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Microstructure and properties of new Mg-Li-Zn wrought alloys*

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Abstract: Cold-rolling workability, heat treatment characteristics and mechanical properties of Mg-5%-22%Li-2%Zn(mass fraction) wrought alloys were studied. Density of alloys is between 1.19 and 1.62 g/cm³. The limit of reduction for cold rolling of the β phase alloys at 16% and 22%Li exceeds 90% at room temperature. The properties and microstructures of Mg-Li-Zn alloys were studied, which were homogenized, cold rolled, then annealed at different temperatures. Recrystallization behaviors of the alloys were investigated through microstructures observing and hardness measuring. The results show that the cast billets are suitable for rolling after homogenization at 573K for 12 h for Mg-9Li-2Zn-2Ca alloy and at 523K for 24 h for Mg-9Li-2Zn-2Ca alloy. The cold rolled plates were completely recrystallizated by annealing at 573K for 1 h.

Key words: Mg-Li-Zn wrought alloy; homogenization; cold-rolling; heat treatment

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1 Introduction

Magnesium-Lithium alloy is the lightest alloy at present. It is one of ultra-light weight alloy systems with high intensity. It is as light as engineering plastics, but it has the properties of a metal such as high specific rigidity, impact ductility, good electrical and thermal conductivities, machining, electromagnetic shielding, and shockproof etc.[1]. In addition, it can be reclaimed and reused, and don't pollute environment, thus it is called a "green" alloy for 21st century.

Nowadays, most of magnesium alloys are produced by casting (including traditional casting technique and new semisolid casting technique etc.).

Compared with casting alloys, wrought magnesium alloys have better foreground. Plates, rods, pipes, section bars and forging productions can be manufactured by forming. They have higher intensity, better elongation and more diversified mechanical properties than casting magnesium alloys by controlling alloys' microstructures and annealing states[2]. Therefore, it is the most important and agelong aim brought forward by International Magnesium Association (IMA) in 2000 to investigate new wrought magnesium alloys, exploit new technique of productions and manufacture fine productions[3].

Western developed countries have attached importance to the investigation of wrought magnesium al-

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loys. Especially, Magnesium-Lithium alloy has been studied extensively by the countries such as Russia, America, Japan and German etc.. But it was not studied too much in our country, few articles are about it, and it almost was not applied to commerce. Therefore, it is significant to strengthen the research of Magnesium-Lithium base alloy[4-6].

In this experiment, it is the aim to investigate ultra-light weight and cold rolled Magnesium-Lithium base alloy plates with high strength. It was studied about its melting technique, homogenizing treatment, cold-rolling, heat treatment, and effect of addition elements (Zn, Ca) on mechanical properties.

2 Experimental procedure

The alloys used in this study consisted of highly pure Mg, Li, Zn, and Ca. They were melted and cast in a low carbon steel crucible under a protective gas of Ar and a molten flux of 75%Li+25%LiF. Mg-5, 9, 16, 22%Li-2%Zn(mass fraction) alloys were melted chiefly. The compositions and density of these alloys are given in Table 1.

Table 1 Chemical composition and measured density of specimens

Alloy	Li	Zn	Mg	Density /(g·cm^{-3})	Alloy	Li	Zn	Mg	Density /(g·cm^{-3})
LZ52	4.6	1.97	bal.	1.62	LZ162	16.97	2.33	bal.	1.32
LZ92	11.33	2.27	bal.	1.48	LZ222	22.86	2.32	bal.	1.21

The ingots were then homogenized at different temperature and for different time. Because lithium was much lost in the surface during homogenization, every surface was milled by 2—3 mm. The plates of 5 mm thickness were cold rolled to 3 mm by 5% each pass. Work hardening and annealing conditions were investigated.

Alloys' compositions were tested by the way of chemical analysis. The etching reagent was: 4g picric acid, 100 mL ethanol, 0.7 mL phosphoric acid or 2% nitric acid.

Microstructures were observed under optical microscope. Vickers hardness measurements were used to evaluate the mechanical characteristics, the model being HVA—10A, the load being 9.8 N for 15 s.

