QUENCHING AND AGEING BEHAVIORS OF Mg-Li-Zn ALLOY①

Le Qichi, Cui Jianzhong, Liu Hanwu
Department of Metal Forming,
School of Material and Metallurgy,
P. O. Box 317, Northeastern University, Shenyang 110006

ABSTRACT The effects of the condition of solid solution treatment and the kind of quenching medium on the ageing behaviors of the Mg-7Li-14Zn(%) alloys were studied. The optimum conditions of solid solution treatment were certained as solid solution at 370 ℃ for 1 h, and water quenching. The experiments indicates that the mechanical properties of the ternary alloy are σ_b = 305. 1 MPa, $\sigma_{0.2}$ = 191. 8 MPa, δ = 6. 28% after solid solution at 370 ℃ for 1 h, water quenching, and ageing at 38 ℃ for 20 h; and those of the alloy with the optimum constituent (Mg-7Li-14Zn-0. 57La-1. 22Nd-1. 0Ce-1. 6Ag)[7] are σ_b = 405. 1 MPa, $\sigma_{0.2}$ = 201. 1 MPa, δ = 8. 98% after the same treatment. Finally, the ageing processes of the ternary alloy and the optimum alloy were observed through X-ray diffraction spectrums.

Key words Mg-Li-Zn quenching ageing

1 INTRODUCTION

Mg-Li alloys, the lightest alloy nowadays, which have good ductility, however, lower tensile strengths, can be developed optimistically. Although their binary alloy cannot be strengthened by heat treatment, Mg-Li alloys with zinc or aluminum as additives have higher tensile strength, and can be strengthened by ageing after solid solution treatment[1-4], which had been utilized to make components[5]. However, the systematic studies on their quenching and ageing behaviors are not found yet. Compared with Mg-Li-Zn system, Mg-Li-Al system has lower strength and the precipitation of AlLi brittle phase is apt to be collected at grain boundaries, therefore the former has a brighter future, therein, Mg-7Li-14Zn (%) alloy has higher strength and better ductility[5], so its ternary and the optimum constituent alloys with Ag, La, Ce, and Nd elements as additives were studied on the quenching and ageing behaviors.

2 EXPERIMENTAL

The specimens sampled from the hot rolling sheets with 1. 5 mm thickness were wrapped with two layers of aluminum foil (0. 1 mm thickness for each) respectively. When treated with solid solution, and immersed into silicone oil bath during ageing, the surfaces of specimens were bright as initial after treatment in such protection. The Brinell hardness (HB) experiment was carried out in multi-purpose hardness-meter. The process included preloading 10 kg and slowly loading with 62. 5 kg on the test ball (d 2. 5 mm), and then maintaining 30 s before recording. All the tensile tests were conducted on the INSTRON tensile machine at 3. 0 mm/min movement of the test head at room temperature (25 ℃). The tensile specimens with 25 mm gauge length followed GB6397- 86. The precipitation analyses were conducted in Y-2 type X-ray diffractometer, whose anode bar was CuKα. The specimens (10 mm × 15 mm) were tested at 30 V tube voltage and 20 mA tube current.

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3 RESULTS AND DISCUSSION

3.1 Conditions of quenching and ageing

3.1.1 Quenching medium

Fig. 1 gives the curves of hardness *vs*. time of Mg-7Li-14Zn-1.6Ag-1Nd-2Ce alloy after solid solution at 370 ℃ for 30 min and quenching in different mediums, and then ageing at 38 ℃ and 75 ℃ respectively. The hardness of the specimens after quenching in liquid nitrogen is higher than that of those in water as ageing at the same temperature. The former only exhibits softening, and the latter presents peak value after ageing for 1 d. The decreasing rate of hardness is lower than former during over ageing, and its absolute hardness values are higher. After ageing at 38 ℃ for 9 d, the hardness for quenching in the both different mediums all remains about 110, which is far higher than that of hot rolling sheet (HB 85.6) (Fig. 1(a)). Ageing at elevated temperature (75 ℃), the time needed in arriving ageing peak for those after water treatment is cut down to about 4 h, and the peak value also is fallen. After 32 h, the hardness value is almost equal to that of the hot rolling sheet. The change tendency of ageing hardness at 75 ℃, which is similar to that of ageing at 38 ℃ for liquid nitrogen treatment, only shows as softening (Fig. 1(b)). The above results indicate that the suitable treatment for this system is water quenching, and ageing at 38 ℃.

