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Procedia Engineering 10 (2011) 1835–1840

Engineering Procedia

ICM11

Mechanical and creep properties of Mg-4Y-3RE and Mg-3Nd-1Gd magnesium alloy

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Abstract

A study has been undertaken to reveal the microstructure, mechanical and creep properties of two Mg-4Y-3RE and Mg-3Nd-1Gd magnesium alloys. The relationship between the ageing parameters, microstructure, mechanical and creep properties was specified. Structure investigations showed that the mechanical properties maximum during the ageing at 200°C/16h (Mg-3Nd-1Gd alloy) and at 250°C/16h (Mg-4Y-3RE alloy) resulted from the formation of fine β" and β' precipitates in the α-Mg solid solution. Further ageing led to decrease of the mechanical properties due to formation of β_1 and β phases in Mg-4Y-3RE alloy or only β phase in Mg-3Nd-1Gd. The creep tests of the Mg-3Nd-1Gd alloy at temperature 200°C in the stress range 90-150MPa show the larger creep strain and steady-state creep rate than the Mg-4Y-3RE alloy.

Selection and peer-review under responsibility of ICM11

Keywords: magnesium alloys; creep, mechanical properties, microstructure, fracture;

1. Introduction

Magnesium alloys are characterised by low density and good mechanical properties. Mainly for these reasons, they have a widespread application in the automotive and aircraft industries. The disadvantages are poor properties in elevated temperature [1, 2]. A range of alloys for high temperature application are commercially available from Mg-Zr alloys with addition of yttrium and another rare earth (RE). The rare earth elements have beneficial effect of on the creep properties and thermal stability of microstructure and mechanical properties of magnesium alloys [3]. However, alloys containing yttrium have high associated cost due to the difficulties in casting. Therefore there is a need for an alternative alloy which has similar properties to Mg-Y-RE alloys, but with foundry handling and associated costs like non-yttrium containing alloys [4,5]. The Mg-3Nd-1Gd alloy is a new magnesium sand casting alloy for used to approximately 200°C. It has high strength, good corrosion resistance and excellent castability and is being used in both

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Selection and peer-review under responsibility of ICM11 doi:10.1016/j.proeng.2011.04.305

civil and military aircraft and also in automobile (motorsport) industry [5]. The article presents the results of the microstructure, mechanical and creep investigations of two magnesium alloys Mg-4Y-3RE and Mg-3Nd-1Gd.

2. Material and methodology

2.1. Material

The material for the research were two sand casting Mg-4Y-3RE and Mg-3Nd-1Gd magnesium alloys. The chemical composition of these alloys is given in Table 1.

Table 1. The chemical composition of the sand casting Mg-4Y-3RE and Mg-3Nd-1Gd magnesium alloys (in wt.%)

Alloy	Gd	Nd	Y	Zn	Zr	Fe	Ag	TRE	Mg
Mg-4Y-3RE	-	2.5	4.0	<0.01	0.5	0.002	-	3.3	balance
Mg-3Nd-1Gd	1.2	2.7	-	0.4	0.49	0.003	0.01	4.2	

2.2. Methodology

Sand casting was performed at 780°C temperature. The as-cast specimens were solution treated at 520 °C for 8h and quenched into water. Ageing treatments were performed at 200°C and 250°C/4÷96h with cooling in air. The OLYMPUS GX71 metallographic microscope, a HITACHI S-3400N scanning electron microscope (SEM) and a Tecnai G2 transmission electron microscope were used for the microstructure observation. Hardness tests have been performed with a Vickers indenter. The examination of the mechanical properties was conducted on an MTS-810 machine at ambient (ca. 20°C) and 200°C. Constant-load tensile creep tests were performed at 200°C, 250°C and 300°C in a stress range 90-150 MPa. Creep strain was measured by extensometers which were attached directly to the gauge section of specimens. The length of the specimen was 125 mm, the gage length was 60 mm and the diameter of the reduced section was 6 mm.

3. Results

3.1. Age-hardening behaviour

The effect of ageing temperature and time on the hardness of both alloys is shown in Fig. 1.

