MECHANICAL PROPERTIES AND MICROSTRUCTURES OF Al-Mg-Li-Zr ALLOYS-CONTAINING SILVER①

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ABSTRACT

The effect of adding Ag on the mechanical properties and microstructures of Al-Mg-Li-Zr alloys was investigated. The results show that small addition of Ag in the alloys can evidently refine the grains of as-cast alloys, accelerate the aging process, promote the precipitation of δ' (Al_3Li) and then lead to increase of the strength of the alloys. Mechanisms of refining and strengthening were discussed.

Key words: Al-Li alloys silver microstructures mechanical properties

1 INTRODUCTION

Al-Mg-Li-Zr alloy is one of the commercial Al-Li alloys and the 01420 alloy developed by Russian researchers during the 1960s is a typical one among them[1,2]. This alloy has lower density, better weldability and corrosion resistance than that of other Al-Li alloys. The effect of adding RE in Al-Li alloys has been investigated and valuable results have been obtained by Russian researchers. It has been found that Ce, Y and Sc are the most effective elements for improving properties of Al-Li alloys, Ce could mainly improve elevated temperature mechanical properties, Y could mainly improve the ductility, and Sc could obviously improve the weldability[3]. The 01421(Al-Mg-Li system) and 01460-1 (Al-Cu-Li system) alloys with Sc have been developed on the basis of 01420 alloy. In addition, the effect of La on the properties of 01420 alloy has also been investigated[4]. The 049 alloy (Al-Cu-Li system) developed by Mattin Marietta Co. during the 1980s has high strength and good weldability due to the addition of small amount Ag and Mg[5]. However, the effect of adding Ag in the Al-Mg-Li-Zr alloy has not been reported up to now. The purpose of this work is to examine the effect of Ag on the mechanical properties and microstructures of Al-Mg-Li-Zr alloys.

2 EXPERIMENTAL

The alloys were melted under the flux protection and poured into chill mold in argon atmosphere. Ingots were hot rolled to sheet in thickness of 2 mm after homogenizing at 520 ℃. The analyzed compositions of the alloys are shown in Table 1. Tensile samples were taken from the sheet along the rolling direction. Various samples were solutionized at 520 ℃ for 30 min, then water quenched and immediately aged at 170 ℃ for various times. The tensile test was carried out at the rate of 2 mm/min by Instron 8019 Material Test Machine.

Table 1 Composition of the tested alloys(wt. -%)

alloy No.	Mg	Li	Zr	Ag	Al
1	4.35	1.49	0.125	0	bal
2	4.40	1.48	0.118	0.214	bal
3	4.63	1.63	0.120	0.470	bal
4	4.43	1.67	0.123	0.816	bal

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Microstructures of samples were observed by optical microscopy and H-800 TEM.

3 RESULTS

The tensile properties of tested alloys after different treatments are shown in Table 2. The hardness dependence of aging time is shown in Fig. 1.

The results show that Ag obviously increases strength of quenched samples and slightly improves their ductility, strength and hardness of the alloys increase with the increase of Ag content. The peak hardness of alloy 1 without Ag occurred after aging at 170 ℃ for 24 h. The peak hardness of alloy 2 with 0.214 wt.-% Ag and alloy 3 with 0.470 wt.-% Ag occurred after aging at 170 ℃ for 12h. The peak hardness of alloy 4 with 0.816 wt.-% Ag occurred after aging at 170 ℃ for 6h. These results show that Ag can accelerate aging process of alloys. From Table 2, strength increment $\Delta\sigma$ and increasing rate R of the alloys with Ag are obtained (Table 3). The $\Delta\sigma$ dependence of aging time and Ag content is shown in Fig. 2. In Table 3,

$$\Delta\sigma = \sigma_{Ag} - \sigma_0; \quad R = \Delta\sigma/\sigma_0 \times 100\%$$

where σ_{Ag} and σ_0 are ultimate strength, σ_b, of the alloys with/without Ag, respectively, in a same condition. These show that the change of strength relates to adding Ag in the alloys.

The optical microstructures of the as-cast alloys are shown in Fig. 3. It can be found that Ag can refine grains in tested alloys, and the effect of grain refinement is enhanced with the increase of Ag content up to 0.816 wt.-%.

