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Effects of thermal treatment on microstructure and mechanical properties of a Mg-Gd-based alloy plate

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ABSTRACT

The Mg-8Gd-4Y-Nd-Zr alloy plate was prepared by casting, homogenization and extrusion. Microstructure of the as-cast alloy was comprised of α-Mg and eutectics $Mg_{5.05}RE$. These eutectics were able to dissolve in matrix during subsequent homogenization, but rare earth (RE) solutes precipitated from the matrix again during extrusion in the form of irregular $Mg_{5.05}RE$ particles. In order to dissolve particles and improve mechanical property, companion samples were solution treated at temperatures ranging from 450 °C to 520 °C. With the solution temperature increasing, the volume fraction of $Mg_{5.05}RE$ particles decreased, and finally, almost all of the particles dissolved in the matrix when solution temperature increased to 520 °C. The strength of the solution and ageing treated samples increased first and then decreased as the solution temperature increasing, and the best property was achieved by 475 °C/0.5 h treatment followed by ageing. The ultimate tensile strength, tensile yield strength and elongation of the sample were 419 MPa, 321 MPa and 2.6%, respectively. Fracture analysis indicated that the residual $Mg_{5.05}RE$ particles were responsible for the sample's failure. It was also the reason for the failure of other samples solution treated at lower temperatures. However, in 520 °C/0.5 h-T6 treated sample, the fracture was induced by promoted twinning behavior, which was caused by the formation of β′ precipitates during ageing. The critical resolved shear stress (CRSS) for basal slip was improved much higher than that for twinning, which suppressed slip but promoted twinning and finally resulted in the deterioration in elongation.

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1. Introduction

Magnesium alloys containing rare earth elements, particularly those based on the Mg-Gd system, due to their high strength, have attracted many researchers [1–9]. The high strength was mainly attributed to the formation of precipitates during ageing, which provide effective obstacles for basal dislocations slip [1,10]. Because of this, precipitation process of Mg-RE alloys was extensively investigated by a number of researchers and a four-stage precipitation sequence was proposed [11–17]: Mg (s.s.s.s) → metastable β″ (DO_{19}) → metastable β′ (*c*-base centered orthorhombic) → metastable β_1 (cubic) → stable β (cubic). Metastable β″ precipitates usually formed at the initial stage of ageing. The crystal structure of β″ precipitate was hexagonal DO_{19}, and it was coherent with the matrix. So, its inhibition effect to dislocations was limited. β′ precipitate was also a metastable phase and usually existed at the peak-aged state. It was semi-coherent with the matrix, and was determined to be the most effective precipitate. In the later period of ageing, the β′ precipitate transformed to β_1 and then β precipitate, both of which were incoherent with the matrix, and the strengthening effect decreases. Thus, in order to obtain high strength, formation of high volume fraction of β′ precipitates was thought to be an effective method.

Grain boundary strengthening mechanism was another efficient way to enhance the strength of magnesium alloy because of its high Hall-Petch K value [1,18–20]. As we know, the deformation temperature was in inverse proportion to the size of the recrystallized grain size if other deformation conditions were fixed [21–24]. For the purpose of grain refinement, relatively low deformation temperature was usually favorable. However, according to the previous investigations [20,25–29], RE-containing particles usually precipitated from the matrix when deformed at low temperatures, which consumed a number of RE atoms and decreased the volume fraction of β′ precipitates after ageing. This may induce the decrease in strength. Similarly, this problem has also been encountered by aluminum alloy, and solution treatment

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was employed to solve this problem [30,31]. Nevertheless, in magnesium alloys, this process has rarely received much attention as it deserved. In present work, for the sake of achieving high performance, solution process was adopted for Mg-8Gd-4Y-Nd–Zr alloy plate fabrication. The microstructure and mechanical property evolution were investigated, and the fracture mechanisms during tensile testing were discussed.

2. Experimental procedures

The ingot with a nominal composition of Mg-8.0Gd-4.0Y-1.0Nd-1.0Zr (wt%) was prepared from high purity Mg (> 99.93%), Mg-31.25Gd (wt%), Mg-25.48Y (wt%), Mg-30.15Nd (wt%) and Mg-30.23Zr (wt%) master alloys by melting in a mild steel crucible at 760 °C under argon atmosphere. The actual chemical composition of the ingot was determined to be Mg-7.71Gd-3.45Y-1.02Nd-0.51Zr (wt%). The ingot was homogenized at 520 °C for 12 h and quenched into cold water. Then, the ingot was reheated to 400 °C and extruded to be a plate with the extrusion ratio of 11.3. The section size of the plate was 180 × 25 mm. Solution treatments of the samples cut from the plate were carried out at 450 °C, 475 °C, 500 °C and 520 °C with the fixed time of 0.5 h. Half of the solution treated samples were then aged at 225 °C, and the peak-aged samples were denoted by 450 °C/0.5 h-T6, 475 °C/0.5 h-T6, 500 °C/0.5 h-T6 and 520 °C/0.5 h-T6, respectively.