3 Results and discussion

3.1 Microstructure and properties in as-cast conditions and homogenized states

Microstructure in as-cast conditions and homogenized states were shown in Fig. 1 and 2. In Fig. 1, there were largely arborescent structures and single magnesium-rich α phase in Mg-5%Li alloys. Magnesium-rich α phase and Lithium-rich β phase lay in Mg-9%Li alloys together. Mg-16. 22%Li alloys were composed of single β phase. After adding Ca element, grains became small and spheroidized. Intercrystalline segregation existed as casting condition: fine lamellar nonequilibrium phase and intermetallic compound congregated on the grain boundary. This was deleterious to cold-rolling, so it was necessary for alloys to be homogenized.

In order to carry out cold-rolling and improve the homogeneity of compositions, alloys need to be homogenized. Annealing temperature is a crucial factor for Magnesium-Lithium base alloy[7]: when the temperature is low because of low coefficient of diffusion of other elements in magnesium matrix, the time for homogenization has to be prolonged and the effect is poor; when the temperature is high, the conglomeration of elements easily leads to excessive sintering and tampers with posterior work performance, especially Mg-Li-Zn alloys were oxidated seriously at high temperature.

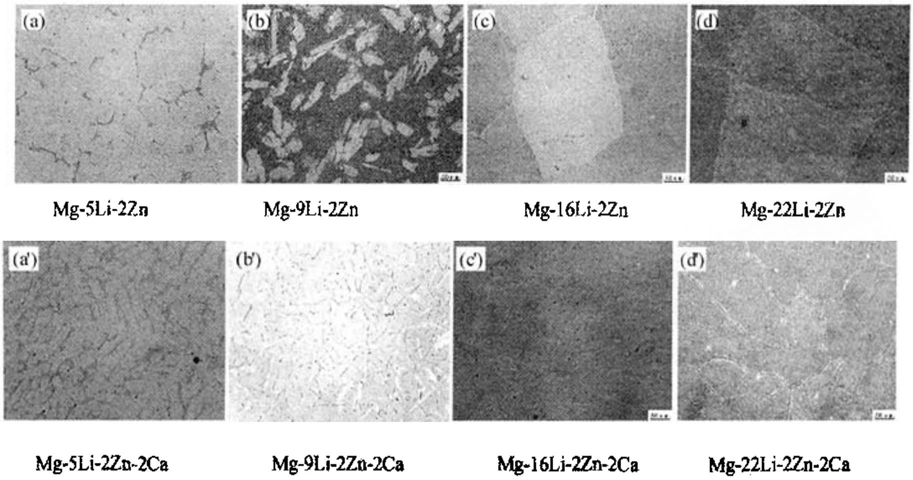

Fig. 1 Microstructure of as-cast alloys

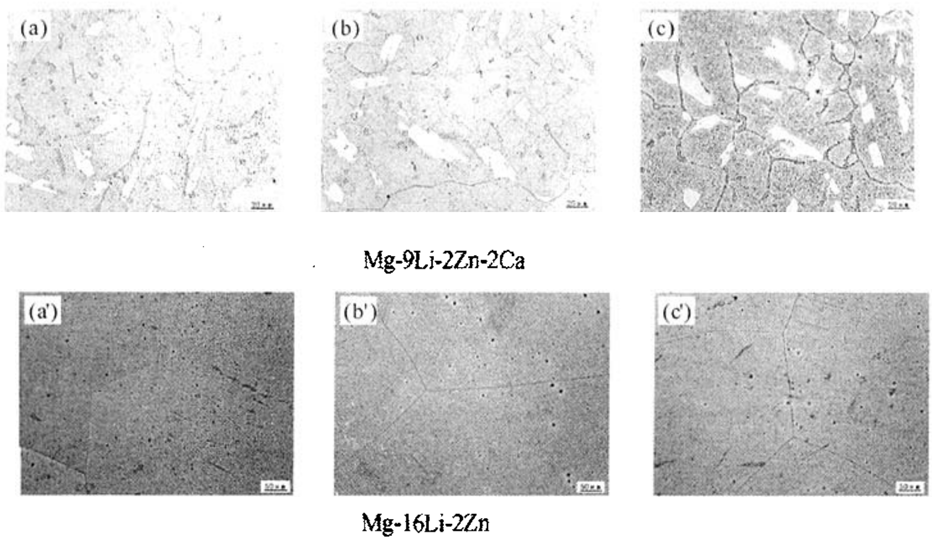

Fig. 2 Microstructure of different homogenized alloys

(a) 300℃, 8 h; (b) 300℃, 12 h; (c) 300℃, 16 h

(a') 250℃, 24 h; (b') 300℃, 12 h; (c') 300℃, 16 h

Liquidus line temperature of Mg-5%－22% Li alloys is about 873K, so alloys were homogenized at 523K and 573K. Microstructures are shown in Fig. 2. For Mg-9% Li-2%Zn alloy grain boundary became fine and composition became even after homogenization at 523K for 24 h. Good microstructure was formed. But with the temperature rising (573K), grain