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Microstructure and mechanical properties of Elektron 21 alloy after heat treatment

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Materials

ABSTRACT

Purpose: Elektron 21 is new magnesium based casting alloy contains neodymium, gadolinium and zinc for used to at 200°C. It is a Mg-RE-Zn-Zr alloy designed for aerospace and specialty application ns. This alloy has high strength, good corrosion resistance and excellent castability. The aim of the research was to determine the effect of heat treatment parameters on the microstructure and mechanical properties of Elektron 21 magnesium alloy
Design/methodology/approach: Solution treatment was performed at 520°C/8h with water cooling. Ageing treatments were performed at 200°C/4÷96h and then quenched in air. The microstructure was characterized by JEM 2010 ARP microscope The examination of the mechanical properties was conducted on an MTS-810 servo hydraulic machine at two temperatures: ambient (ca. 20°C) and 200°C. Hardness measurements by Vickers method were performed on a ZWICK/ZHV50 hardness tester.
Findings: The microstructure of the cast alloy consists of α-Mg phase matrix with precipitates of intermetallic phase Mg12(Ndx,Gd1-x) at grain boundaries. After solution treatment the Mg12(Ndx,Gd1-x) phase dissolves in the matrix. The aging treatment applied after solution treatment with air-cooling caused precipitation of a β”, β’ and β intermetallic phases. The best mechanical properties (Rm=308MPa, R0.2=170MPa, A5=9.5%) has a alloy with β’ intermetallic phase.
Research limitations/implications: The future research will contain microstructural investigations of Elektron 21 alloy after creep tests.
Practical implications: Elektron 21 magnesium alloy is used in the aircraft industry for engine casings, gear box casings and rotor heads in helicopters. Results of investigation may be useful for preparing heat treatment technology of the Mg-Nd-Gd alloys.
Originality/value: The results of the researches make up a basis for the next investigations of magnesium alloys with addition of Gd and Nd designed to exploitation at temperature to 300°C.
Keywords: Metallic alloys; properties; Mechanical properties; Elektron 21 magnesium alloy

1. Introduction

Magnesium is the lightest of metals used for constructional alloys. These alloys are characterised by low density and good mechanical properties [1,2], however they show poor properties in elevated temperature [3-5]. Among various magnesium alloys, rare earth containing alloys are known to show good mechanical properties and excellent creep resistance [6].

A range of alloys are commercially available from high temperature Mg-Zr alloys with addition of yttrium. However alloys that contain yttrium have high associated cost due the difficulties in founding. Therefore there is a need for an alternative alloy which has similar properties to Mg-Y alloys, but with foundry handling and associated costs like non-yttrium containing alloys [7, 8]. Mg-Nd-Gd magnesium alloys are characterised by high-strength and good creep-resistant alloys for automotive and aerospace applications [9, 10]. The rare earth elements have beneficial effect of on the creep properties and thermal stability of structure and mechanical properties of magnesium alloys [4]. The strength of this alloy is achieved essentially via precipitation strengthening. Depending on the ageing temperature and time, the precipitation sequence in Mg-Nd-Gd alloys has been reported to involve formation of phases designated β”, β’, and β. These alloys precipitate from the solid solution according to the sequence of phases: $\alpha Mg \rightarrow \beta$” (hex. $D0_{19}$)$\rightarrow \beta$’(bcc)$\rightarrow \beta$(fcc) [4, 11]. Elektron 21 is new magnesium based casting alloy containing neodymium, gadolinium and zinc for used to approximately 200°C. This alloy has high strength, good corrosion resistance and excellent castability. Elektron 21 is fully heat treatable [7]. Neodymium has a positive effect on tensile strength at elevated temperatures and reduces porosity of casts and susceptibility to cracking during welding. Gadolinium, like neodymium shows a decreasing solid solubility as temperature falls, indicating potential for precipitation strengthening. Zinc is added to magnesium alloys in sufficient quantities to achieve precipitation strengthening. It improves strength without reducing ductility [7]. 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 and castability and corrosion performance [12].

