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Effect of heat treatment on corrosion resistance of WE54 alloy

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Materials

ABSTRACT

Purpose: Poor corrosion resistance is one of the main causes to prevent magnesium alloys for wide applications. The addition of rare earth elements (RE) is an effective way to improve corrosion resistance of magnesium alloys. Heat treatment condition can also influence the corrosion behavior of magnesium alloys. The purpose of the investigation was to study the corrosion resistance of WE54 alloy after heat treatment.
Design/methodology/approach: The study was conducted on WE54 alloy in the as-cast condition and after heat treatment at 250-300˚C for periods of time 4 – 96 h. Immersion test was performed using not deaerated 3.5% NaCl solution at room temperature. Specimens were placed in 3.5% NaCl solution for periods of time between one and 7 days. The dissolution rates (mg cm-2 day-1) were determined by weight loss measurements. After immersion test, the microstructure and the appearances of the corroded structure were examined by scanning electron microscopy.
Findings: The corrosion rate of WE54 alloy strongly depends on heat treatment condition. WE54 alloy in the as-cast and after solution treated have similar corrosion behavior, different from that of aged specimens. The curves of corrosion rate for aged specimens were higher than that for as-cast and solution treated conditions. It was also noticed that the longer time of ageing the higher corrosion rates were observed.
Research limitations/implications: The knowledge about corrosion behavior of Mg-RE-Zr alloys is currently under evaluation on many speciality applications where lightweight connected with optimum corrosion resistance are required.
Practical implications: The knowledge about corrosion behavior of Mg-RE-Zr alloys is currently under evaluation on many speciality applications where lightweight connected with optimum corrosion resistance are required.
Originality/value: This paper includes the effect of heat treatment condition on corrosion resistance of WE54 magnesium alloy.
Keywords: Metallic alloys; Methodology of research; Corrosion; Heat treatment

1. Introduction

High performance magnesium-yttrium-rare earth alloys offer considerable advantages to the aerospace and racing automotive industries. Key properties of these alloys include high specific strength at both room and elevated temperature and good creep resistance, combined with the excellent castability and damping characteristics of magnesium alloys. However these alloys have the poor corrosion resistance. [1÷5]. The reason for the poor corrosion resistance of magnesium and its alloys lies on two aspects: 1) the oxide films forming on surface are not perfect and protective; 2) galvanic or bimetallic corrosion can be caused by impurities or secondary phases [6]. The most common Mg alloys are those alloyed with Al and Mn (e.g. AM50 and AM60) and with Al and Zn (e.g. AZ91), whose mechanical properties and corrosion behaviour are well established [7].

Data concerning corrosion and electrochemical behaviour of Mg alloys are numerous [8÷11], but those concerning Mg-RE alloys are scarce. There is not work on the effect of ageing on corrosion resistance of WE54 alloy. However, the latter data seem to indicate that, in addition to favourable high temperature properties, certain Mg-RE alloys present good corrosion resistance. Unsworth [12] showed that WE54 alloy had a corrosion resistance comparable to that of A356 and A347 Al alloys in 28 day tests in sea water. Geary [13] measured a corrosion rate of 0.4 mm/y) on WE43 in NaCl solution and reported that this alloy had the lowest maximum pit depth of all the Mg alloys tested. Nakatsugawa [14] compared the polarization curves of AZ91D and different Mg-RE alloys, WE54 included, recorded in 5% NaCl solution saturated with $Mg(OH)_2$. The authors deduced from the electrochemical impedance spectra that Mg-RE alloys have a corrosion resistance about four times higher than that of AZ91D. WE43 alloy has a corrosion rate comparable to that of WE54 alloy and lower than Elektron 21 magnesium alloy in NaCl solution [15]. The addition of rare earth elements (RE) is an effective way to improve corrosion resistance of magnesium alloys. Heat treatment condition can also influence the corrosion behavior of these alloys. It can be dependent upon whether microscopic segregation of cathodic phases can be dissolved and dispersed during the heat treat process.

2. Experimental

The studied samples were obtained from commercial WE54 magnesium alloy after semi-continuous casting, with a nominal composition showed in Table 1.

Table 1.
Chemical composition (wt-%) of experimental alloys

Alloy	Y	Gd	Nd	RE	Zn	Zr
WE54	5.0	-	1.7	3.1	<0.01	0.55

Solution treatment was performed at 525°C/8h in air, quenched in water. Ageing treatments were performed at 250°C. The duration of treatment varied between 4 and 48 hours. For the microstructure observation, a OLYMPUS GX71 metallographic microscope and a HITACHI S-3400N scanning electron microscope were used. TEM examination after ageing was carried out on a JEOL JEM 3010 microscope. Specimens for TEM were ion milled using the Precision Ion Polishing System (GATAN).

