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ScienceDirect
Trans. Nonferrous Met. Soc. China 20(2010) s352−s356
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Microstructures and mechanical properties of Mg-2%Zn-0.4%RE alloys

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Received 23 September 2009; accepted 30 January 2010

Abstract: The solidification microstructures and hardness of Mg-2%Zn (mass fraction) based alloys with addition of 0.4%Ce, 0.4%Gd, 0.4%Y or 0.4%Nd (mass fraction) were investigated, and the effects of the rare earth elements on the microstructures and mechanical properties of these alloys extruded at 310 ˚C were also compared. The results indicate that the trace rare earth Ce, Gd, Y or Nd in the Mg-2%Zn alloy has obviously different grain refinement effects on its solidification microstructures, and the as-cast and hot-extruded alloy with 0.4%Ce has the smallest average grain size and the highest strength. However, the extruded alloys containing 0.4%Nd or 0.4%Y with the elongation of 26.6% and 30%, respectively, show higher plasticity in spite of lower strength as compared with the alloy containing 0.4%Ce.

Key words: rare earth; Mg-2%Zn alloy; microstructure; mechanical properties

1 Introduction

Magnesium alloys, as the lightest metal in structural materials, have wide applications in automotive, electronics and aerospace industries due to their high specific strength and stiffness, good electromagnetic shielding and damping characteristics, excellent shock absorption and good machinability[1−3]. However, the relatively low mechanical strength and poor heat resistivity of magnesium alloys have retarded their applications. It is well known that Zn as a major alloying element in magnesium alloys has a marked response to precipitation hardening[4], but binary Mg-Zn alloys with hot shortness, brittleness, and coarse and uneven grains[5] were always modified by further alloying by Zr[6−7] or rare earth elements such as misch metal[8], yttrium[9], neodymium[10], gadolinium[11], combining rare earth elements[12] and calcium[13] in commercial alloys. However, this also increases the alloy cost. Therefore, the research and development of low cost magnesium alloys with high strength and toughness are of great urgency[14]. In addition, above researches almost focus on magnesium alloys with high zinc content (4%−6%), and few work were reported on the low-zinc magnesium alloy. In this work, the solidification microstructures and hardness of alloys in Mg-2%Zn with addition of a small amount of rare earth Ce, Gd, Y or Nd were investigated, and the effect of rare earth elements on the microstructures and mechanical properties of these alloys extruded at 310 ˚C were also compared.

2 Experimental

Mg-2%Zn alloys containing 0.4% different rare earth elements respectively and their corresponding casting temperature and extrusion temperature are listed in Table 1. The raw materials used in this experiment were the first class magnesium ingot and zinc ingot, Ce-rich misch metal, Mg-Y, Mg-Gd and Mg-Nd master alloys. The alloys were smelted and refined in a resistance furnace. Firstly, the magnesium ingot was heated to 710 ˚C, and then the pre-heated Zn block was added. After being stirred for 5 min, the prepared Ce-rich misch metal or corresponding master alloy was added into the melt at 730 ˚C. Then, it should be stirred thoroughly and held at 720 ˚C for 15−20 min. Finally, the melt was cast at 690 ˚C. Besides, during both smelting and casting, the mixed gas was selected as protective gas.

Foundation item: Projects(2007CB613701; 2007CB613702) supported by the National Basic Research Program of China; Project(NCET-08-0098) supported by the Program for New Century Excellent Talents in University; Project(50974037) supported by the National Natural Science Foundation of China; Project(90209002) supported by the Special Fund for Basic Scientific Research of Central Colleges in China
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After solidification, the samples taken from the central section of ingots were used for analyzing and testing. The microstructures were observed by Leica DMR metalloscope, and the grain size was detected by area method which calculates the average diameter of grain by counting the number of grain. The hardness test was carried out by 450SVDTM Vickers hardness tester. The tensile properties of extruded bars were conducted by INSTRON 8032 stretcher, and the tensile fractures were characterized by JSM-5600LY scanning electron microscope.

