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Structure and mechanical properties of casting MSR-B magnesium alloy

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Materials

ABSTRACT

Purpose: MSR-B is a high-strength magnesium alloy characterized by good mechanical properties both at an ambient and elevated temperature (up to 200°C). It contains silver and rare earth elements. The aim of this paper is to present the results of research on the microstructure and mechanical properties of the MSR-B magnesium alloy in an as-cast condition.
Design/methodology/approach: For the microstructure observation, a Reichert metallographic microscope MeF2 and a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS equipped with SYSTEM SIX were used. A qualitative phase analysis was performed with a JEOL JDX-7S diffractometer. Quantitative examination was conducted using the "MET-ILO" automatic image analysis programme.
Findings: Based on the investigation carried out it was found that the MSR-B alloy in an as-cast condition characterized with a solid solution structure α with island of divorced eutectic (α + $(Mg,Ag)_{12}Nd$ and probably $(Mg,Ag)_{41}Nd_5$ phase). The mean area of the solid solution α grain equals $\bar{A}$=543 μm^2, and the mean surface fraction of eutectic regions is A_A= 5.81%. The yield strength is near 90 MPa in 20°C and near 70 MPa in 200°C. Tensile strength is near 180 MPa in both temperatures. The material hardness is 47 HV.
Research limitations/implications: Future researches should contain investigations of the influence of alloy additives on microstructure and mechanical properties of MSR_B alloy in as-cast condition and after heat treatment.
Practical implications: MSR-B magnesium alloy is used in the aircraft industry, for wheels, engine casings, gear box casings and rotor heads in helicopters. Results of investigation may be useful for preparing casting technology of the Mg-Ag-Nd alloys.
Originality/value: The results of the researches make up a basis for the next investigations of magnesium alloys with addition of Ag and Nd designed to exploitation at temperature to 300°C.
Keywords: Metallic alloys; Methodology of research; Electron microscopy; MSR-B magnesium alloy

1. Introduction

Magnesium components are most commonly produced by high-pressure and sand casting. Sand casting is used for production of magnesium alloys not containing aluminum for aeronautical components [1]. The aeronautics industry used magnesium alloys for reason of weight. Mg alloys are generally used for aircraft transmission systems and large magnesium castings have been used in the cold areas of engine such as the intermediate housing [2]. In the 1950s, favourable effects of silver on the mechanical properties of magnesium alloys containing rare earth elements were discovered. The research conducted at that time resulted in the fabrication of commercial alloys, such as QE21 and QE22, containing up to 3 wt.-% of Ag and a blend of rare earth elements rich in neodymium (didymium) or a blend rich in cerium and lanthanum [3]. The advantageous influence of Ag and RE alloying in Mg alloys on the creep resistance and thermal stability of structure and mechanical properties has been recognized and already applied in commercial alloy QE22 [4,5].

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Mg-RE-Ag alloys show a high yield point, good tensile strength and fatigue strength at a temperature of up to 300 °C. They are characterized by good casting properties and good workability enabling the application of high machining speed. They achieve good mechanical properties after solution heat treatment at 525 °C and ageing treatment at 200 °C. Drawbacks of these alloys are their susceptibility to cracking and deformation during heat treatment, their high production cost resulting from the presence of silver and their low corrosion resistance [6]. These alloys are mostly used in the aircraft industry, for wheels, engine casings, gear box casings and rotor heads in helicopters. They are also used in the automotive and military industries [7,8].

The basic alloying components in Mg-RE-Ag-Zr alloys are rare earth elements and silver. A mixture of rare earth elements (didymium) consists of ca. 85% of neodymium and 15% of praseodymium. Neodymium has a positive effect on tensile strength at elevated temperatures and reduces porosity of casts and susceptibility to cracking during welding. Silver causes solution hardening and participates in precipitation processes, enhancing the creep resistance, although the use of silver resulted in rather poor corrosion resistance [9]. Zirconium, which does not form any phases with magnesium or alloying elements, contributes to the obtaining of a fine grain structure and improves the mechanical properties at an ambient temperature [3,11] .

