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The influence of ageing on structure and mechanical properties of WE54 alloy

A. Kiełbus *
Department of Materials Science, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: andrzej.kielbus@polsl.pl

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Materials

ABSTRACT

Purpose: WE54 magnesium alloy offers attractive properties for aerospace and automotive industries. It reaches high specific strength, creep resistance and corrosion resistance up to a temperature of 250°. The alloy contains 5%$_{wt}$.Y, 1.7%$_{wt}$.Nd and 0.55%$_{wt}$. Zr. The strength of this alloy is achieved essentially via precipitation strengthening. Depending on the ageing temperature and time, the precipitation sequence in WE alloys has been reported to involve formation of phases designated β", β' and β. The aim of the research was to determine the effect of ageing parameters on the microstructure and mechanical properties of WE54 magnesium alloy.
Design/methodology/approach: Solution treatment was performed at 525°C/8h with water cooling. Ageing treatments were performed at 250°C/4÷96h in air. The microstructure was characterized using Transmission Electron Microscope (TEM). The examination of the mechanical properties was conducted on an MTS-810 machine at two temperatures: ambient and 200°C. Hardness measurements by Vickers method were performed on a ZHV50 hardness tester.
Findings: The microstructure of the WE54 alloy in as-cast condition consists of alpha-Mg phase matrix with some fine-dispersion precipitates of Mg_2Y and $Mg_{24}Y_5$ intermetallic phases inside and on grain boundaries. After solution treatment followed by water-cooling, the intermetallic phases dissolve in the matrix. The ageing treatment caused precipitation of β", β' and $β_1$ intermetallic phases. The best mechanical properties (R_m=333MPa, $R_{0.2}$=257MPa, A_5=6,3%) has a alloy with β' intermetallic phase after ageing at 250°C/16h.
Research limitations/implications: The future research will contain corrosion and creep tests of WE54 magnesium alloy.
Practical implications: The established heat treatment parameters can be useful for preparing heat treatment technology of WE54 casts.
Originality/value: The relationship between the ageing parameters, microstructure and mechanical properties in WE54 magnesium alloy was specified.
Keywords: Metallic alloys; Properties; Mechanical properties; WE54 magnesium alloy

1. Introduction

Magnesium alloys exhibit low densities and high specific strengths, these benefits are the driving force for the use of magnesium alloys in automotive and aerospace industries [1÷4]. In automobiles the most interesting area for magnesium usage is the front section where the engine is located. Any reduction in weight in this area will help to improve the performance and weight balance of a car. Potential magnesium components include power train applications, the instrument panel and the front bonnet [5,6]. Mg alloys containing yttrium and rare earth elements have the best combination of mechanical properties and corrosion resistance [7]. They reach high specific strength, creep resistance, good castability, and corrosion resistance up to a temperature of 250 °C. The improved mechanical properties through RE addition have been attributed to solution and precipitation hardening, and particularly the precipitation of a fine dispersion of intermetallic particles [8]. Depending upon ageing temperature, precipitation sequence in Mg–Y–Nd alloys has been reported to involve the formation of β', β_1 and β phase precipitates [9,10]. Mg–Y–Nd alloys precipitate from the solid solution according to the sequence of phase's α–Mg→β"(hex. $D0_{19}$)→β' (bcc)→β (fcc) [10÷12]. The β" phase has a $D0_{19}$ crystal structure (hexagonal, a=0.642 nm and c=0.521 nm) [13]. It has an Mg_3RE type crystallographic structure [10]. The β' phase has an orthorhombic crystal structure (a=0.640 nm, b=2.223 nm and c=0.521 nm). The β_1 phase has a face-centred cubic structure with lattice parameter a=0.74 nm [13]. Under further ageing the β_1 phase transforms into the equilibrium β phase [10]. The equilibrium β phase is face-centred cubic (a=2.223 nm) [9].

2. Description of the work methodology and material for research

2.1. Material for research

A cast magnesium alloy, WE54, was examined. The alloy was purchased from Magnesium Elektron, Manchester, UK. The alloy's chemical composition is given in Table 1.