Elektron 21 generates a useful range of mechanical properties which can best be summariesed by comparison with other Mg alloys currently available. Up to 200°C strength Elektron 21 is similar to WE43 alloy. Properties are superior to ZE41 and AZ91 alloys [7]. Elektron 21 is being used in both civil and military aircraft and also in motorsport industry for aircraft transmission systems and in the cold areas of engine such as the intermediate housing [13-15].

2. Description of the work methodology and material for research

2.1. Material for research

The material for the research was a casting Elektron 21 magnesium 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 Elektron 21 alloy in wt.-%

Gd	Nd	Zr	Zn	Mn	Fe	Ag	TRE	Mg
1,2	2,7	0,49	0,4	0,001	0,003	0,01	4,2	balance

2.2. Research metodology

Solution treatment was performed at 520°C/8h with water cooling. Ageing treatments were performed at 200°C/4÷96h and then quenched in air. For the microstructure observation a HITACHI S-3400N scanning electron microscope was used. Samples for TEM investigations were given in Gatan PIPS ion beam. 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 the achieved results of own researches

3.1. Microstructure of the Elektron 21 alloy

The Elektron 21 alloy in as-cast condition is characterized by a solid solution structure α with precipitates of $Mg_{12}(Nd_x,Gd_{1-x})$ intermetallic phase on grain boundaries (fig.1). The $Mg_{12}(Nd_x,Gd_{1-x})$ phase is a modification of $Mg_{12}Nd$ phase with neodymium substituted by gadolinium without destroying the crystal structure, due to reasonably small difference in the atomic radii of gadolinium r_{Gd}=0,1802 nm and neodymium r_{Nd}=0,1821 nm. After solution treatment at a temperature of 520°C /8h the $Mg_{12}(Nd_x,Gd_{1-x})$ intermetallic phase dissolved in the matrix.

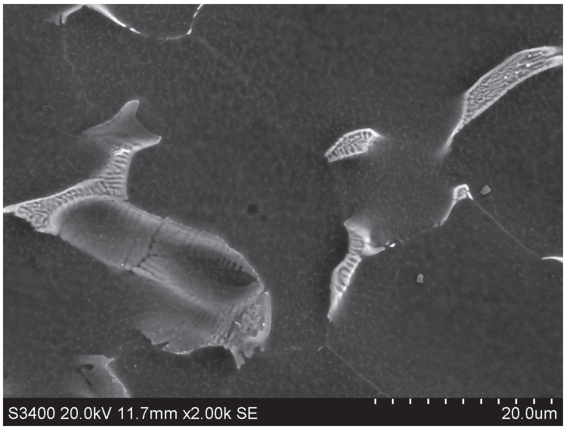

Fig. 1. SEM image of Elektron 21 alloy in as cast condition

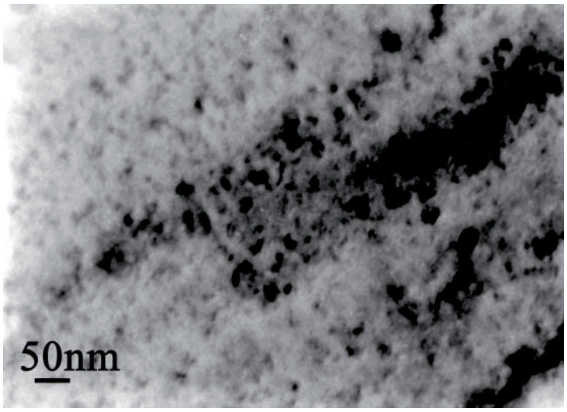

Fig. 2. TEM bright-field images of microstructures taken from the alloy aged at 200°C for 16h

The Elektron 21 alloy after aged 16h at 200°C is characterized by the fine dispersion of β' precipitates in the a matrix (fig.2). The size of these precipitates was very small, that it was difficult to obtain electron diffraction patterns from individual particles to identify their structure.