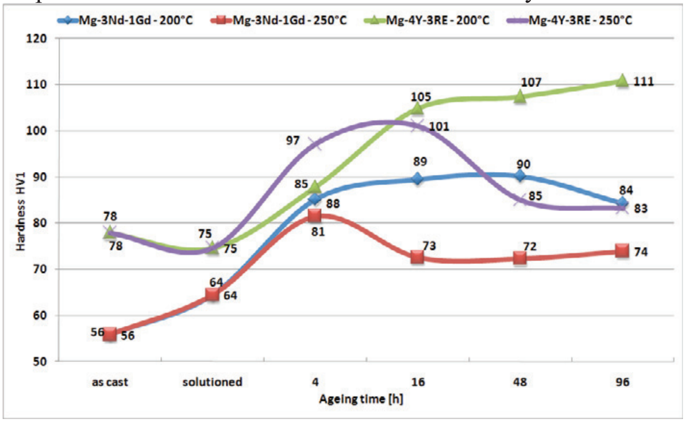


Fig. 1. Age-hardening curves of the alloys after ageing at 200°C and 250°C.

It shows typical hardness curves for the decomposition of the supersaturated solid solution, but with some peculiarities for every alloy. The Mg-3Nd-1Gd alloy shows the lower hardness in as-cast condition and after quenching. The Mg-4Y-3RE water quenched hardness's are nearly equal, which are ascribed to the little solid solution of Y and RE in the Mg matrix. However in Mg-3Nd-1Gd alloy after quenching the hardness increase to 64HV due to the bigger solid solution of Nd and Gd in α-Mg matrix. Both alloys exhibit age-hardening behavior and similar age response processes. The hardness increases gradually at the beginning of ageing and decreases evidently after peak hardness range. In 200°C the Mg4Y-3RE alloy takes more than 100h to reach the peak hardness of ~110HV. However, in ageing at 250°C the peak hardness (101HV) was obtained after about 16h. Further ageing led to decrease of the hardness to 83HV after 96h. In the Mg-3Nd-1Gd alloy the peak hardness (89HV) was obtained at about 16h of ageing at 200°C. Further ageing or ageing at 250°C led to decrease of the hardness of this alloy.

3.2. Tensile properties

The mechanical properties including hardness (HV), ultimate tensile strength (UTS), yield strength (YS) and elongation (ε) of the investigated alloys in T6 condition (peak hardness) at RT and 200°C are listed in Table 2. At both room and elevated temperatures, the yield strength, ultimate tensile strength and hardness of Mg-4Y-3RE alloy were all considerably higher than those of the Mg-3Nd-1Gd alloy.

Table 2. The mechanical properties of investigated alloys in T6 condition

Alloy	Ageing	HV	Yield strength (MPa)		Ultimate tensile strength (MPa)		Elongation (%)	
			20°C	200°C	20°C	200°C	20°C	200°C
Mg-4Y-3RE	250°C/16h	101	225	209	331	299	6	6
Mg-3Nd-1Gd	200°C/16h	89	163	152	293	268	7	17

3.3. Microstructure after ageing

Structure investigations showed that the hardness maximum during the ageing of the Mg-4Y-3RE resulted from the formation of fine β" and β' precipitates in the α-Mg solid solution. Between the

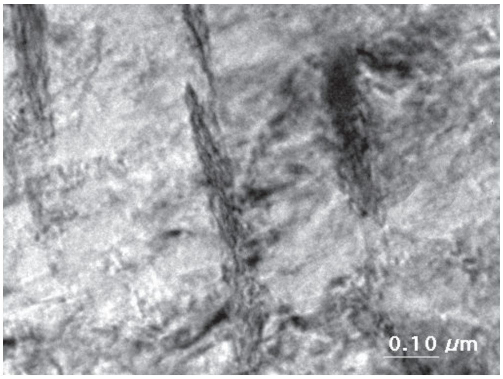


Fig. 2. TEM image with corresponding (SAED) pattern of the Mg-4Y-3RE alloy aged at 250°C for 16h.