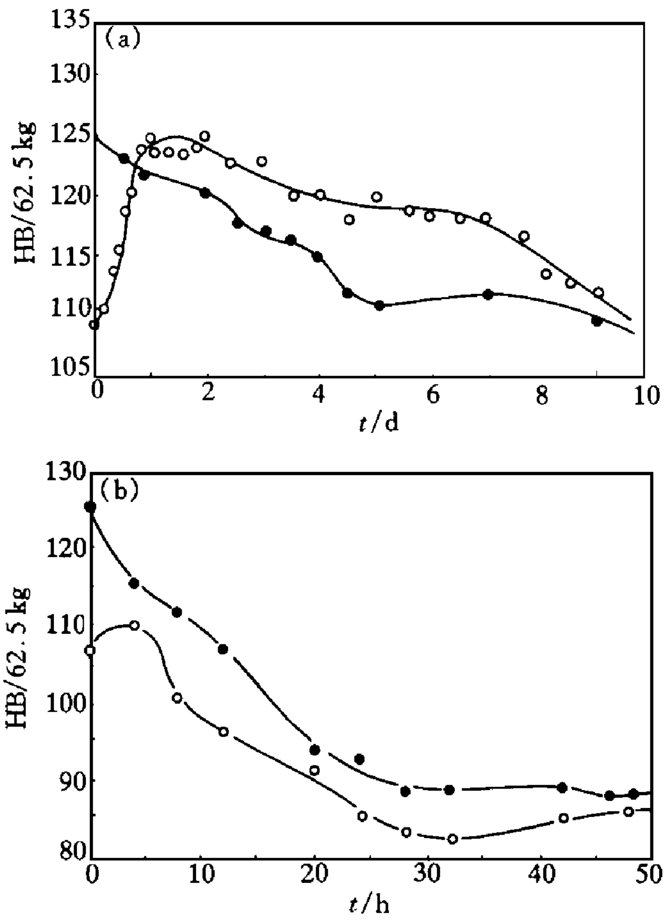

Fig. 1 The ageing curves of the hardness *vs* time of Mg-7Li-14Zn-1.6Ag-1Nd-2Ce alloy after quenching in different mediums

○—water quenching; ●—Liquid nitrogen quenching
(a) —ageing at 38 ℃; (b) —ageing at 75 ℃

3.1.2 Temperature and time of solid solution

Weinberg *et al*[4] indicated that the melting point of Mg-7Li-14Zn ternary alloy should be about 400 ℃. The lost of lithium in the surface of specimens would be increased heavily as solid solution at too high temperature, on the other hand, the solid solution can not be completed at too low temperature. So, we chose the temperature range of solid solution as 350 ℃~ 370 ℃.

From the four solid solution treatments, we find that at the same solid solution temperature, the hardness enhances sharply as the time of solid solution prolonged (30 min → 1 h), and the time needed in arriving agei‘ ng peak shortened evidently; at the same solid solution time, raising solid solution temperature (30min, 370 ℃→ 390 ℃; 1 h, 350 ℃→ 370 ℃) also results in the increasing of peak value and the shortening of time needed in approaching ageing peak. The curves of the four treatments indicate that the higher hardness peak can be obtained after solid solution at 370 ℃ for 1 h, and water quenching, in which two clear ageing peaks exist at about 8 ~ 10 h and 30 h (Fig. 2(a)). The change tendency of the yield strength $\sigma_{0.2}$ *vs* ageing time is similar to that of hardness *vs* ageing time. The ageing peak of $\sigma_{0.2}$ is at 10h and 30h respectively (Fig. 2(b)).