The specimens (S~15 cm^2) were exposed 7 days to 3.5% NaCl solution maintained at room temperature, without stirring. Before the tests, the specimens were polished with SiC papers up to 1200 grit. After cleaning with acetone and drying, they were weighed to obtain their original weight (m_o) before corrosion. After immersion test, the corroded specimens were taken out of the solution, cleaned with distilled water and dried. They were then immersed in chromate acid (200g/dm^3 CrO_3 + 10g/dm^3 $AgNO_3$) to remove corrosion products. After that, the specimens were cleaned again with distilled water, rinsed with acetone and dried. The specimens were weighed on an analytical balance to an accuracy of ± 0.1 mg. The dried specimens were weighed (m_1) after immersion. The difference between m_o and m_1 is the corrosion weight loss (Δm). According the test results, the corrosion rate was calculated.

3. Results

3.1. Microstructure of WE54 alloy

The microstructure of the solution treated and quenched specimen revealed by optical metallography shows that the grains are not equiaxed and have a mean grain size of about 120 μm (Fig. 1). SEM observations using high magnification did not reveal any evidence of precipitation from system Mg-Y-Nd in the as-quenched condition [16].

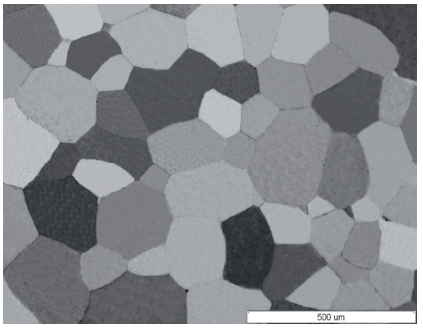

Fig. 1. Microstructure of WE54 after solution treatment at 525 °C/8 h

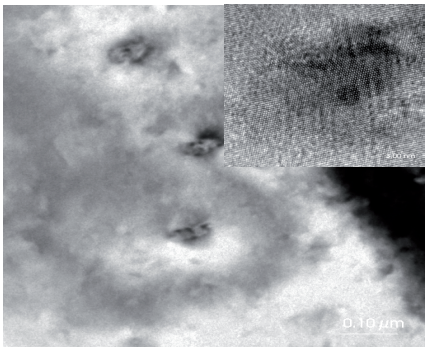

Fig. 2. TEM micrograph showing spheroidal particles of β' in sample aged 4 h at 250 °C

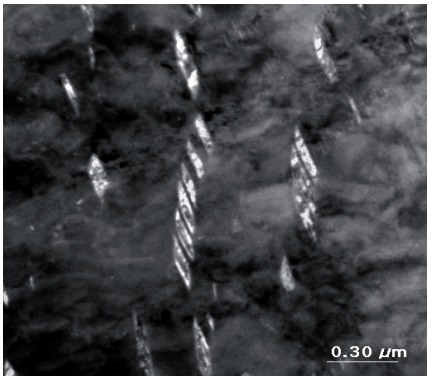

Fig. 3. Dark field micrograph showing plates of β_1 in sample aged 16 h at 250 °C

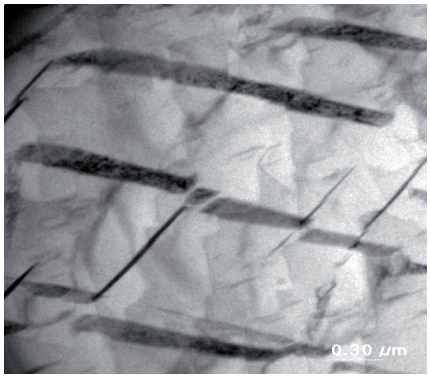

Fig. 4. Bright field micrograph showing plates of β phase in sample aged 48 h at 250 °C

Fig. 2. shows the microstructure of a sample aged 4 h at 250°C. In this underaged condition, the microstructure contained small spheroidal precipitates. These particles were identified, by Nie and Muddle [17], to be β' phase (base-centered orthorhombic - $Mg_{12}NdY$). They were very fine but their densities varied from grain to grain. With increased ageing time (Fig. 3), microstructure contained coarser plate precipitates. These particles nucleated preferentially in the strain field of the β' phase [17]. After a 250 °C ageing for 48 h, precipitates of equilibrium β phase were observed (Fig. 4).

3.2. Immersion corrosion test

Fig. 5 compares the corrosion rates of WE54 alloy in the as-cast condition and after heat treatment. All curves exhibit a gradually increase in corrosion rate with time under immersion in 3.5% NaCl. It can be seen that WE54 alloy in the as-cast and after solution treatment have similar corrosion behavior, different from that of aged specimens. The curves of corrosion rate for aged specimens are higher than that for as-cast or solution conditions. Fig. 6 shows the effect of heat treatment on the corrosion resistance of WE54 alloy after exposure in 3.5% NaCl for 7 days. It can be found that corrosion rate of as-cast WE54 alloy increase with ageing time. After solution treatment (525°C/8h), the corrosion rate remains almost unchanged as compared to as-cast condition and reached maximum value 0.6 mg cm^{-2} day^{-1}. Ageing at 250°C for 4 h caused only slight increase in corrosion rate, while after ageing for 16 h and 48 h the corrosion rate increase to value 0.9 and 1.02 mg cm^{-2} day^{-1}, respectively.

