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Study of processing technology and structural evolution of a Mg-Y-Nd-Zr alloy

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The processes of extruding and forging were applied to a Mg-Y-Nd-Zr alloy separately, then the deformed specimens were solid solution treated and aged. The structural evolution of this alloy was analyzed by means of optical microscopy, scanning electron microscopy and energy dispersive X-ray spectroscopy. The mechanical performance of cast, extruded, forged and heat treated alloy specimens were tested at room temperature and 250°C. The study shows that complete recrystallization occurred when samples were extruded at temperatures of 350-400°C, and better mechanical performance was achieved. Those specimens which were forged after being extruded, gave mechanical performance at room temperature and 250°C which were improved compared with extruded specimens. Solid solution treatment and aging after deformation caused the size of precipitated phases near grain boundaries to become finer and more homogeneous, so the mechanical performance of these specimens was enhanced.

Key words: Magnesium-RE alloy, plastic deformation, microstructure, mechanical performance.

Introduction

The beneficial influence of rare earth (RE) metals on the room and elevated temperature mechanical performance of Mg alloys has long been recognized [1]. Rare earth elements such as Y and Nd can enhance the room temperature tensile strength and heat resistance of magnesium alloys [2, 3]. Cast alloy Mg-Y-Nd-Zr is a good alloy of this type, which exhibits higher tensile strength and heat resistant property than other Mg alloys. The tensile properties of this alloy are further improved after extrusion and forging in the T5/T6 condition.

The objective of the present work has been to study the influence of microstructures and mechanical performance of samples of a Mg-Y-Nd-Zr alloy, which were made by extrusion, forging and heat treatment.

Experiment

Alloy Preparation

The Mg-Y and Mg-Nd master alloys were prepared from Mg of 99.96 wt% purity, Y of 99.86 wt% purity, and Nd of 99.85 wt% purity by melting in a high-frequency induction furnace under a flux. The flux contained 50 wt%KCl and 50 wt%LiCl, and was used in order to preserve the melts from burning. Melting and pouring temperatures were 780-800°C. Then the ternary master alloys were re-melted in an electrical resistance furnace in iron crucibles under the protection of the flux. Zr in the form of a Mg-30 wt%Zr master alloy was added to the ternary alloy melt at 780°C. A refining flux of 54-56 wt%KCl, 28-31 wt%$BaCl_2$ and 13-18 wt% (NaCl+$CaCl_2$), was used during stirring. After stirring, and holding for 10 minutes, the molten liquid was poured into 220 mm diameter × 500 mm length water-cooled metal die. The actual chemical composition of this alloy prepared: Mg-3.86 wt%Y-3.22 wt%Nd-0.47 wt%Zr.

Some of the cast ingots were solution treated at 520°C for eight hours and were air cooled, then these were extruded at 350-400°C to produce 40 mm×30 mm (cross sectional area) billets (extrusion ratio of 32:1). In order to promote the tensile properties of this alloy as much as possible and level the extruded billets, the extruded billets were forged at 320°C to prepare 35 mm×30 mm (cross sectional area) flat billets (a reduction of 12%). Then some of the forged billets were solution treated at 520°C for eight hours, cooled in air and aged at 250°C for 16 hours (T6). Some of the billets were aged at 250°C for 16 hours after forging without a solution treatment (T5).

Test specimens of cast, extruded, forged and heat treated samples, were prepared to test the tensile properties at room temperature and 250°C, which were conducted using an Instron-type tensile tester. The microstructure and its evolution were observed under an optical microscope (Olympus C2500L). Fractured surfaces of specimens were examined under a scanning electron microscope (SEM) JSM-840. Energy dispersive X-ray spectroscopy (EDS) EDAX PV9100 was used to analyze the elemental composition of the

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precipitated phases near grain boundaries. To identify the structure of precipitated phases, X-ray diffraction (XRD) Shimadzu-6000 was used.