With continued ageing, the volume fraction of β' phase increased. The β' precipitates formed in the Elektron 21 alloy have convex lens morphology (fig.3).

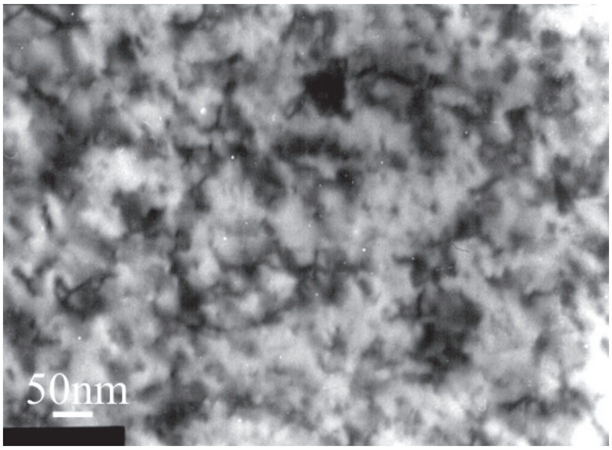

Fig. 3. TEM bright-field images of microstructures taken from the alloy aged at 200°C for 48h

With continued ageing at 200°C, there was a precipitation of coarse equilibrium β phase (face-centered cubic structure - isomorphous to Mg_5Gd). The microstructure now contained a small number of β precipitates inside grains and areas with planar faults – stacking faults (fig.4).

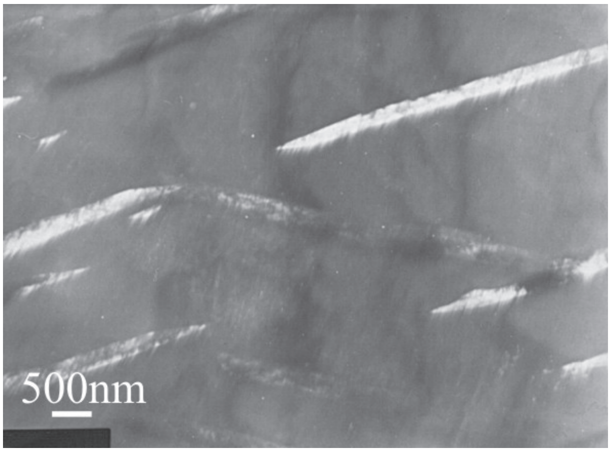

Fig. 4. TEM dark-field images of microstructures taken from the alloy aged at 200°C for 96h

Rare earth elements in solid solution in magnesium decrease stacking fault energy. The value of stacking faults is depended on heat treatment temperature and ageing time. In Elektron 21 some stacking faults were observed after ageing at 200°C for 48h. After prolonged ageing time to 96h the density of stacking faults increasing (Fig. 5).

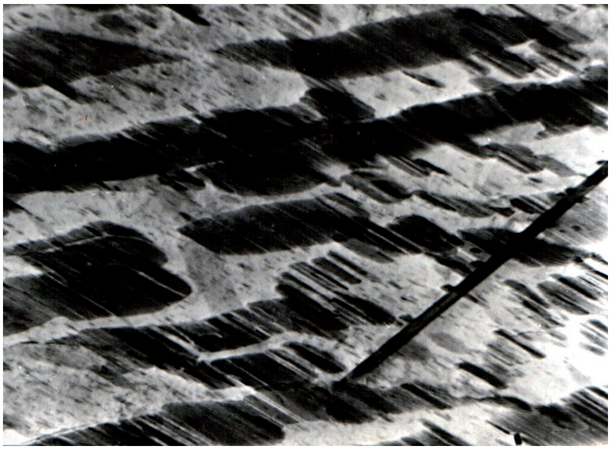

Fig. 5. TEM bright-field images of microstructures taken from the alloy aged at 200°C for 96h

3.2. Mechanical properties of the Elektron 21 alloy

Fig. 6 shows a hardness curve for the Elektron 21 alloy aged at 200°C. At the beginning of ageing (4 h), the hardness increased and the peak hardness (86 HV) was obtained at about 16 h. It was noticeable that there was a plateau of peak-ageing region from 4 to 48 h. Further ageing led to decrease of the hardness.