became large and uneven, which is bad for mechanical behaviours. For Mg-9%Li-2%Zn-2%Ca alloy when homogenized at 523K it took on the microstructures as casting conditions because of low temperature. After homogenized at 573K for 12 h, conglomerated solute atom diffused into the grains so that meshy grain boundary became discontinuous as shown in Fig. 2(b), and it is a typical homogenized structure. With it being 16 h, as shown in Fig. 2 (c), excessive sintering occurred; some low melting point phases congregated again on the grain boundary and the compound come into being again.

3.2 Microstructures and properties of plates

3.2.1 Properties of cold rolled plates

The largest percent of reduction of cold rolled alloys and work-hardening curves are shown in Fig. 3 and 4. In Fig. 3, the largest percent of reduction of 5% Li alloys are only about 40%; that of 9% Li alloys can reach 60%; even that of 16, 22% Li alloys can exceed 90%. The theory of the cold-rolling texture of metals closed-packed hexagonal structure has been widely considered in some literatures[8]. It was assumed that the deformation ability of closed-packed hexagonal metals depends strongly on the ratio of c/a. Adding Lithium to Magnesium can reduce the value of c/a in hexagonal system of Magnesium, then the reduction of space between atoms decreases the startup energy of hexagonal system along $\{10\bar{1}0\}<\bar{1}\bar{2}10>$ face, so that this slippage along $\{0001\}<\bar{1}\bar{2}10>$ face can occur simultaneously at room temperature[9], which can enhance alloy's ductility and formability greatly. With the larger addition of Lithium element, the crystal structure transforms are as follows: α (hcp)$\rightarrow\alpha+\beta\rightarrow\beta$ (bcc), which allows the magnesium to be cold worked, thus the ductility and intensity can be more improved and at the same time alloys may avoid being oxidated at high temperature ,which is a important hand.