Magnesium alloys with Ag addition are characterized by a structure composed of dendrites of a solid α-Mg solution and a eutectic of a solid α-Mg solution and Mg_4Ag phases, distributed in interdendritic spaces. A 2.5% addition of Nd to a Mg-2.5Ag alloy results in a reduction of interdendritic distances and the occurrence of a $Mg_{41}Nd_5$ and $Mg_{12}Nd$ phases [12÷14].

2. Description of the work methodology and material for research

2.1. Material for research

The material for the research was a casting MSR-B alloy. The alloy was purchased from Magnesium Elektron, Manchester, UK. The chemical composition of this alloy is provided in Table 1.

Table 1.
Chemical composition of the MSR-B alloy in wt.-%

Ag	RE	Zr	Zn	Si	Cu	Mn	Fe	Mg
2,4	2,5	0,42	<0,05	<0,01	<0,01	<0,03	0,002	balance

2.2. Research methodology

The microsections for structural examination were subjected to grinding with sandpaper of 250 to 1200 granulation. Next, they were polished. The surface of the specimen was etched in a reagent containing 2g of oxalic acid and 100 ml of H_2O.

For the microstructure observation, a Reichert metallographic microscope MeF2 and a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS spectrometer equipped with SYSTEM SIX were used. A qualitative phase analysis was performed with a JEOL JDX-7S diffractometer. For a quantitative description of the structure, stereological parameters describing the size and shape of the solid solution grain and phase precipitations were selected. To measure the stereological parameters, a program for image analysis “MET-ILO” was used.

The examination of the mechanical properties was conducted on an MTS-810 servo hydraulic machine. The examination was carried out for two temperatures: ambient (ca. 20°C) and 200°C. Hardness measurements by Vickers method were performed on a ZWICK/ZHV50 hardness tester.

3. Description of achieved results of own researches

3.1. Microstructure of the MSR-B alloy

The MSR-B alloy is characterized by a solid solution structure α with divorced eutectic (α + intermetallic phases) on grain boundaries. Diversity in the chemical composition of the solid solution was found (Fig. 1, 2).

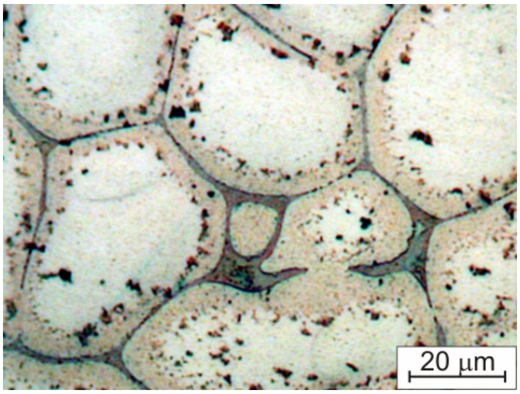

Fig. 1. LM picture of MSR-B magnesium alloy. Diversity of the solid solution chemical composition

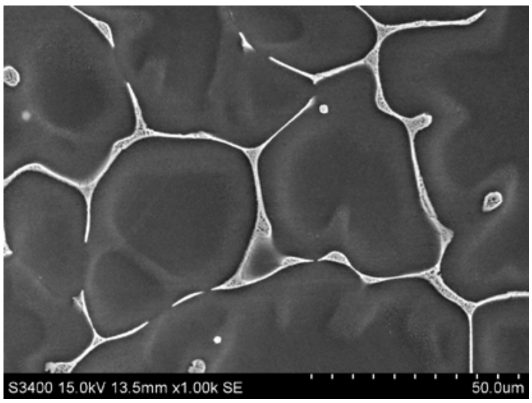

Fig. 2. SEM picture of MSR-B magnesium alloy. Solid solution α + divorced eutectic (α+intermetallic phases)

A quantitative evaluation of the MSR-B alloy microstructure has shown that the mean area of the solid solution α grain equals $\bar{A}$=543 μm^2, and the mean shape coefficient value ξ = 0.69%. The mean surface fraction of eutectic regions is A_A= 5.81%, whereas the mean shape coefficient value ξ = 0.51%.

