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Microstructure of WE43 casting magnesium alloy

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Materials

ABSTRACT

Purpose: WE43 is a high-strength magnesium alloy characterized by good mechanical properties both at an ambient and elevated temperature (up to 300°C). It contains mainly yttrium and neodymium. The aim of this paper is to present the results of research on the microstructure of the WE43 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. Microstrucutral examinations were performed JEOL 3010 transmission electron microscope.
Findings: Based on the investigation carried out it was found that the microstructure of WE43 alloy after continuous casting consists of α-Mg matrix and irregular precipitates of $Mg_{41}Nd_5$, rectangular particles of MgY phase, particles of $Mg_{24}Y_5$, longitudinal precipitates of β ($Mg_{14}Nd_2Y$) compound at grain boundaries and the grain interiors. All of these phases contain yttrium and neodymium.
Research limitations/implications: Future researches should contain investigations of the influence of heat treatment parameters on microstructure, corrosion resistance and mechanical properties of WE43 alloy.
Practical implications: WE43 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 development casting technology of the Mg-Y-Nd alloys.
Originality/value: The results of the researches make up a basis for the next investigations of magnesium alloys with addition of Y and Nd designed to exploitation at temperature to 300°C.
Keywords: Metallic alloys; Methodology of research; Electron microscopy; WE43 magnesium alloy

1. Introduction

Magnesium alloys are widely employed in aerospace, automotive and electronic industries, everywhere where weight reduction is essential. In fact, they exhibit low density, high specific strength and excellent machinability [1÷6]. Magnesium alloys containing both neodymium and yttrium are interesting as light structural materials with high strength properties at near room and elevated temperatures [7]. The high strength properties of these alloys are related to particular characteristics of the Mg-Nd-Y phase diagram. It is characterized by the existence of binary compounds of the systems Mg-Nd and Mg-Y in equilibrium with the Mg solid solution [7,8]. The maximum strength of WE43 and WE54 alloy is achieved by conventional age-hardening treatments, which typically involve a solution treatment of 8 h at 525 °C, a hot water quench and a subsequent ageing treatment of 16 h at 250 °C [9÷11]. Depending on the ageing temperature, the precipitation sequence in WE alloys has been reported to involve formation of phases designated β", β', β_1 and equilibrium β. The β" metastable phase has a $D0_{19}$ hexagonal structure and is coherent with the α-Mg ($a = 2a_{Mg}$, $c = c_{Mg}$) matrix. The β" composition may be $Mg_3(Y_{0.85}Nd_{0.15})$. The metastable β' phase, which forms during ageing from 200 °C to 250 °C, has a base centered orthorhombic structure and is semicoherent with the α-Mg phase ($a = 2a_{Mg}$, $b \approx 8d_{Mg}(1\text{-}100)$, $c = c_{Mg}$). The composition of this phase is cause of disagreement

and can be $Mg_{12}NdY$ or $Mg_{24}Y_2Nd_3$. The intermediate β_1 phase is face centered (a = 0.74 nm) and was found to be isomorphous with phases of the form Mg_3RE (RE = Nd, Ce, La, Gd) The precipitation sequence ends with the equilibrium β phase. This phase is fcc and isomorphous with the Mg_5Gd compound (a = 2.23 nm). The stable β phase has a $Mg_{12}NdY$ composition in WE54 alloy. In WE43 alloy, a $Mg_{14}Nd_2Y$ composition for the equilibrium phase is mentioned [12÷17]. The aged microstructure at maximum hardness contains metastable β' and equilibrium β phase as dispersed precipitates [6].