Results and Discussion

Microstructures of Specimens in Different Conditions

Figure 1 shows microstructures of as-cast specimens, as-extruded specimens, as-forged specimens and heat-treated specimens. The grains of as-cast specimens were refined by the Zr addition and their diameter were about 60-80 μm. Eutectic phases precipitated along grain boundaries and at triple junctures, Fig. 1(a). Dynamic recrystallisation occurred during hot extrusion at 350-400°C, and the recrystallised grains were nucleated around the precipitated phases. Grain growth was retarded by the rare-earth compounds and hence the grain size of as-extruded specimens became finer than that of as-cast specimens and was about 10-15 μm, Fig. 1(b) and (c). After forging at 320°C, the grain size of as-forged specimens became finer and more homogeneous than that of the as-extruded specimens and was about 10 μm, moreover, which shows obvious deformed microstructures, Fig. 1(d) and (e). Both Fig. 1(b) and (d) image the stretching marks among the grains and their boundaries along the directions of metal flow which were caused by the processes of extrusion and forging. The grain size of specimens in the T5 condition (extruded-forged-artificially aged), is equal to that of the as-extruded specimens, and the grains exhibit complete shapes, Fig. 1(f). After treatment in the T6 condition (extruded-forged-solutionised-artificially aged), the grains grew rapidly and reached 100-200 μm in diameter, and presented an inhomogeneous size. Moreover, the massive eutectic compounds disappeared by the solution treatment and many much finer particles were dispersed in the interior of the grains and near the grain boundaries, Fig. 1(g).

Precipitated Phases

Figure 2 shows SEM image, EDS and XRD analysis results of as-cast specimens. Precipitated phases can be observed, which are distributed along grain boundaries and at triple junctures, Fig. 2(a). According to the analytical result of EDS, both Nd and Y can be found in the precipitated phases of as-cast specimens, and the number and percentage of Nd are more than for Y, Fig. 2(b). This is because the maximum solid solubility of Mg-Y is greater than that of Mg-Nd. The maximum solid solubility of Mg-Y is 12.4 mas%, but that of Mg-Nd is 3.6 mass% [4, 5]. Seen from Fig. 2(c), the precipitated phases of Mg-Y and Mg-Nd were tested by XRD. Two new precipitate phases $Mg_{24}Y_5$ and $Mg_{12}Nd$ were formed during alloying, both of which affect the room and high temperature mechanical properties of this Mg-Y-Nd-Zr alloy.