The corrosion propagation was most uniform for the as-cast condition. Aged specimens were more severely corroded than as-cast alloy, and the difference in corrosion damage depends on ageing time. With increased ageing time, the volume fraction of precipitates increased gradually and these particles behaved as the cathodic sites and thus matrix attack is favoured by micro galvanic cell formation.

Fig. 7 shows the surface morphology (SEM) of WE54 alloy with different heat treatment condition after 7 days exposure in 3.5% NaCl. In all cases, corrosion sources appear on overall surface of specimens.

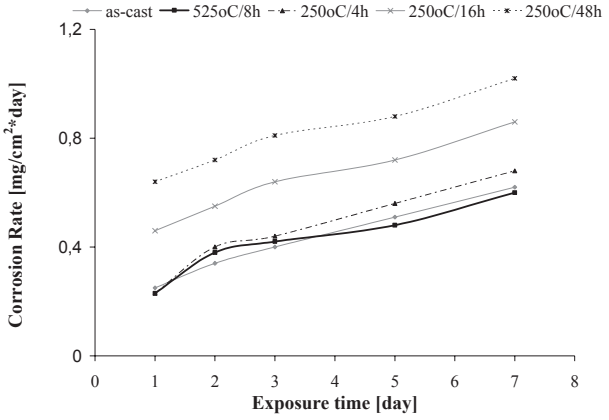

Fig. 5. Corrosion rates of WE54 alloy during immersion test in 3.5% NaCl

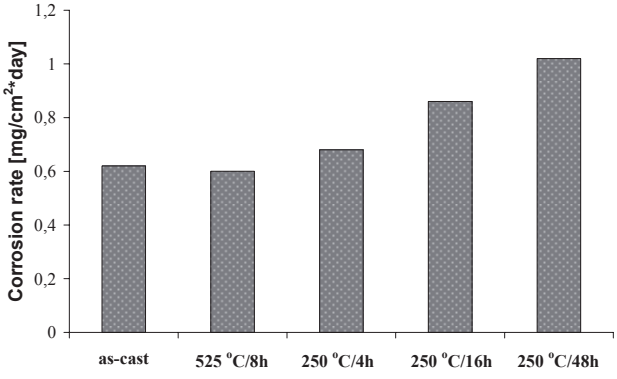

Fig. 6. Corrosion rates of WE54 alloy after immersion test in 3.5% NaCl for 7 days

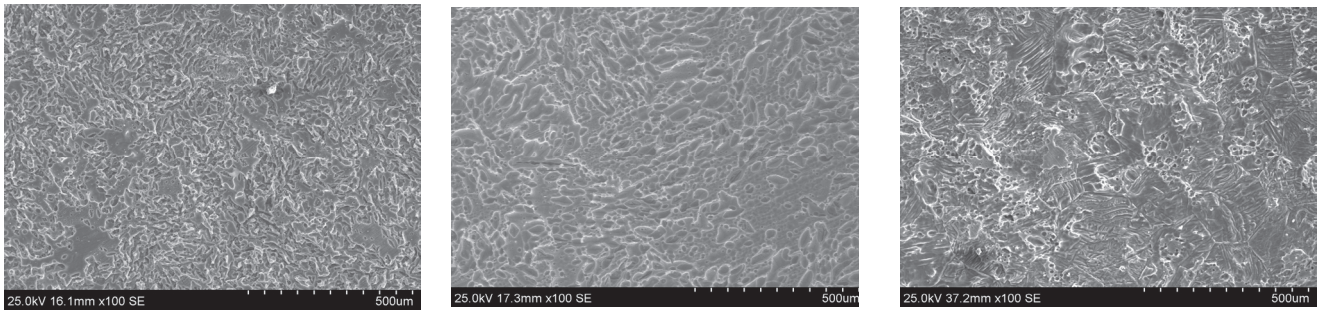

Fig. 7. Corrosion morphologies of WE54 alloy after 7 days of immersion test in 3.5% NaCl: (a) solution treated 525°C/8h, (b) aged 250°C/4h, (c) aged 250°C/48h

4. Conclusions

Based on the research results obtained, it has been found that:

1. Corrosion behavior of WE54 alloy strongly depends on heat treatment condition.
2. Corrosion rates of aged specimens are higher than those for as-cast and solution condition. The longer time of ageing caused higher corrosion rates of WE54 alloy.
3. Higher corrosion rate of WE54 alloy after ageing treatment is caused by precipitation of β', β_1, and equilibrium β phases in microstructure.

Acknowledgements

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