2. Material and methodology

The studied samples were obtained from commercial WE43 magnesium alloy after casting, with a nominal composition of Mg-4Y-2.4Nd-3.3RE (heavy rare earth)-0.55Zr, where RE represents rare earth elements, provided by Magnesium Elektron Company, Manchester, England. The test specimens were prepared for examination according to the guidelines of Struers specimen preparation system. Samples were etched with solution contains 4.2 g picric acid, 10 ml acetic acid, 70 ml ethanol, 10 ml distilled water [18]. Images of the examined specimens were acquired with a Reichert MeF-2 type optical microscope using bright field technique and a scanning electron microscope Hitachi S-3400N equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). EDS analysis were performed with an accelerating voltage of 15 keV. The phase identification of these alloys was identified by X-ray diffraction (JDX-75) using Cu Kα radiation. Specimens for TEM were ion milled using the Precision Ion Polishing System (GATAN). Microstructural examination was performed in JEOL 3010 transmission electron microscope.

3. Results

3.1. XRD and scanning electron microscopy

The microstructure of as-cast WE43 alloy consists of solid solution α-Mg matrix with precipitates of intermetallic phases at grain boundaries and the grain interiors (Fig.1).

Fig. 2 is the XRD pattern taken from the specimen of as-cast alloy WE43, in which diffraction lines were identified arising from three phases, the α-Mg matrix and of $Mg_{24}Y_5$ and $Mg_{41}Nd_5$ phase (Fig. 2). Overall peak intensity of intermetallic phases is slightly above the background noise, in order to avoid ambiguity, additional verification using other analytical techniques would be required.

Irregular phases with large size (points 1 and 2, Fig. 3, Tab. 1) contain magnesium and neodymium, as proved by the energy dispersive X-ray results. The content of yttrium is very low. Chemical composition of these precipitates indicates that could be $Mg_{41}Nd_5$ type with yttrium that substitutes part of neodymium, because the size atoms of these elements are similar. The high amount of magnesium was probably caused by overlapping of the magnesium matrix with the particles. Rectangular precipitates (points 3 and 4, Fig. 3) are composed of magnesium, yttrium and small amounts of neodymium. These particles could be $Mg_{24}Y_5$ (point 4), but content of yttrium in larger rectangular precipitate (point 3) is too high. This indicates that in investigated alloy could be other phases from Mg-Y or Mg-Y-Nd system.

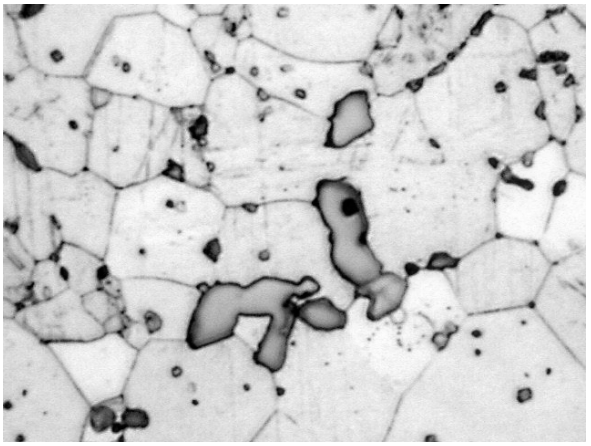

Fig. 1. Optical micrograph taken from as-cast sample of WE54 magnesium alloy (1000x)