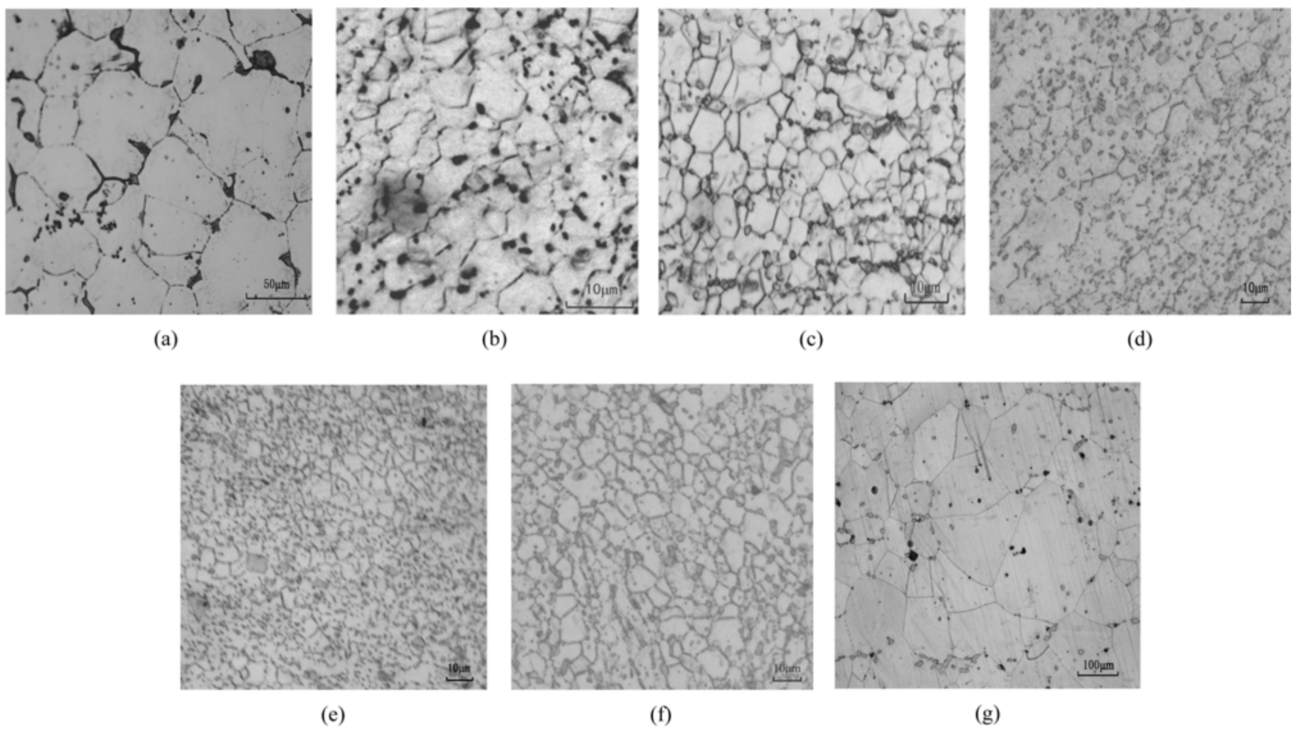
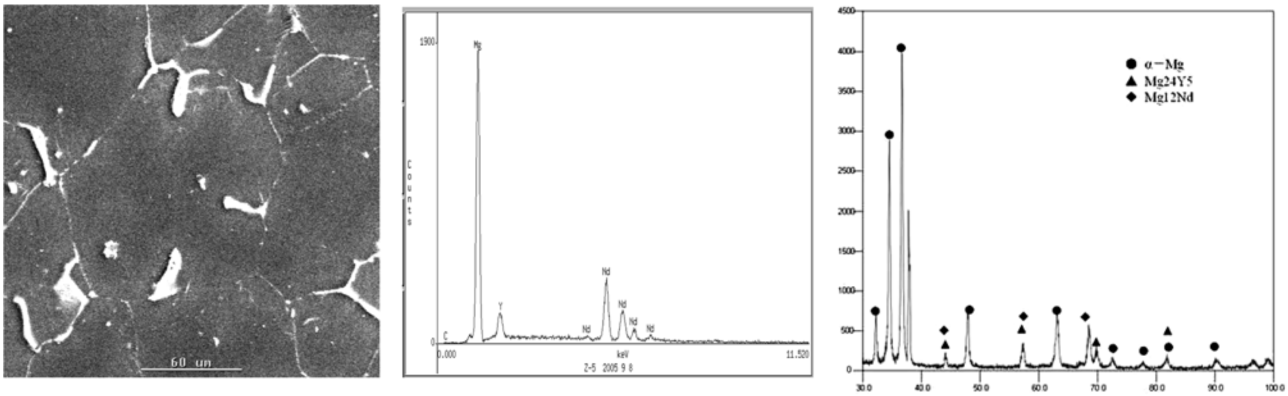
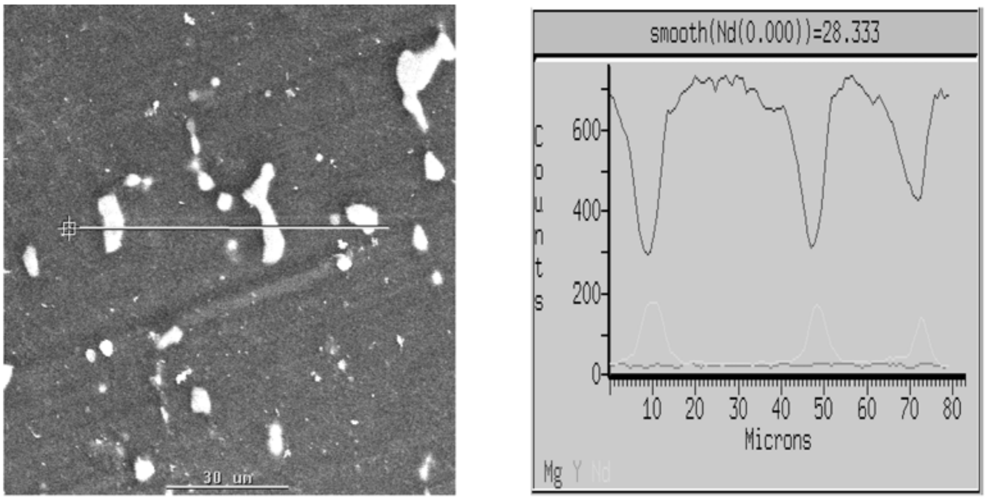