It implies that both raising solid solution temperature and prolonging solid solution time can enhance the hardness peak value of this material, and shorten the time needed in arriving the ageing peak; and the change tendency of hardness also reflects that of the yield strength of this material very well. Therefore, although the hardness of Mg-7Li-14Zn-1.6Ag-1Nd-2Ce alloy is not the highest after solid solution at 370 ℃ for 1 h, then water quenching, and ageing at 38 ℃ for 30 h, both the yield strength $\sigma_{0.2}$ and the ultimate tensile strength σ_b are at peak value at that time, *i.e.* it gives better total mechanical properties.

3.2 Ageing behaviors of the ternary and the optimum alloy

The experiment following $L9(3^4)$ orthogonal table indicated that the optimum amount of La, Ce, Nd, and Ag as additives of ternary alloy is 0.4～0.6, 0.8～1.0, 1.1～1.3, and 1.6 respectively[7]. Accordingly we melted the orthogonal optimum alloy Mg-7Li-14Zn-0.57La-1.22Nd-1.0Ce-1.6Ag (short as the optimum alloy later), and investigated its ageing behavior comparing with the ternary alloy.

Figs. 3 and 4 are the ageing curves of the mechanical properties *vs* time of the ternary and the optimum alloy after solid solution at 370 ℃ for 1 h, and water quenching. For the ternary alloy, ageing at 75 ℃, the decrease of whose σ_b is 55 MPa after 10 h and then become slow, $\sigma_{0.2}$ has a peak value of $\sigma_{0.2}$ after 30 h, and a rising elongation (Fig. 3(a)); while ageing at 38 ℃, the alloy has σ_b and $\sigma_{0.2}$ peaks at 10 h and 20 h respectively, and a change of elongation similar to that at 75 ℃ ageing (Fig. 3(b)). For the optimum alloy, ageing at 75 ℃, whose σ_b decreases sharply during first 20 h, $\sigma_{0.2}$ decreases 17 MPa in the first 10 h and then exists a peak at 30 h or so, and the change of elongation is almost contrary to that of $\sigma_{0.2}$ (Fig. 4(a)) jageing at 38°, σ_b exists a peak when ageing at 20 h, and $\sigma_{0.2}$ has a higher value at about 10 h (Fig. 4(b)). Ageing at 38 ℃, σ_b of the optimum alloy reaches peak value 10 h later compared with the ternary alloy; and ageing at 75 ℃, the change tendency of the strength between them is similar, however, the absolute values of strength for the optimum alloy is higher than that of the ternary one, and the ductility decline slightly due to the alloying additives.

Therefore, the fairly good total mechanical properties can be available for the two alloys after solid solution at 370 ℃ for 1 h, then water quenching, and ageing at 38 ℃ for 10 h to 20 h. Nevertheless, the two alloys all only exhibit softening when ageing at 75 ℃. Table 1 gives the best mechanical properties of them as ageing at 38 ℃.

3.3 Precipitation of the ternary and the optimum alloy

Fig. 5 is X-ray diffraction spectrums of the ternary and the optimum alloy at different conditions. From Fig. 5(a)－1 we can find that the new phases such as θ′ ($MgLi_2Zn$) and θ (MgLiZn) had precipitated in rather large numbers between α and β matrixes due to the natural ageing from after the heat treatment to being tested. θ′ is a simple ordered BCC structure[6, 7] and θ exists as a disordered FCC structure or simple ordered cubic structure[7]. As θ′, a metastable structure[1, 4, 8], decomposes partial-