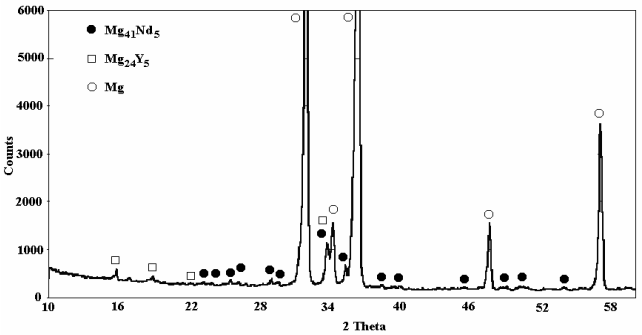

Fig. 2. XRD pattern of WE43 magnesium alloy

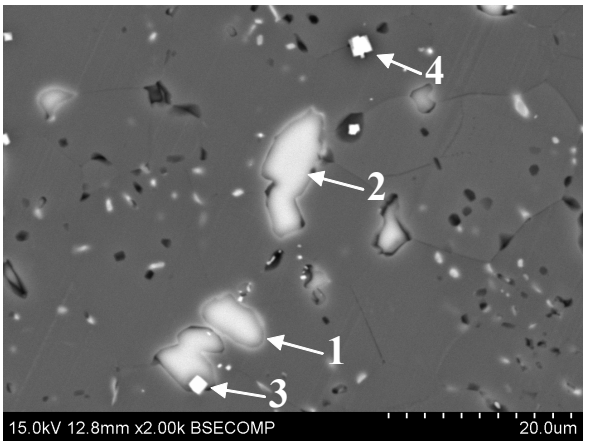

Fig. 3. SEM micrograph with analyzed points of investigated alloy

Table 1.
EDS results from Fig. 2.

	Mg-K	Y-L	Nd-L
Point 1	93.75	0.94	5.31
Point 2	92.77	1.02	6.22
Point 3	66.09	28.26	5.65
Point 4	82.94	16.14	0.92

3.2. Transmission electron microscopy

TEM thin foil examinations provided the characteristics of a subtle microstructure of the matrix grains and fine precipitates which were not detected by optical and SEM techniques. In the α-Mg grains were observed of distinct contrast caused by different densities of dislocations. The precipitates revealed at TEM magnifications represented at least three categories. In addition to relatively large precipitates like Mg-Nd phase detected above by XRD and SEM, TEM revealed fine particles (Fig. 4). Selected area diffraction identified them as $Mg_{41}Nd_5$. Fig. 5 shows the bright-field image and the corresponding selected area electron diffraction pattern. Some interplanar distances of the precipitate calculated from the SAED pattern indicate that the precipitate could be Mg_2Y. Further TEM observations revealed the presence of fine precipitates of $Mg_{24}Y_5$ (body centered cubic, a = 1.12 nm) phase at grain boundaries (Fig. 6). TEM micrograph as well as a selected area diffraction pattern taken from longitudinal particles are shown in Fig. 7, which can be indexed as arising from β phase with a face centered cubic structure (a = 2.2 nm). The β phase is isomorphous with the Mg_5Gd [14] compound and its chemical composition is reported as $Mg_{14}Nd_2Y$ [12].

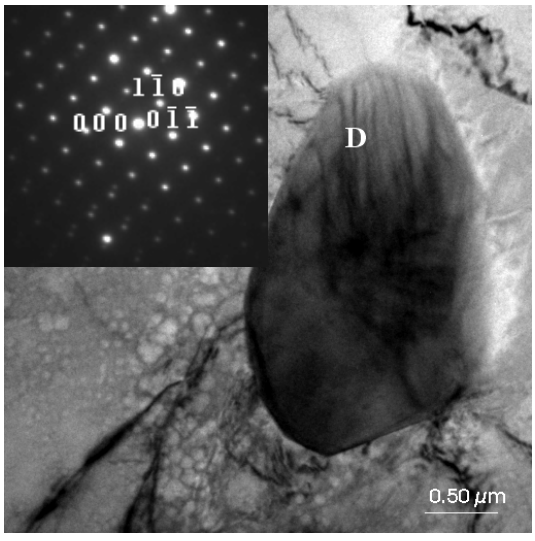

Fig. 4. The TEM image and corresponding SAED diffraction pattern of the particle identified as $Mg_{41}Nd_5$ (B‖ [-1-11])

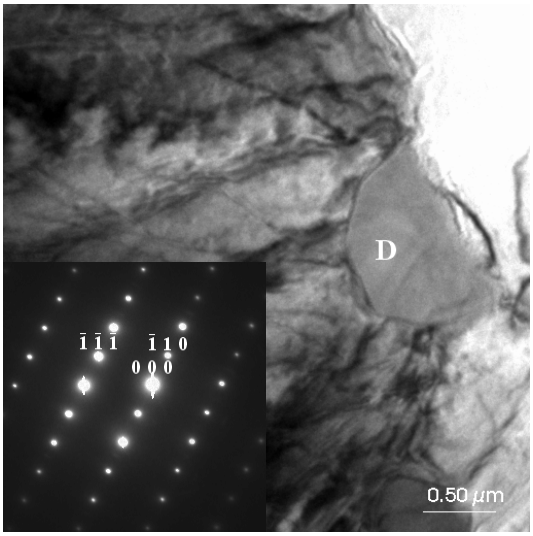

Fig. 5. The TEM image and corresponding SAED diffraction pattern of the particle identified as Mg_2Y (B‖[-1-11])