Fig. 1. Microstructures of specimens in different conditions.
(a) As-cast, (b) As-extruded (viewing section parallel to the extruded direction), (c) As-extruded (viewing section vertical to the extruded direction), (d) As-forged (viewing section parallel to the extruded direction), (e) As-forged (viewing section vertical to the extruded direction) (f) Artificially aged (T5), (g) Solutionised-Artificially aged (T6)



(a) (b) (c)

Fig. 2. Figures showing a morphologic image, compositional analysis and structure of precipitated phase of as-cast specimens by: (a) SEM, (b) EDS, (C) XRD.



(a) (b)

Fig. 3. Figures showing a morphologic image and a line scan analysis of the precipitated phases in the solutionised-artificially aged specimen by: (a) SEM, (b) EDS.

Figure 3 shows an SEM image and EDS line scan results of a solutionised-artificially aged specimen. It can be seen from Fig. 3(a), after the solid solution and artificially aging treatment, that the precipitated phases of these specimens became finer than that of as-cast specimens. From the EDS results, these precipitated phases were composed of Mg, Y and Nd, and the number and percentage of Nd were more than for Y, Fig. 3(b).

Tensile Properties

Table 1 shows the room-temperature tensile properties of as-cast, as-extruded, as-forged, artificially aged (T5) and solutionised-artificially aged (T6) specimens. The tensile strength and 0.2% proof strength of this Mg-Re alloy was significantly increased by extruding, forging and heat treatment and reached 365 MPa and 335 MPa in the T6 condition (the tensile direction parallel to the extruded direction), but the elongation was reduced to 4.5%. The tensile strength and proof strength at 250°C were reduced, but the elongation of specimens increased, Table 2. It may be concluded that the plastic deformation processes could promote the room-temperature tensile strength and proof strength but weaken the elongation. The heat treatment, especially treated by the T6 condition, contributed to the improvement of the strength both at room temperature and 250°C. This is because, (a) the grains and precipitated phases were refined by extrusion and forging, which are the main reasons for the improvement of strength at room and elevated temperatures [6]. (b)

Table 1. Tensile properties of specimens in different conditions at room temperature

	As-cast	As-extruded	As-forged	T5	T6
σ_b, MPa	190	260	295	310	365
$\sigma_{0.2}$, MPa	132	200	250	265	335
δ_5, %	6.5	12	8	7.5	4.5

Tensile direction parallel to the extruded direction

Table 2. Tensile properties of specimens in different conditions at 250°C

	As-cast	As-extruded	As-forged	T5	T6
σ_b, MPa	130	200	230	205	300
$\sigma_{0.2}$, MPa	90	145	205	183	265
δ_5, %	12	22	18	25.5	7.0

Tensile direction parallel to the extruded direction

treated by the T6 condition, massive precipitated phases were dissolved into the base body (α-Mg), and much finer particles precipitated during the artificially aging, which enhanced the tensile properties. Because the grains grew sharply after the T6 treatment, the elongation of specimens reduced. (c) precipitated phases involving Y and Nd contributed to improving the tensile properties at elevated temperature [7].

Fracture Surfaces

Figure 4 shows SEM images of fracture surfaces of specimens tested at room temperature. Fig. 4(a) is a fine grained fracture image such as from an as-extruded and as-forged specimens indicate a dimple pattern which characterizes a ductile fracture corresponding to the greater elongation. The dimensions of dimples are fine and uniform which reflects the fine grained microstructures of the specimens. Fig. 4(b) shows a coarse grained fracture image which characterizes a brittle fracture with lamellar fracture planes vertical to the tensile direction corresponding to the lower elongation, moreover, the surface areas of most fracture planes are large because the grains of as-cast and as-solutionised specimens are coarse.