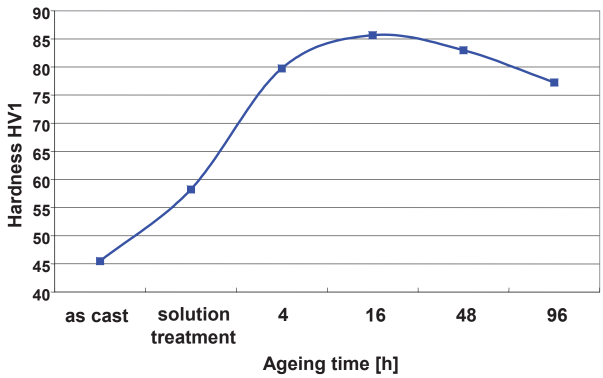

Fig. 6. An age-hardening curve at 200°C for the Elektron 21 alloy

Fig. 7 and 8 show a tensile strength and yield point curves for the Elektron 21 alloy aged at 200°C. They show typical curves for the decomposition of the supersaturated solid solution. At the beginning of ageing (16 h), the tensile strength and yield point increased and the peak mechanical properties was obtained at about 48 h. Further ageing led to decrease of the mechanical properties at ambient and elevated temperature.

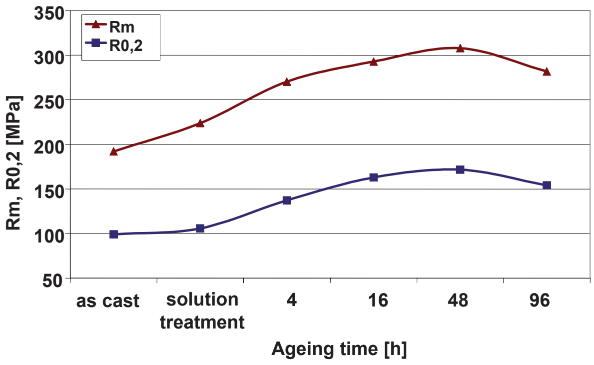

Fig. 7. Change of a tensile strength and yield point during ageing at 200°C (ambient temperature)

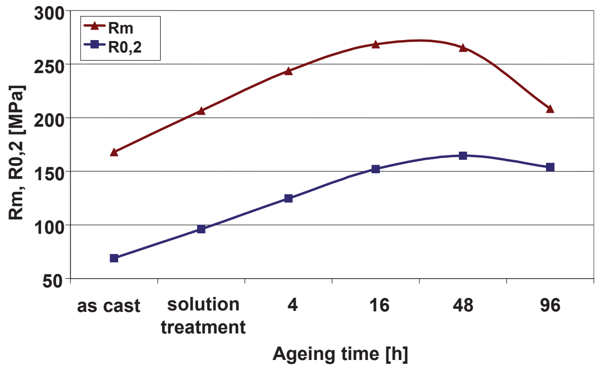

Fig. 8. Change of a tensile strength and yield point during ageing at 200°C (temperature 200°C)

4. Conclusions

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

1. The Elektron 21 alloy in as-cast condition is characterized by a solid solution structure α with precipitates of $Mg_{12}(Nd_x,Gd_{1-x})$ phase on grain boundaries. After solution treatment the $Mg_{12}(Nd_x,Gd_{1-x})$ phase dissolved in the matrix what caused the growth of mechanical properties.
2. The precipitation process in Elektron 21 magnesium alloy, aged isothermally at 200°C, has been found to be a three-stage successive precipitation sequences: α-Mg → probably β"(D019) →β' (cbco)→β (fcc).
3. Structure investigations showed that the hardness and mechanical properties maximum during the ageing at 200°C/48h 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 equilibrium β phase and increase the density of stacking faults.

Acknowledgements

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