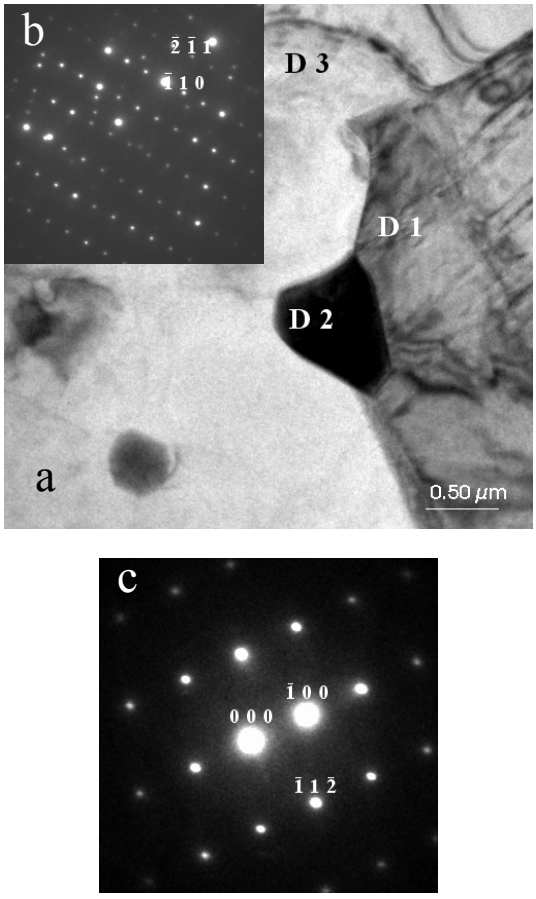

Fig. 6. The TEM image (a) and SAED (b) of the $Mg_{24}Y_5$ (B‖[113]) – D2 (b); SAED of Mg matrix (B‖[021])– D3 (c)

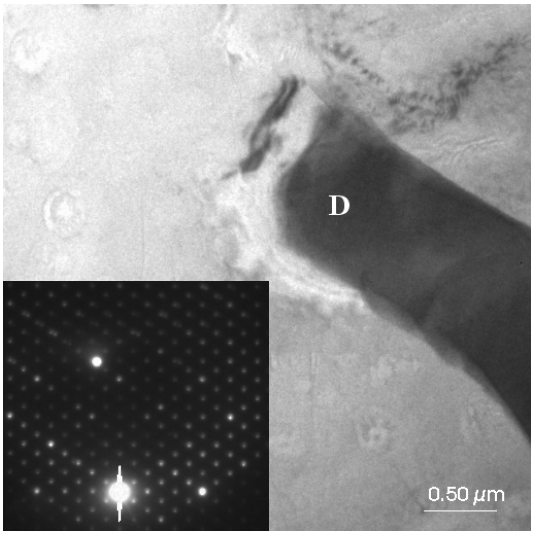

Fig. 7. The TEM image and corresponding SAED diffraction pattern of the particle identified as β equilibrium phase (B‖[-1-11])

4. Summary

The microstructure of WE43 alloy after continuous casting consists of α-Mg matrix and irregular precipitates of $Mg_{41}Nd_5$, rectangular particles of MgY phase, particles of $Mg_{24}Y_5$, longitudinal precipitates of β ($Mg_{14}Nd_2Y$) compound at grain boundaries and the grain interiors. All of these phases contain yttrium and neodymium. It is very likely that the local segregation of yttrium and neodymium led to a variety of phase observed. A variation in the morphology of intermetallic compounds indicates different mechanism of their formation.

Acknowledgements

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