Table 1 Casting temperatures and extrusion temperatures of alloys

Sample No.	Composition *w*/%	Casting temperature/℃	Extrusion temperature/℃
1	Mg+2.0%Zn+0.4%Ce (Ce-rich misch metal)	690	310
2	Mg+2.0%Zn+0.4%Gd	690	310
3	Mg+2.0%Zn+0.4%Y	690	310
4	Mg+2.0%Zn+0.4%Nd	690	310

3 Results and discussion

3.1 Effect of rare earth on microstructures and mechanical properties of Mg-2%Zn alloy

3.1.1 Effect of rare earth on microstructures of Mg-2%Zn alloys

The microstructures of as-cast Mg-2%Zn-0.4%Ce, Mg-2%Zn-0.4%Gd, Mg-2%Zn-0.4%Y, Mg-2%Zn-0.4%Nd alloy are shown in Figs.1(a)−(d), respectively. It can be seen that the grains of Mg-2%Zn-0.4%Gd or Mg-2%Zn-0.4%Y alloy are relatively coarse, while those of Mg-2%Zn-0.4%Ce or Mg-2%Zn-0.4%Nd alloy appear very small and uniform. Besides, the grain size of the alloy with addition of 0.4%Ce is the smallest.

The relative atomic mass of rare earth element and its maximum solid solubility[15] and eutectic temperature in magnesium are listed in Table 2. It is found that as compared with other elements, the maximum solid solubility in magnesium is the smallest (0.13%), and the eutectic temperature with magnesium is the highest (593 ˚C) for Ce element. Therefore, the significantly different refinement effects of various rare earth elements on microstructures of as-cast magnesium alloy are closely related to their maximum solid solubility in magnesium melt. Due to the fact that

Table 2 Rare earth element's maximum solid solubility[15], relative atomic mass and eutectic temperature in magnesium

Rare earth element	Maximum solid solubility/%	Relative atomic mass	Eutectic temperature/℃
Ce	0.13	140.000	593
Gd	4.53	157.250	540
Y	3.6	88.906	567
Nd	0.63	144.200	552