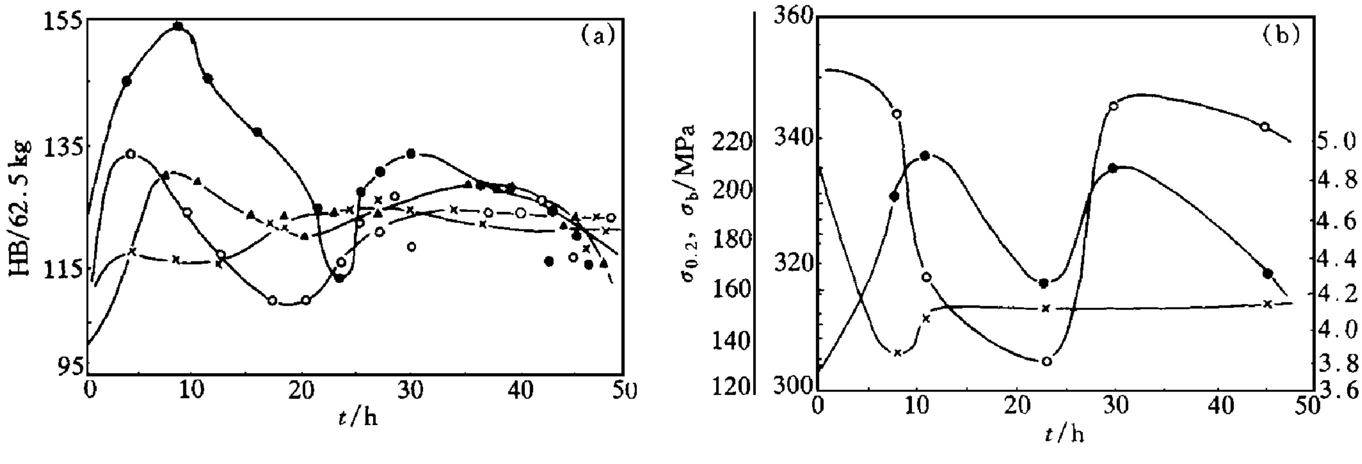

Fig. 2 The hardness and the mechanical properties of Mg-7Li-14Zn-1.6Ag-1Nd-2Ce alloy
(a) ●—370 ℃, 1 h; ○—390 ℃, 30 min; △—350 ℃, 1 h; ×—370 ℃, 30 min; (b) ●—$\sigma_{0.2}$; ○—σ_b; ×—δ

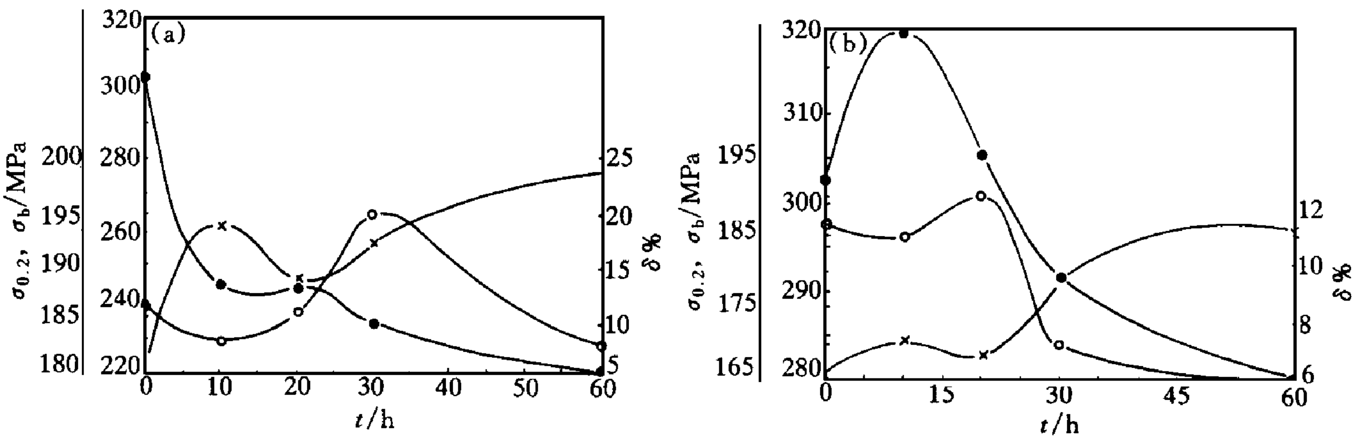

Fig. 3 The ageing curves of the mechanical properties *vs* time of the Mg-7Li-14Zn ternary alloy