Microstructure observations were performed on the optical microscopy (OM) and a scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometer. Samples for OM and SEM observation were prepared by standard metallography technique and were etched in a solution of 4.0 vol% HNO_3 with ethanol. In SEM examination, the fracture morphology observation was operated in secondary electron image mode and others were in backscattered electron image mode. The grain size was measured by linear intercept method. X-ray diffraction (XRD) studies were carried out by a Rigaku D/max 2500 diffractometer with Cu K_α radiation. The samples for electron backscatter diffraction (EBSD) were prepared by mechanical polishing followed by electrolytic polishing (15.0 vol% acetic acid, 5.0 vol% nitric acid, 60.0 vol% ethanol and 20.0 vol% distilled water). EBSD examination was carried out on the FEI Sirion200 FEG SEM operated at 15 kV. Statistic orientation analysis was processed using OIM TSL software provided by EDAX. The step size was 1.0 μm during EBSD for 520 °C/0.5 h sample after being deformed to a tensile strain of 5.4%, and 0.4 μm for 520 °C/0.5 h-T6 sample, respectively. The average confidence index for Fig. 14 (a) and (b) were 0.44 and 0.66, respectively. Characterization of phases was performed in a Tecnai G2 20 transmission electron microscopy (TEM). The samples for transmission electron microscopy tests were ion milled using the Precision Ion Polishing System (GATAN 691).

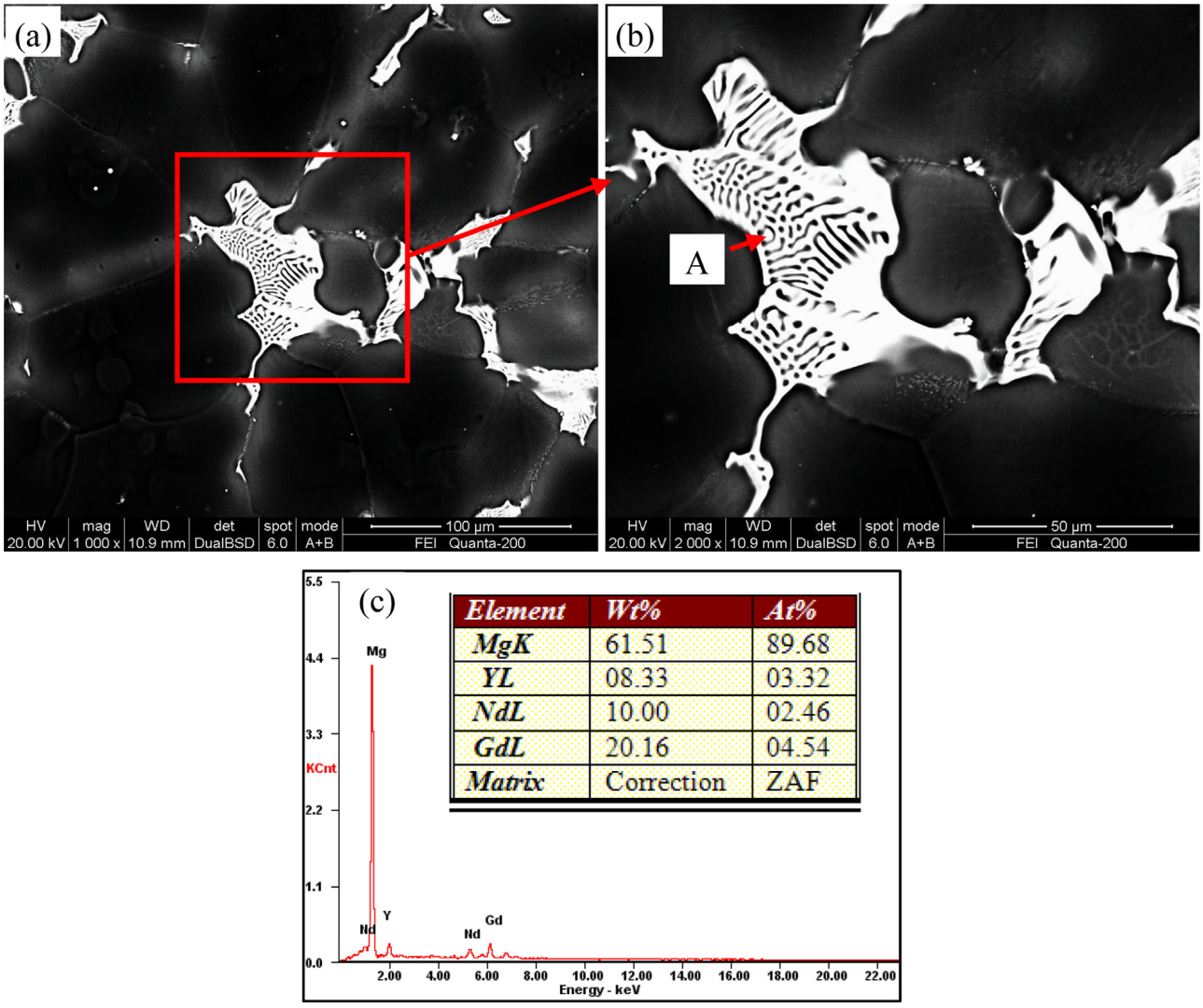

Fig. 1. SEM images of the as-cast alloy: (a) low magnification (b) partial region feature (c) EDS of second phase A.

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