Conclusions

In the present study, Mg-3.86 wt%Y-3.22 wt%Nd-0.47 wt%Zr alloy samples were cast, extruded, forged and heat treated, and their microstructures were observed by optical and scanning electron microscopy and their room temperature and 250°C properties were investigated. The results obtained are summarized as follows:

(1) The grain size of as-cast specimens is refined by the addition of Zr. Extrusion and forging also refines the microstructure, but the intermediate phases of Mg-RE partly precipitate in the alloys containing large quantities of RE.

(2) In this Mg-RE alloy treated by the T6 condition, the precipitates including $Mg_{24}Y_5$ and $Mg_{12}Nd$ contribute to age hardening.

(3) The tensile strength and 0.2% proof strength, at room temperature and 250°C, are higher than those of conventional Mg alloys. In particular, the tensile strength of the T6 specimens reaches 300 MPa when tested at 250°C. The strength improvement may be caused by solid solution strengthening and dispersion strengthening of Nd and Y precipitated along the grain boundaries.

(4) Fine grained and coarse grained tensile fracture surfaces of specimens at room temperature were examined by SEM, which indicates that the fine grained specimen shows a dimple pattern reflecting higher elongation and the coarse grained specimen gives a brittle fracture pattern corresponding to lower elongation.

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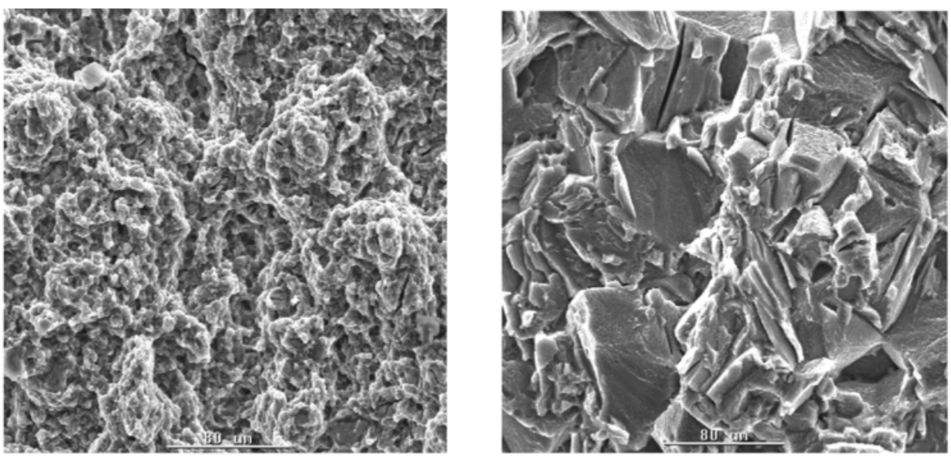

(a) (b)

Fig. 4. Scanning electron micrographs of fractured surfaces of the specimens at room temperature (viewing section vertical to the extruded direction).
(a) fine grained fracture image (as-extruded and as-forged), (b) coarse grained fracture image (as-cast and T6)

References

1. A. Luo and M.O. Pekguleryuz.. J. Materials Science 29[12] (1994) 5259-5271.
2. P.E. Shaling. J. Material Engineering 1 (1993) 1-5.
3. Cheng. Zhenhua, in “Magnesium Alloy” (Chemical Industry Press, Beijing, 2004) p. 53-56.
4. T.B. Msssalski, H. Okamoto, P.R. Subramanian, etc. Binary Phase Diagrams [M]. Second Edition. ASM International 2 (1990).
5. T. Sato, I. Takahashi, H. Tezuka, and A. Kamio. J. Japan Institute of Light Metals 42[12] (1992) 804-809.
6. R.A. Khosrhoshahi, R. Pikington, and G.W. Lorimer. Proceedings of the Third International Magnesium Conference, April 1996, edited by G.W. Lorimer (The Institute of Materials Press, 1997) p.240.
7. C. Sanchez, G. Nussbaum, P. Azavant, and H. Octor. J. Materials Science and Engineering A221 (1996) 48-57.