The TEM micrographs of the aged alloys are shown in Figs. 4 and 5. Fig. 4 indicates that no δ' precipitates within the grains and no equilibrium phase at grain boundaries in alloy 1 aged at 170 ℃ for 3 h can be seen under magnification of 35 000, but the TEM diffraction pattern gives evidence of superlattice spots (Fig. 4(b)), which means the precipitation of δ' occurred, but the size of precipitates is very small. However, at the same aging condition, δ' precipitates are uniformly precipitated within the grains of alloy 3 with 0.47 wt.-% Ag (Fig. 4(c)), and a few equilibrium phases are precipitated at grain boundaries (Fig. 4(d)). After aging at 170 ℃ for 24 h, large amount of δ' in alloy 1 and alloy 3 is uniformly precipitated within grains and equilibrium phases are non-uniformly at grain boundaries. At the same time, both δ' and equilibrium phases are coarsened, as shown in Fig. 5.

4 DISCUSSION

4.1 *Effect of Adding Ag on Grain Refinement*

As shown in Fig. 3, the effect of grain refinement is enhanced with the increase of Ag content up to 0.816 wt.-% Ag. It is obvious that this effect of Ag in the alloys can improve not only their workability but also their weldability.

Ag refines grains in the alloys, which may result from the enhancement of composition supercooling in the alloys. In a wide range of composition situated at the aluminium corner in Al-Mg-Ag system phase diagram, primary α nucleates and grows from the liquid during the solidification[6]. Ag may be eliminated from α and enriched in the liquid of α/L interface front due to that equilibrium repartition coefficient, K, of Ag in aluminium is less than 1, leading to enhancement of composition super-

Table 2 Mechanical properties of tested alloys

aging time/h (170 ℃)	alloy 1 σ_b /MPa	alloy 1 $\sigma_{0.2}$ /MPa	alloy 1 δ%	alloy 2 σ_b /MPa	alloy 2 $\sigma_{0.2}$ /MPa	alloy 2 δ%	alloy 3 σ_b /MPa	alloy 3 $\sigma_{0.2}$ /MPa	alloy 3 δ%	alloy 4 σ_b /MPa	alloy 4 $\sigma_{0.2}$ /MPa	alloy 4 δ%
as-quenched	298	247	22	312	264	23	319	274	24	350	291	24
3	316	277	21	346	291	19	379	322	17	433	365	16
6	319	281	20	352	296	20	410	340	16	443	378	13
12	338	299	18	364	311	19	424	355	15	437	366	11
24	358	339	15	321	300	16	412	343	14	368	324	8

cooling in the liquid. This is not favourable to growth of α grains, but favourable to nucleation of α grains. In addition, the compound with Ag is possibly formed during the solidification of the alloys, thus effect of Ag grain refinement may also relate to the compound with Ag as inhomogeneous nuclei of α grain.

Table 3 Strength increment of the alloys

alloy	2		3		4	
aging time/h (170 ℃)	$\Delta\sigma$ /MPa	R%	$\Delta\sigma$ /MPa	R%	$\Delta\sigma$ /MPa	R%
as-quenched	14	4.7	21	7.0	52	17.4
3	30	9.5	63	19.9	117	37.0
6	33	10.7	91	29.5	124	38.9
12	26	7.7	86	25.4	99	29.3

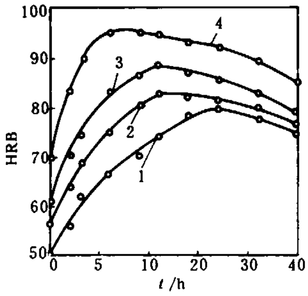

Fig. 1 Hardness HRB dependence of aging time at 170 ℃
1—alloy 1; 2—alloy 2; 3—alloy 3; 4—alloy 4

4.2 *Effect of Adding Ag on Strengthening*

From Table 1, content of main alloying elements, Mg and Li, is about the same in alloy 1 and alloy 2, while Li content is about the same in alloy 3 and alloy 4, but Mg content in alloy 3 is higher than that in alloy 4, proving that increase of strength closely relates to Ag in various condition.

The TEM analysis shows that black particles

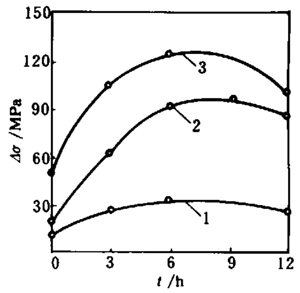

Fig. 2 $\Delta\sigma$ dependence of aging time at 170 ℃
1—alloy 2; 2—alloy 3; 3—alloy 4

Fig. 3 Optical micrographs of as-cast alloys
(a)—alloy 1; (b)—alloy 3; (c)—alloy 4

