected temperatures with use of SEM (electron microscope JEOL 50A, the same samples as in the figure 2, 3.)

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