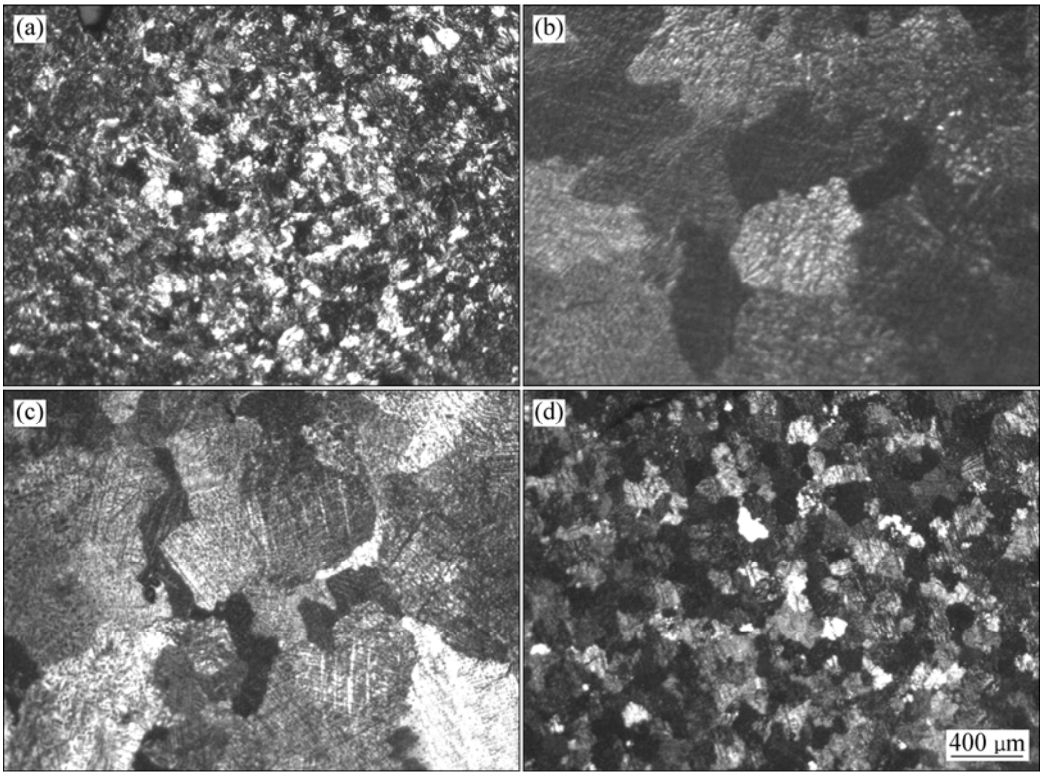

Fig.1 Microstructures of Mg-2%Zn alloys containing 0.4%Ce (a), 0.4%Gd (b), 0.4%Y (c), or 0.4%Nd (d)

the maximum solid solubility of Ce in magnesium is very low and furthermore the eutectic reaction of its compound with magnesium occurs at a comparatively high temperature, it is quite probable that the undercooling in front of solid/liquid interface[16−17] is enhanced by addition of Ce in magnesium alloy, which in turn results in refinement effects.

3.1.2 Effect of rare earth on hardness of Mg-2%Zn alloys

The hardness and grain size of Mg-2%Zn alloys containing 0.4%Ce, 0.4%Gd, 0.4%Y, or 0.4%Nd are shown in Fig.2. The results indicate that as compared with Mg-2%Zn-0.4%Gd, Mg-2%Zn-0.4%Y, and Mg-2%Zn-0.4%Nd alloy, the macrohardness of Mg-2%Zn-0.4%Ce is obviously higher, which corresponds to the smallest grain size. Generally, the different rare-earth elements have obviously different strengthening effect, which is related directly to the different microstructural refinement effects, and also related to the quantity and the shape of precipitated phase of rare earth and magnesium resulted from different solid solubilities. The latter probably causes the remarkable different strengthening effects between Nd and Ce, whose grain sizes are both relatively small.

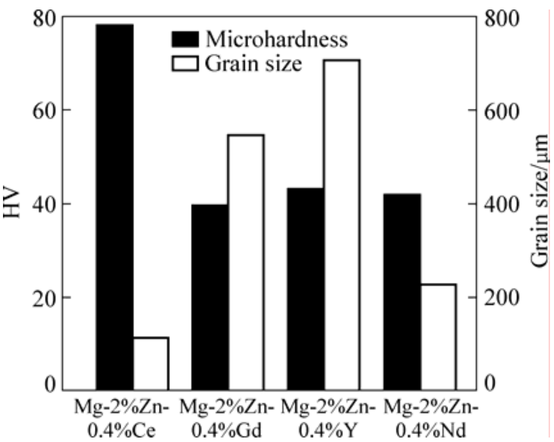

Fig.2 Hardness and grain size of Mg-2%Zn alloys containing 0.4%Ce, 0.4%Gd, 0.4%Y, or 0.4%Nd

3.2 Effect of rare earth on microstructures and mechanical properties of extruded Mg-2%Zn alloy

3.2.1 Effect of rare earth on microstructures of extruded Mg-2%Zn alloys

The transverse and longitudinal microstructures of extruded Mg-2%Zn alloys containing 0.4%Ce, 0.4%Gd, 0.4%Y, or 0.4%Nd are shown in Figs.3−6, respectively. It can be seen that all the microstructures of these alloys are equiaxed in stead of stripped occurring commonly after deformation and have been refined markedly. The average grain size of alloys containing Ce, Gd or Y is about 30−35 μm, which is much larger than the average grain size (6 μm) of alloy containing Nd. This means that the deformation microstructure not only depends on the original microstructure and deformation processing, but also is affected by alloying element. In addition, twins exist in the microstructure of alloy containing Ce or Y,