The X-ray diffraction analysis of the as cast MSR-B alloy has shown the occurrence of $Mg_{12}Nd$, $Mg_{41}Nd_5$ and $Ag_{51}Nd_{14}$ phase precipitations in the solid solution structure α (Fig. 3).

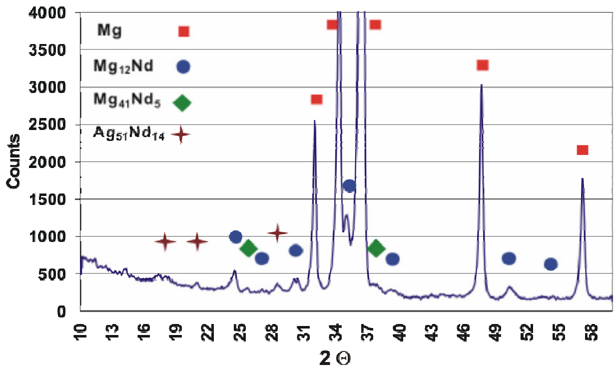

Fig.3. X-ray pattern of the MSR-B alloy

The point (Fig. 4, table 2) and linear (Fig. 5) analyses of the chemical composition have shown a change of the silver content from ~0.48 at.-% in the solid solution grain core (point 1, Fig. 4), through 2.39 at.-% in an area located near eutectic regions (point 2, Fig. 4), to 4.82 at.-% in the eutectic (point 3, Fig. 4). The neodymium content changes in a similar way. No neodymium was observed in the solid solution grain core. However, with approaching the solid solution grain boundaries, thus approaching the eutectic regions, an increase in neodymium content was observed up to 2.03 at.-% in an area located in the vicinity of grain boundaries (point 2, Fig. 4), and to 4.05 at.-% in eutectic regions (point 3, Fig. 4).

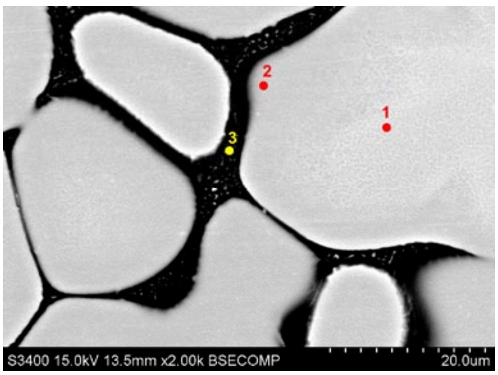

Fig.4. Microareas of the chemical composition analysis in the MSR-B alloy

The chemical composition of the eutectic regions (Fig. 4) allows the supposition that the eutectic mostly consists of phases $\alpha + Mg_{12}Nd$. This, however, does not exclude the occurrence of a $Mg_{41}Nd_5$ phase.

Table 2.
Results of the point analysis of chemical composition from Fig. 3.

point	Mg		Ag		Nd	
	% wt.	% at.	% wt.	% at.	% wt.	% at.
1	97.90	99.52	2.10	0.48	-	-
2	80.84	95.58	8.96	2.39	10.21	2.03
3	66.72	91.13	15.67	4.82	17.61	4.05