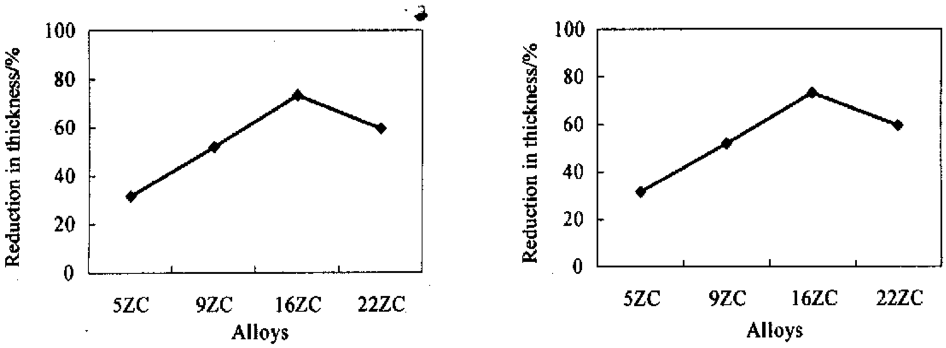

Fig. 3 The largest percent of reduction of alloys

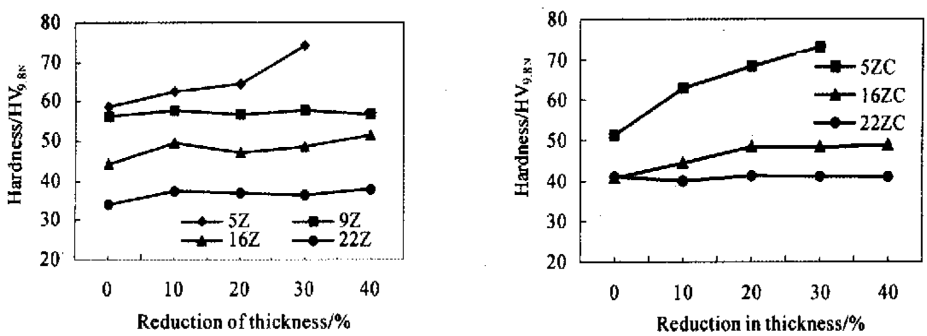

Fig 4 Work-hardening curves for cold-rolling of Mg-Li-Zn and Mg-Li-Zn-2Ca alloys

Work-hardening curves are shown in Fig. 4. When the Lithium content is low (5%), microstructure was single α phase, so work hardening was obvious; with the Lithium contents rising (9%Li), β phase started to appear, so work hardening falls; when microstructure took on single β phase (22% Li), work hardening hardly occurs. This indicated adding Lithium element can changes the crystal structure and then reduces the resistance to deformation, so work hardening falls gradually.

3.2.2 Recrystallization of cold rolled plates

The hardness and microstructures after annealing are shown in Figs. 5 and 6. Annealing is an important process to ensure propitious cold-rolling. It can make alloys obtain adequate deformability and have important influence on microstructures and mechanical properties[2], so it is necessary to be conscious of proper annealing system for plates. During cold-rolling dynamic recrystallization didn't occur completely because of short machining time, thus it is necessary to master the rule of subsequent static recrystallization. The plates were heated to 0.5 $T_{m.p.}$ or so, then had heat preservation. If the time for heat preservation was invariable three stages can be gone through : reversion , recrystallization and grain growth with heat temperature rising gradually[10]. During reversion stage the hardness descends tiddly but formability increases in a way; during recrystallization the hardness descends notably but formability increases greatly. The plates cold rolled approximately 40% were annealed at different temperature for 1 h, then recrystallization was estimated by measuring the hardness[11]. As shown in Fig. 5, the hardness of Mg-Li-Zn alloys cold rolled is high, but with the annealing temperature rising, the hardness started to descend and the speed of intenerate was increased after 373K. After annealing at 573K, the hardness fell to half of that of cold rolled alloys. This shows that complete recrystallization occurs, as shown in Fig. 6 in which cold rolled structure had completely been transited to recrystallised structure.

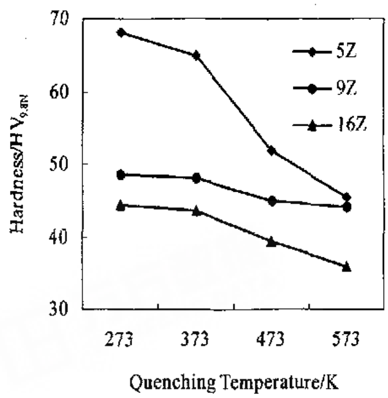

Fig. 5 Relationship between annealing temperature and the hardness of alloys

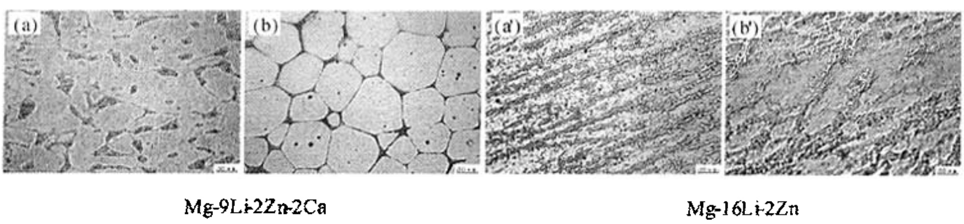

Fig. 6 Microstructure of cold rolled and heat treated alloys

(a) cold-rolling; (b) after heat treatment; (a') cold-rolling; (b') after heat treatment

4 Conclusions

(1) Adding Ca element could make grains fine obviously.

(2) Alloys are homogenized at different temperatures and for different time. The results show the proper conditions are as follows: Mg-9Li-2Zn alloy, at 250℃ for 24h; Mg-9Li-2Zn-2Ca alloy, at 300℃ for 12h.

(3) The density and hardness of the Mg-Li-Zn alloys decrease and formability increases notably with Lithium contents rising. The density of Mg-22Li-2Zn-2Ca alloy is only 1.19 g/cm^3. The largest percent of reduction of Mg-22Li-2Zn alloy can exceed 90% at room temperature.

(4) Grains spheroidized obviously after annealing at 300℃ for 1 h, so it might be cold rolled again easily.

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