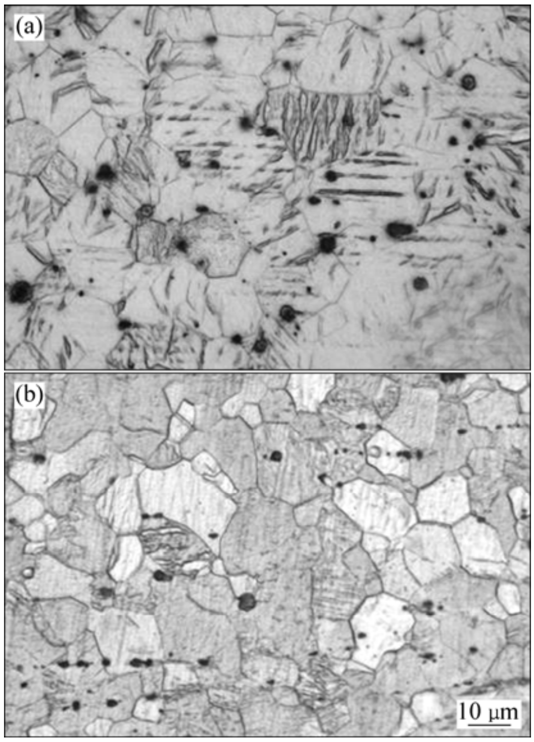

Fig.3 Microstructures of extruded Mg-2%Zn-0.4%Ce alloy: (a) Transverse microstructure; (b) Longitudinal microstructure

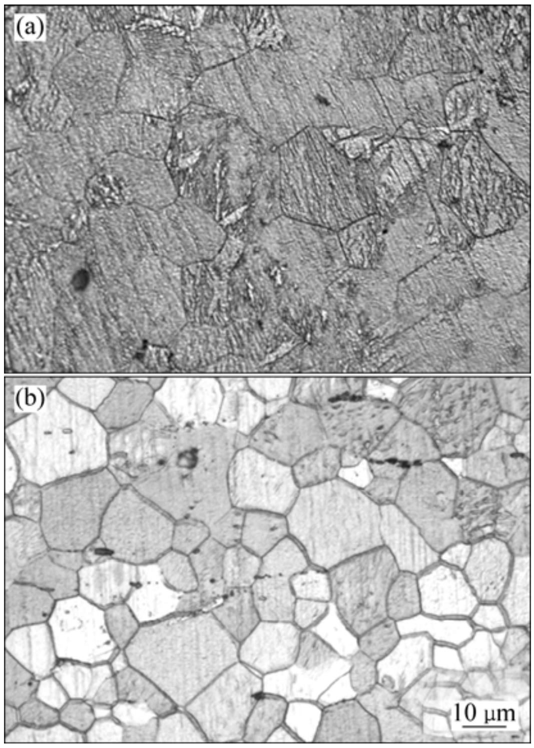

Fig.4 Microstructures of extruded Mg-2%Zn-0.4%Gd alloy: (a) Transverse microstructure; (b) Longitudinal microstructure