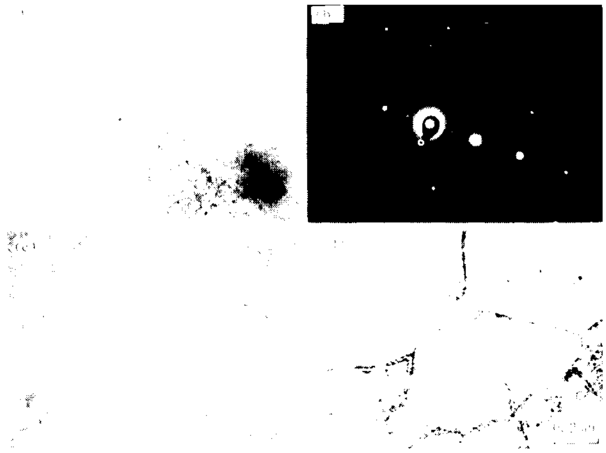

Fig. 4 TEM micrographs of samples aged at 170 ℃ for 3 h
(a), (b) -alloy 1; (c), (d) alloy 3

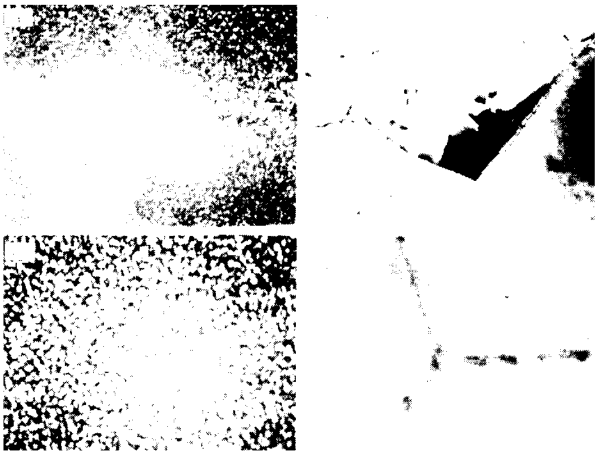

Fig. 5 TEM micrographs of samples aged at 170 ℃ for 24 h
(a), (b) alloy 1; (c), (d)—alloy 3

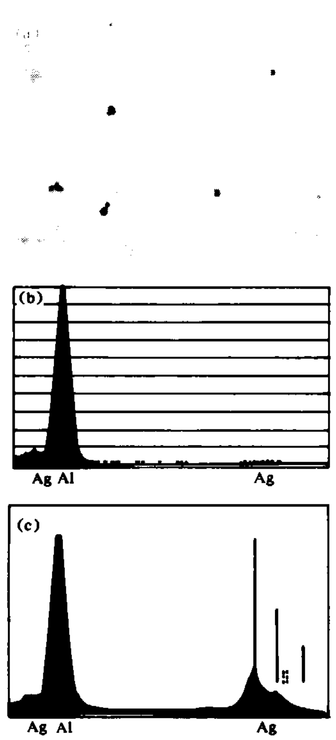

Fig. 6 TEM micrograph and diffracting pattern of alloy 3, as quenched
(a)—micrograph; (b)—black particle; (c)—matrix in Fig. 6(a)

in quenched sample of alloy 3 are Ag-rich, while there is only small amount of Ag in matrix (α phase), as shown in Fig. 6. These black particles should be Ag-rich compound. As a result, the strength of quenched alloys with Ag is higher than that of Ag-free alloy 1 due to both solid solution strengthening of Ag and dispersion-strengthening of compound with Ag. Based on same reasons, strength of quenched alloys increases with the increase of Ag content.

For the aged condition, the increase of strength of the alloys with Ag is not mainly due to solid solution strengthening of Ag and dispersion-strengthening of compound with Ag. It could be due to the fact that Ag accelerates aging process and promotes precipitation of δ' . This effect of Ag on strength of aged alloys possibly relates to that Ag decreases the solid-solubility of Li in the alloys. This leads to precipitate δ' more easily supersaturated solid solution α, which is beneficial to the increase of strength for underaged and peakaged samples. On other hand, some equilibrium phases, such as δ (AlLi) and T (Al_2MgLi), are also accelerated preferential precipitation at grain boundaries, and δ' phase is accelerated coarsening for the alloys with Ag during aging process. Therefore, the aging time of achieving peak is shortened with the increase of Ag content in the alloys.

5 CONCLUSIONS

(1) Adding small amount of Ag in the Al-Mg-Li-Zr alloys can refine the grains as cast.

(2) The added Ag accelerates the aging process of the alloys, i. e. promotes the precipitation and growth of δ' phases as well as equilibrium phases during aging process.

(3) The strength increases with the increase of Ag content in quenched, underaged and peakaged samples.

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