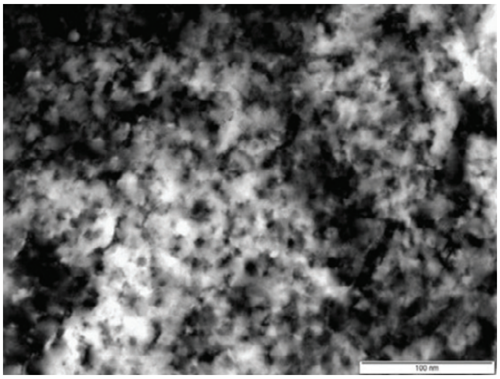


Fig. 3. TEM image with corresponding (SAED) pattern of the Mg-3Nd-1Gd alloy aged at 200°C for 16h.

precipitates and the α-Mg solid solution matrix there existed coherency or semi-coherency. β" phase is fully coherent with the matrix. It has a $D0_{19}$ crystal structure (a=0,64 nm and c=0,52 nm) and is isomorphous with the $Mg_3X(RE)$ phase [6]. The intermediate β' phase is metastable and semi coherent with the matrix. It has an orthorhombic crystal structure (a = 0,64 nm, b = 2,22 nm and c = 0,52 nm) [6].

A typical micrograph from the Mg-4Y-3RE alloy after ageing to reach the hardness maximum is shown in Fig. 2. The microstructure of Mg-3Nd-1Gd alloy aged at 200 °C for 16 h contained also thin precipitate platelets of β" and spherical particles of β' (Fig.3). The precipitates in the Mg-3Nd-1Gd alloy had the same crystal structure as the precipitates formed during solid solution decomposition in binary Mg-4Y-3RE alloy. Further ageing led to decrease of the mechanical properties due to formation of β_1 and β phases in Mg-4Y-3RE alloy or only β phase in Mg-3Nd-1Gd.

3.4. Creep properties of the Mg-4Y-3RE and Mg-3Nd-1Gd alloys

Fig. 4 compares tensile creep curves obtained from peak-aged samples of the Mg-4Y-3RE and Mg-3Nd-1Gd alloys at 200°C and under stresses in the range 90-150 MPa. At 200°C/90MPa both alloys show high creep resistance and their creep curves end at the secondary creep stage after 120 h creep deformation. However, the creep properties of alloys studied decrease and the specimen of Mg-3Nd-1Gd alloy ruptured after 93 h test when the test applied stress is raised to 150 MPa. Total creep strain (ε) and minimum creep rate ($\dot{\varepsilon}$) of the two investigated alloys are listed in Table 3. At both applied creep stresses the Mg-4Y-3RE alloy achieves lower minimum creep rate and creep elongation than Mg-3Nd-1Gd alloy.

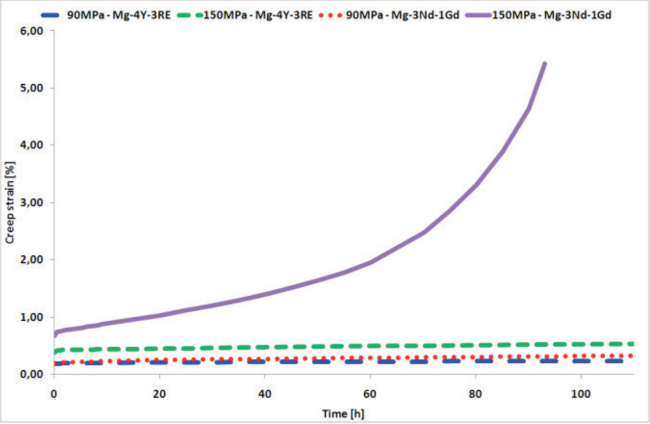


Fig. 4.Creep curves of peak-aged samples of Mg–4Y–3RE and Mg–3NGd–1Gd alloys, tested under 90-150 MPa at 200°C.

Table 3. The creep properties of investigated alloys at 200°C.