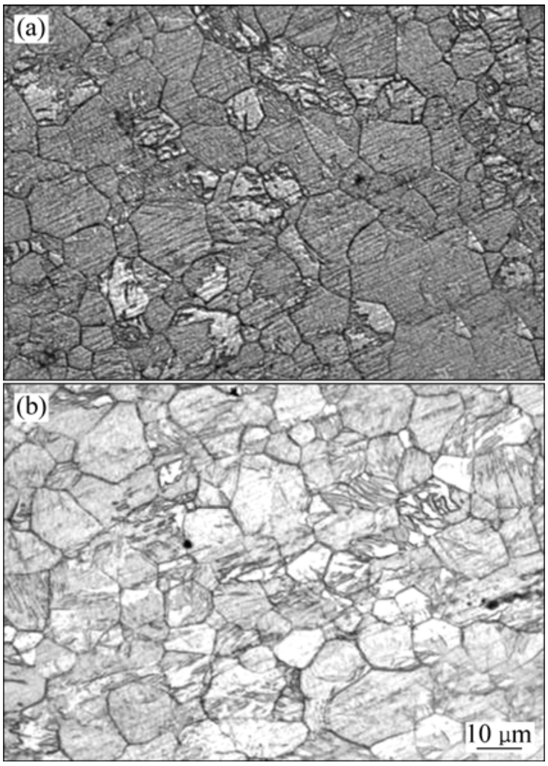

Fig.5 Microstructures of extruded Mg-2%Zn-0.4%Y alloy: (a) Transverse microstructure; (b) Longitudinal microstructure

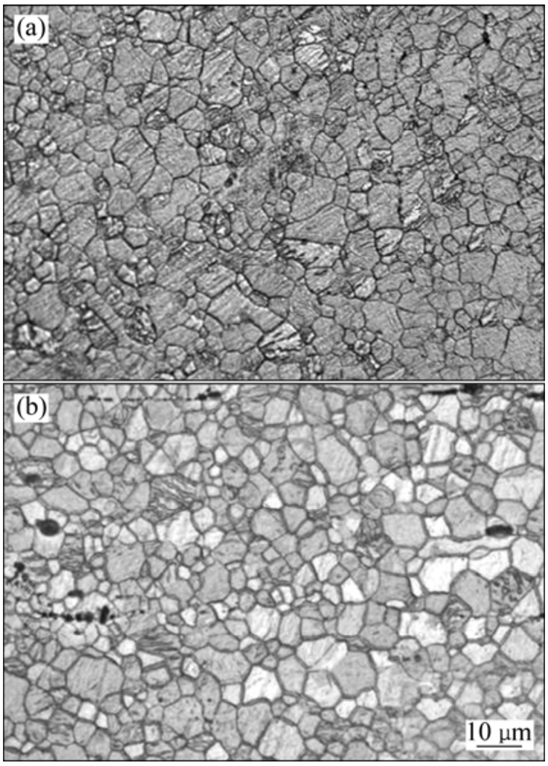

Fig.6 Microstructures of extruded Mg-2%Zn-0.4%Nd alloy: (a) Transverse microstructure; (b) Longitudinal microstructure

which is corresponding to the higher hardness of as-cast alloys.

3.2.2 Effect of rare earth on mechanical properties of extruded Mg-2%Zn alloys

The ultimate strength, yield strength and elongation of extruded Mg-2%Zn alloys containing 0.4%Ce, 0.4%Gd, 0.4%Y, or 0.4%Nd are shown in Fig.7. It can be seen that the four kinds of rare earth elements also have their own different effects on the mechanical properties of extruded Mg-2%Zn alloys, which are closely related to their distinct microstructures. Compared with their corresponding microstructures in Figs.3−6, it can be found that the strengthening effects of Ce respond to the quality of precipitated phase and twins, on the other hand, it is refined crystalline strengthening for Nd. It needs to be noticed that although the strength of Mg-2%Zn-0.4%Nd alloy is inferior to Mg-2%Zn-0.4%Ce alloy, its elongation is distinctly higher. Therefore, it is worthy to addition of Nd in magnesium alloy to improve its plasticity.

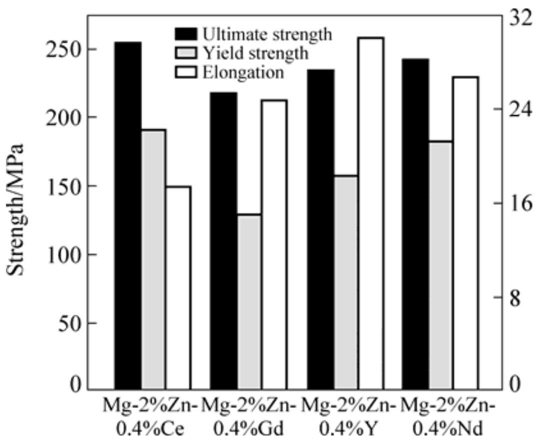

Fig.7 Ultimate strength, yield strength and elongation of extruded Mg-2%Zn alloys containing 0.4%Ce, 0.4%Gd, 0.4%Y, or 0.4%Nd