Table 1.
Chemical composition of the WE54 alloy

Y	Nd	Zr	Zn	Si	Fe	Mn	Cu	Mg
5,0	1,7	0,55	<0,01	<0,01	0,002	<0,01	<0,01	balance

2.2. Research methodology

Solution treatment was performed at 525°C/8h/water. Ageing treatments were performed at 250°C/4÷96h/air. For the microstructure observation a OLYMPUS GX71 metallographic microscope and a HITACHI S-3400N Scanning Electron Microscope (SEM) were used. TEM examinations were carried out in JEM 2010 ARP microscope. The examination of the mechanical properties was conducted on an MTS-810 machine at ambient (ca. 20°C) and 200°C. Hardness measurements were performed on a ZWICK/ZHV50 hardness tester.

3. Description of achieved results of own researches

3.1. Microstructure of the Elektron 21 alloyaterial for research

The WE54 alloy in as-cast condition was characterized by a solid solution structure α with some fine-dispersion precipitates of Mg_2Y, $Mg_{24}Y_5$ and $Mg_{12}YNd$ intermetallic phases inside and on grain boundaries (Fig. 1). Also the Zr core rich areas have been observed (Fig. 2). After solution treatment, the intermetallic phases dissolved in the matrix (Fig. 3).

After ageing 4h at 250°C two types of precipitates have been observed. First, it is platelet precipitates of β" phase [10,14]. The β" phase is metastable and fully coherent with the matrix. It has a $D0_{19}$ crystal structure [13]. Second phase characterizes with spheroidal shape and was identified as β' phase (Fig. 4). It is also metastable and semi coherent with the matrix. It has an orthorhombic crystal structure [13].

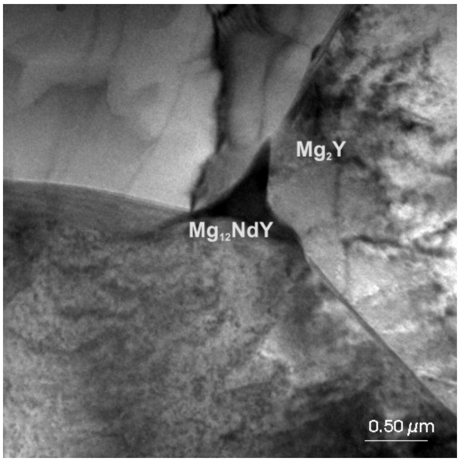

Fig. 1. Precipitates of Mg_2Y and $Mg_{12}YNd$ phases in a-Mg matrix of WE54 alloy in as cast condition, TEM

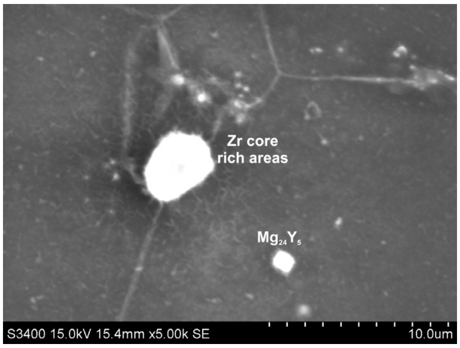

Fig. 2. Zirconium rich core areas and precipitate of $Mg_{24}Y_5$ phase in WE54 alloy in as cast condition, SEM