Alloy	Mg-4Y-3RE		Mg-3Nd-1Gd	
Stress	90 MPa	150 MPa	90 MPa	150 MPa
ε [%]	0,24	0,54	0,34	5,43
$\dot{\varepsilon}$ [1/s]	$7{,}35\cdot10^{-10}$	$2{,}43\cdot10^{-9}$	$2{,}30\cdot10^{-9}$	$6{,}29\cdot10^{-8}$
Time	120 h	120 h	120 h	93,1 h

Fig. 5 compares tensile creep curves obtained from peak-aged samples of both alloys under 90MPa stress in the temperature range 200-300°C. The total creep strain (ε) and minimum creep rate ($\dot{\varepsilon}$) of the two investigated alloys are listed in Table 4.

Table 4. The creep properties of investigated alloys under 90MPa applied stress.

Alloy	Mg-4Y-3RE			Mg-3Nd-1Gd	
Temperature	200°C	250°C	300°C	200°C	250°C
ε [%]	0,24	1,40	12,4	0,34	14,99
$\dot{\varepsilon}$ [1/s]	$7{,}35\cdot10^{-10}$	$3{,}41\cdot10^{-8}$	$3{,}48\cdot10^{-6}$	$2{,}30\cdot10^{-9}$	$2{,}07\cdot10^{-7}$
Time	120 h	120 h	3,7 h	120 h	48 h

At 200°C both alloys had a significantly higher creep resistance. The increase of temperature to 250°C didn't change the creep resistance of Mg-4Y-3RE alloy. However, the creep properties of Mg-3Nd-1Gd alloy decreased and the specimen ruptured after 48h of test. Just in temperature 300°C the creep resistance of the Mg-4Y-3RE alloy significantly decreased. The specimen ruptured after ~4h of test.

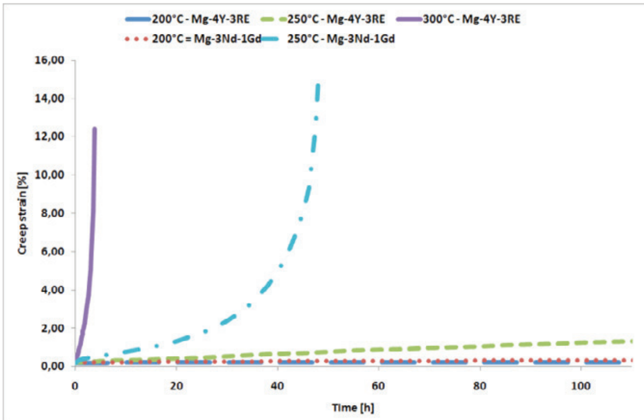


Fig. 5. The influence of temperature on creep curves of peak-aged samples of Mg–4Y–3RE and Mg–3NGd–1Gd alloys, tested under 90MPa.

3.5. Microstructure after creep test

In order to understand the mechanism responsible for the change of creep resistance of investigated alloys, microstructure observations were performed on selected specimens after creep tests. Fig. 6a shows the SEM image of Mg-4Y-3RE alloy after creep test at 200°C/90MPa.