3.2.3 Tensile fracture analysis

The tensile fractures of the four kinds of extruded alloys at room temperature are also analyzed, as shown in Fig.8. The results indicate that the fracture characteristic of Mg-2%Zn alloy containing 0.4%Ce or 0.4%Gd is mainly the river shape cleavage fracture, while that of Mg-2%Zn alloy containing Y or Nd appears small dimples which is clearly plastic fracture characteristic.

4 Conclusions

1) The addition of trace Ce, Gd, Y or Nd in Mg-2%Zn based alloy has obviously different grain refinement effects on its solidification microstructures and its strengthening effects.

2) The ingot of the alloy with addition of 0.4%Ce has the smallest average grain size and the highest

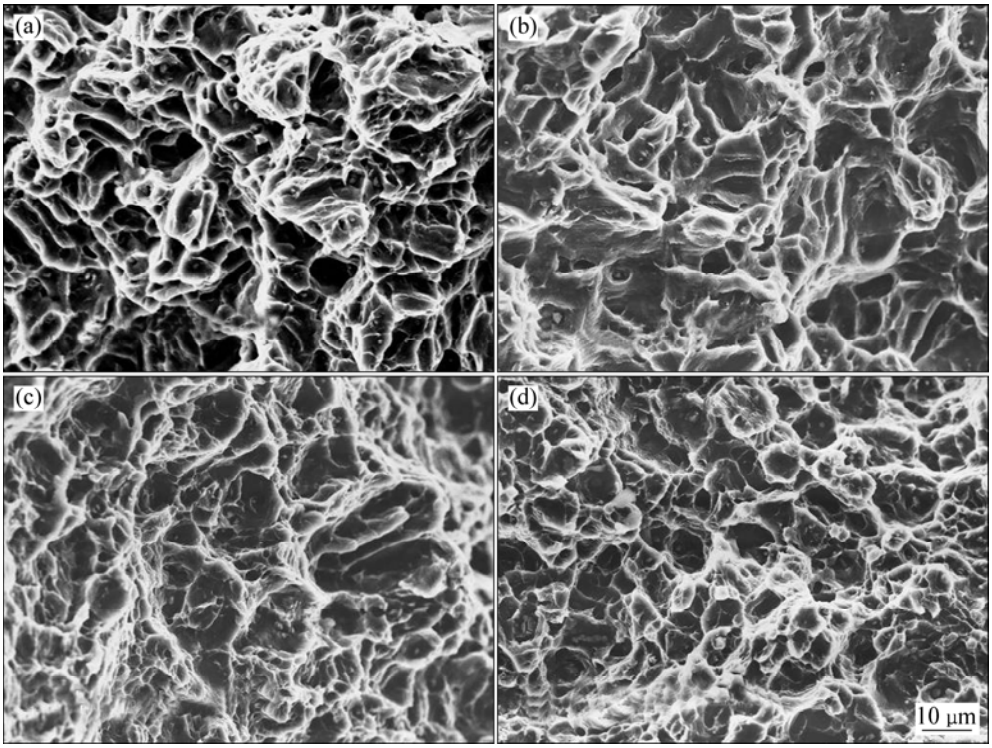

Fig.8 Fractographs of extruded bars of Mg-2%Zn alloy with different rare earth additions: (a) Mg-2%Zn-0.4%Ce; (b) Mg-2%Zn-0.4%Gd; (c) Mg-2%Zn-0.4%Y; (d) Mg-2%Zn-0.4%Nd

hardness. Meanwhile, its extrusion rod also has the highest strength.

3) The alloy with 0.4%Nd or 0.4%Y has higher elongation in spite of lower strength as compared with the alloy with 0.4%Ce.

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(Edited by CHEN Ai-hua)