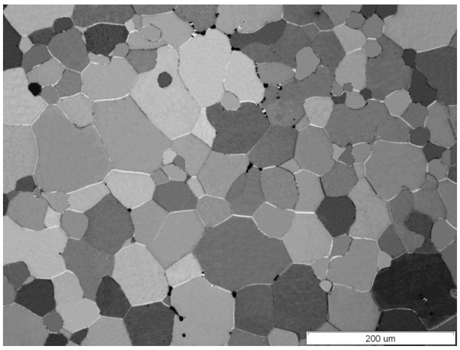

Fig. 3. Solid solution grains in WE54 alloy after solutioning

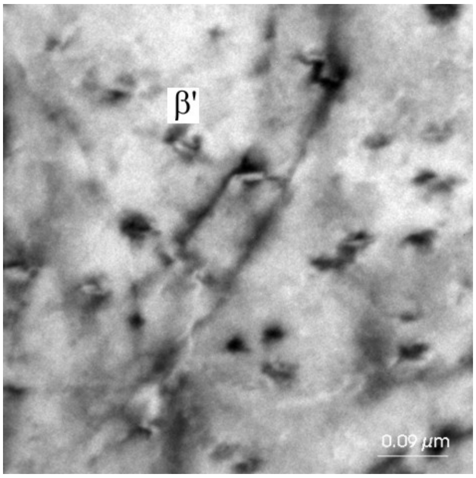

Fig. 4. The β’ precipitates after ageing at 250°C for 4h

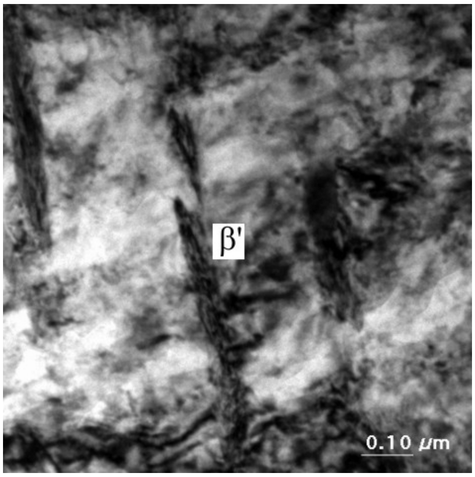

Fig. 5. The β’ precipitates after ageing at 250°C for 16h

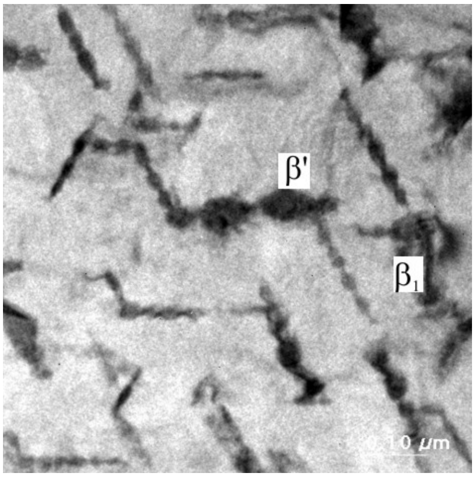

Fig. 6. Network of β’ and β_1 precipitates after ageing at 250°C for 96h

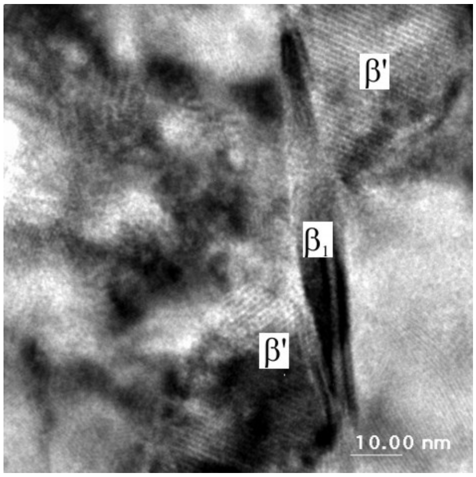

Fig. 7. The β_1 precipitate between two β’ precipitates in WE54 alloy after ageing at 250°C for 96h

With continued ageing (16h), the volume fraction and size of β’ phase increased (Fig. 5).

After ageing for 48 h first precipitates of β_1 phase have been observed [15]. Extension time of ageing to 96h increased volume fraction of β_1 phase. A few of coarse plate-shaped precipitates (β_1) formed within the coarse decomposing precipitates (β’), which had grown into a network (Fig.6). The formation of β_1 phase appears be connected with β’ phase. The β_1 precipitate is attached to two particles of β’ phase (Fig.7).

3.2. Mechanical properties of the WE54 alloy

The hardness of WE54 alloy in as cast condition is equal 77 HV. After solution treatment hardness didn’t change. At the beginning of ageing (4 h), the hardness slightly increased to 78 HV. The peak hardness (84 HV) was obtained at about 16 h. Further ageing led to decrease of the hardness to 80 and 78 HV after 48 and 96h respectively. Fig. 8 shows a hardness curve for the WE54 alloy aged at 250°C.