● —σ_b; ○—$\sigma_{0.2}$ × —δ; (a) —ageing at 75 ℃; (b) —ageing at 38 ℃

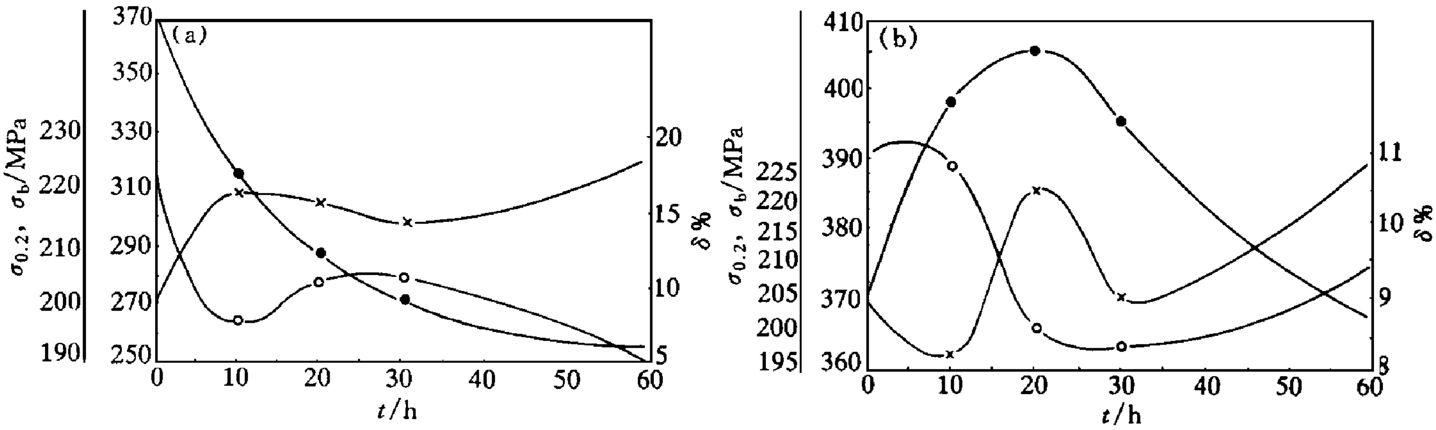

Fig. 4 The ageing curves of mechanical properties *vs* time of the optimum alloy Mg-7Li-14Zn-0.57La-1.22Nd-1.0Ce-1.6Ag