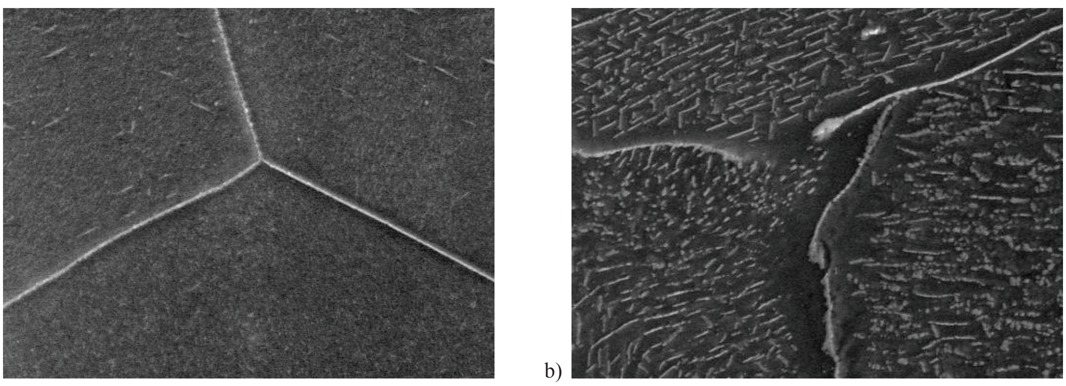
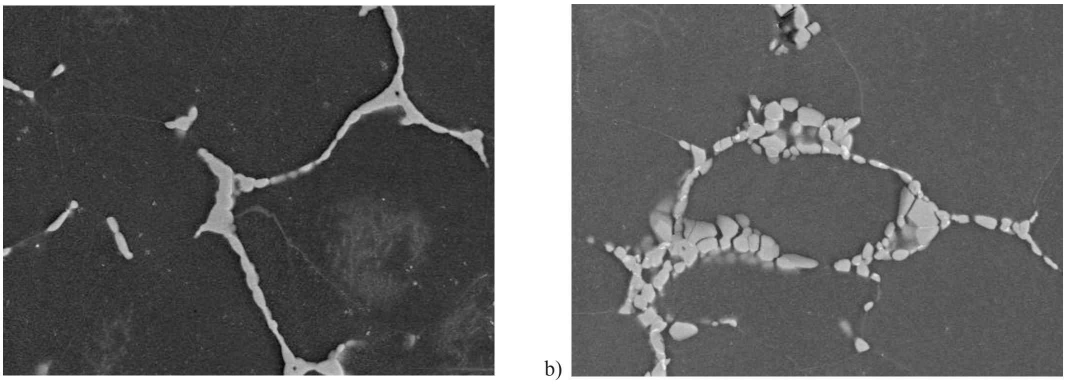
a)  b)

Fig. 6. The microstructure of Mg-4Y-3RE alloy after creep test at: a) 200°C/90MPa, b) 300°C/90MPa.

Compared with the T6 microstructure before creep, no visible morphological change have been observed, indicating that the structure of the alloy have high thermal stability. Just after creep test at 300°C considerable changes in microstructure were observed (Fig. 6b). The volume fraction of regular β phase increase. Their morphology were modified. The precipitates tended to be spheroidised. Moreover these precipitates create the characteristic network on grain boundaries. The microstructure of Mg-3Nd-1Gd alloy after creep tests is presented in Fig.7. It can be seen that after creep test at 200°C/90MPa the precipitates of the $Mg_{41}Nd_5$ phase are presented on α-Mg solid solution grain boundaries (Fig. 7a). After creep test at 250°C/90MPa coagulation process of the $Mg_{41}Nd_5$ precipitates have been observed. Numerous, cracked precipitates of this phase and some creep voids were also observed (Fig.7b).



a) b)

Fig. 7. The microstructure of Mg-3Nd-1Gd alloy after creep test at: a) 200°C/90MPa, b) 250°C/90MPa.

4. Conclusions

The mechanical and creep properties of two Mg-4Y-3RE and Mg-3Nd-1Gd magnesium alloys were investigated. Tested in the peak-aged condition, the mechanical properties of Mg-4Y-3RE alloy are remarkably higher than that of the Mg-3Nd-1Gd alloy, at both ambient and 200°C temperature. The mechanical properties maximum during the ageing at 200°C/16h (Mg-3Nd-1Gd alloy) and at 250°C/16h (Mg-4Y-3RE alloy) resulted from the formation of fine β" and β' precipitates in the α-Mg solid solution. At 200°C/90MPa both alloys show high creep resistance. In the higher temperature and stresses creep strengths of the Mg-4Y-3RE alloy are also considerably higher than those of the Mg-3Nd-1Gd alloy. This significant improvement in tensile and creep properties is associated with a better thermal stability of phases containing yttrium.

Acknowledgements

The present work was supported by the Polish Ministry of Science and Higher Education under the research project No 6ZR7 2009C/07354.

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