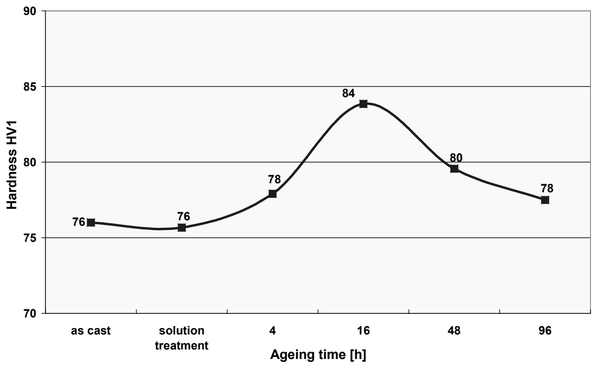

Fig. 8. Change of hardness during ageing at 250°C

The tensile strength and yield point of WE54 alloy in as cast condition are equal 275MPa and 164 MPa respectively. After solution treatment these two parameters decreased. At the beginning of ageing (4 h), the tensile strength and yield point slightly increased. The peak mechanical properties (R_m=333 MPa, $R_{0,2}$=257 MPa) was obtained at about 16 h. Further ageing led to decrease of the tensile strength to 315 MPa and 304 MPa and yield point to 236 MPa and 230 MPa after 48 and 96h respectively. Fig. 9 and 10 show a tensile strength and yield point curves at ambient and 200°C temperature for the WE54 alloy aged at 250°C.

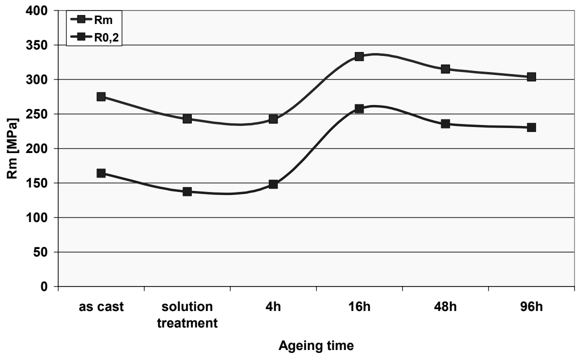

Fig. 9. Change of a tensile strength and yield point during ageing at 250°C (ambient temperature)

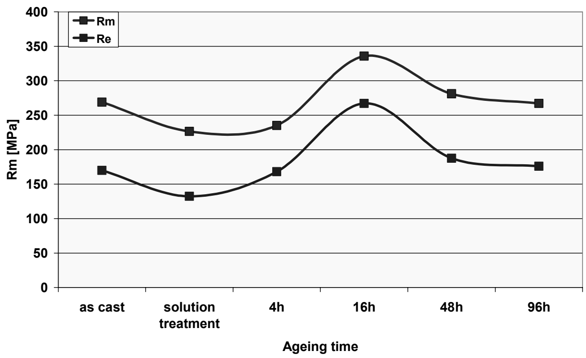

Fig. 10. Change of a tensile strength and yield point during ageing at 250°C (temperature 200°C)

4. Conclusions

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

- The WE54 alloy in as-cast condition is characterized by a solid solution structure α with some fine-dispersion precipitates of Mg_2Y, $Mg_{24}Y_5$ and $Mg_{12}YNd$ intermetallic phases inside and on grain boundaries. After solution treatment the intermetallic phases dissolved in the matrix.
- The precipitation process in WE54 magnesium alloy, aged isothermally at 250°C/4÷96h/, has been found to be a three-stage successive precipitation sequences: α-Mg → β''($D0_{19}$) →β' (cbco)→β_1 (fcc).
- Structure investigations showed that the mechanical properties maximum during the ageing at 250°C/16h resulted from the formation of fine β' precipitates in the Mg solid solution. Further ageing led to decrease of the hardness and mechanical properties due to formation of β_1 phase.

Acknowledgements

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