● —σ_b; ○—$\sigma_{0.2}$; × —δ; (a) —ageing at 75 ℃; (b) —ageing at 38 ℃

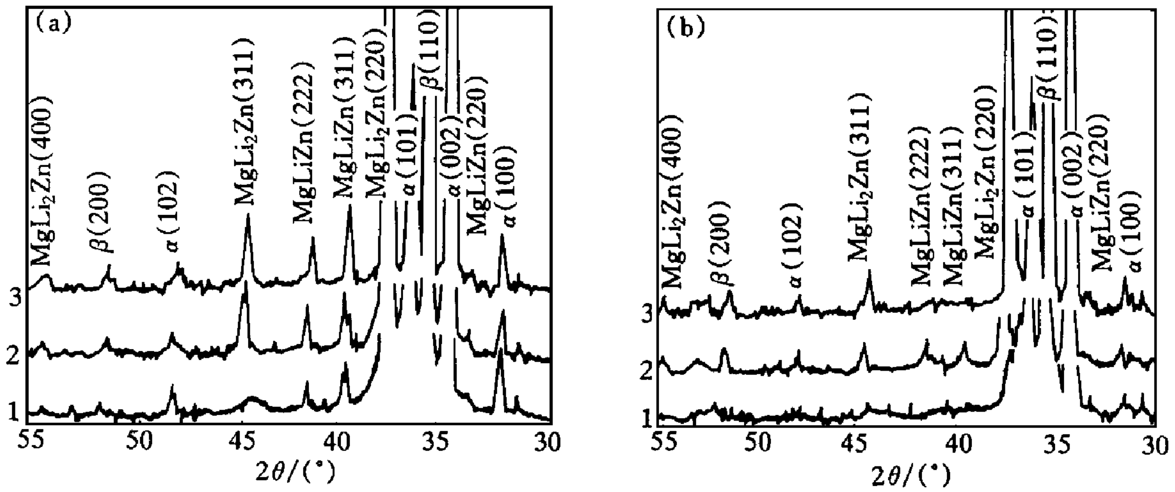

Fig. 5 The X-ray diffraction spectrums of the ternary and the optimum alloy

(1) —370 ℃, 1h+ water quenching; (2) —(1) + 75 ℃, 20 h ageing;

(3) —(1) + 75 ℃, 60 h ageing; (a) —the ternary alloy; (b) —the optimum alloy

Table 1 The comparison of best mechanical properties of ternary and optimum alloy

Name of Alloy	Ageing time/h	σ_b/MPa	$\sigma_{0.2}$/MPa	δ/%
Mg-7Li-14Zn	×10	319.5	184.0	7.28
	20	305.1	191.8	6.28
Optimum Alloy	10	397.9	223.8	7.66
	20	405.1	201.1	10.46

Solid solution at 370 ℃ for 1 h, water quenching, ageing at 38 ℃

ly into θ after precipitating at α and β matrixes, which results in coexisting θ and θ′ as showed in Fig. 5(a)-1. The precipitation of θ′ in a large number and its large rate of decomposing into θ, lead to higher diffraction peak of θ′ and θ in Fig. 5(a)-2, 3. Comparing with the ternary, there are not high peaks of θ′ and θ in the as-quenched optimum alloy (Fig. 5(b)-1), and its diffraction peaks, intensities of precipitation are also far below (Fig. 5(b)-2, 3).

Therefore, the hardening and the softening of the Mg-7Li-14Zn ternary alloy are principally determined by the precipitation and the decomposition of θ′. Hardening of the alloy is largely due to the resistance enhancement of dislocation movement as a result of precipitation of θ′ and slowly due to its decomposition, the ageing peak appears as precipitation and decomposition reach balance, alloy begins to soften as the quantity of θ′ drops, becanse precipitation of θ′ is slower than its decomposition. After the precipitation of θ′ tends to be completed, its effect on dislocation movement is weakened, and then the alloy softening becomes gentle. In the optimum alloy, there are many low diffraction peaks which still cannot be confirmed. From TEM, we know that they are new phases formed by the additives such as La, Ce, Nd, and Ag, which not only are strengthening phases themselves but also cut down the precipitation rate of θ′, especially inhibit the decomposition of strengthen phase θ′. Therefore, the strength of the optimum alloy is higher than that of the ternary, and the time needed in arriving the ageing peak of σ_b delays for 10h.

4 CONCLUSIONS

(1) The heat treatment condition of the alloy based on Mg-7Li-14Zn is solid solution at 370 ℃ for 1 h, then water quenching, and ageing at 38 ℃; the ageing time varies with the composition of alloys;

(2) The hardening and the softening of the Mg-7Li-14Zn ternary alloy are principally determined by the precipitation and decomposition of θ′ ($MgLi_2Zn$);

(3) The new phases, which formed by the additives such as La, Ce, Nd, and Ag, not only are strengthening phases themselves, but also cut down the precipitation rate of θ′, especially inhibit the decomposition of the strengthening phase θ′;

(4) The mechanical properties of optimum alloy (Mg-7Li-14Zn-0.57La-1.22Nd-1.6Ag) are σ_b= 405.1 MPa, $\sigma_{0.2}$= 201.1 MPa, and δ = 8.98% respectively, after solid solution at 370 ℃for 1h, then water quenching, and ageing at 38 ℃ for 20h.

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