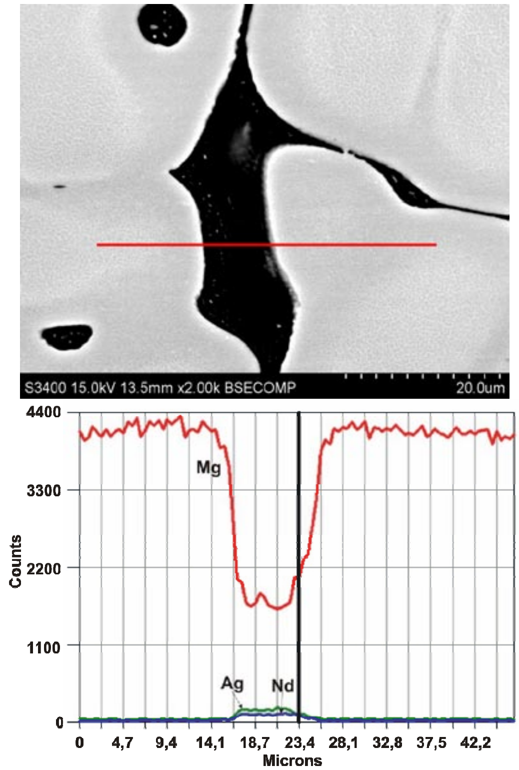

Fig.5. The linear analysis of Mg, Ag and Nd along the marked line in the BSE image. a) BSE image; b) linear analysis

Due to the fact that the diameters of magnesium and silver atoms (r_{Mg}=0,162 nm, r_{Ag}=0,144 nm) slightly differ from each other, atoms of silver can replace magnesium atoms without destroying the crystal structure of intermetallic phases. In this connection, the MSR-B structure is composed of a solid solution α, divorced eutectic $\alpha + (Mg,Ag)_{12}Nd$ + probably the $(Mg,Ag)_{41}Nd_5$ phase and single precipitations of the $Ag_{51}Nd_{14}$ phase.

The eutectic present in the MSR-B alloy is so-called divorced eutectic. In magnesium alloys, two types of divorced eutectic can be present. The first is called a fully divorced eutectic. A fully divorced morphology is where the two eutectic phases are completely separate in the microstructure. For example precipitations of intermetallic phase are surrounded by a solid solution (e.g. in Mg-Al alloys, β-$Mg_{17}Al_{12}$ phase precipitations are surrounded by α-Mg solid solution). This type of eutectic very often occurs in high pressure die casting [15].

The second is called a partially divorced eutectic and is characterized by “islands” of the α-Mg solid solution occur inside intermetallic phase precipitations [15]. This type of eutectic is present in the MSR-B alloy (Fig.6).

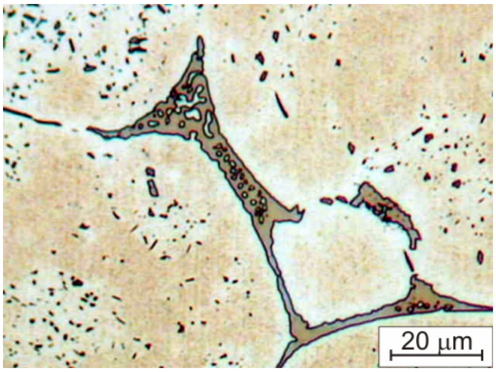

Fig.6. Partially divorced eutectic in the as-cast MSR-B alloy

3.2. Mechanical properties of the MSR-B alloy

The investigations of the mechanical properties of the MSR-B alloy in as-cast condition have shown that the yield strength $R_{0,2}$ is near 90 MPa in ambient temperature and near 70 MPa in 200°C. The tensile strength R_m is near 180 MPa in both temperatures. Elongation is near 12% in 20°C and increase to near 24%in 200°C. The material hardness is 47 HV. The mechanical properties are listed in Table 3.

Table 3.
Results of a static tensile test of MSR-B alloy at an ambient temperature and at 200°C.

Temp.	$R_{0,2}$ [MPa]	R_m [MPa]	A_5 [%]	HV1
20°C	93	182	11,7	47
200°C	70	178	24,3	

4. Conclusions

Based on the experimental results obtained, the following conclusions can be drawn:

1. The MSR-B alloy structure in as cast condition is characterized by a solid solution structure α with divorced eutectic α + $(Mg,Ag)_{12}Nd$, and probably the $(Mg,Ag)_{41}Nd_5$ phase on the grain boundaries.
2. The mean area of the solid solution α grain equals $\bar{A}$=543 µm^2, and the mean surface fraction of eutectic regions is A_A= 5.81%.
3. The yield strength of the MSR-B alloy in as-cast condition is near 90 MPa in 20°C and near 70 MPa in 200°C. The tensile strength is near 180 MPa in both temperatures. The material hardness is 47 HV.

Acknowledgements

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