

# AGEING CHARACTERISTICS AND MICROSTRUCTURE OF Al-Mg-Li ALLOYS CONTAINING SMALL AMOUNT OF SILVER<sup>①</sup>

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**ABSTRACT** The ageing behavior and microstructures of the Al-Mg-Li alloys containing small amounts of silver have been studied. The results showed that small quantities of silver could modify the ageing characteristics of Al-Mg-Li alloys, enhance the peak hardness and strength, and delay the ageing peaks. X-Ray diffraction analysis showed that  $T$  phase was present in the Al-Mg-Li alloy containing 0.52% (mass fraction, %) Ag, and TEM observations showed that silver prevented the growth of  $\delta'$  phase during ageing.

**Key words** Al-Li alloy ageing microstructure silver

## 1 INTRODUCTION

It's been found that small amount of silver exerts a considerable effect on the structure and ageing characteristics of some aluminium alloys, such as Al-Zn-Mg system, Al-Cu-Mg system etc. In a series of papers<sup>[1-3]</sup>, Polmear *et al* reported that in Al-Cu-Mg system alloys the increased ageing hardening response caused by small additions of silver was associated with stimulating nucleation of intermediate precipitates and modification of the precipitation structure. They reported that<sup>[4]</sup> lithium additions in the range 0 ~ 2.5% progressively changed the precipitation processes in the Al-4% Cu-0.3% Mg-0.4% Ag alloy aged at 200 °C, and three intermediate precipitates  $\Omega$ ,  $\theta'$  and  $S'$  contributing to the high level of age hardening in the alloy was found. Afterwards a new family of Al-Li alloys — Wedalite 049 has been developed by Pickens and his co-workers<sup>[5]</sup>, they reported that the ultra high strength of these family of alloys derives from the additions of minor Ag and Mg to the Al-Cu-Li alloys. But up to now most of the investigations concentrated only on the Al-

Li alloys containing copper<sup>[6-9]</sup>, few have been done on the copper-free Al-Li alloys. In this paper the ageing characteristics and microstructure of Al-Mg-Li-Zr alloys containing small amounts of silver were studied.

## 2 EXPERIMENTAL PROCEDURE

The alloys were prepared by melting and casting under argon atmosphere. The chemical compositions of the alloys tested are shown in Table 1. The ingots were homogenized, scalped, then hot rolled and cold rolled to 2 mm sheets. The specimens were solution treated and quenched into cold water, then aged at 120 °C. Tensile specimens were machined from the sheets in the longitudinal directions, and the tensile tests were carried out at room temperature on Instron 8019. The X-Ray diffraction was performed on Simens D500. The specimens for the observation of transmission electron microscopy were prepared by twinjet electropolishing in a 33% HNO<sub>3</sub> and 67% (volume fraction, %) CH<sub>3</sub>OH solution at -20 °C. Examination was carried out in H800 with an accel-

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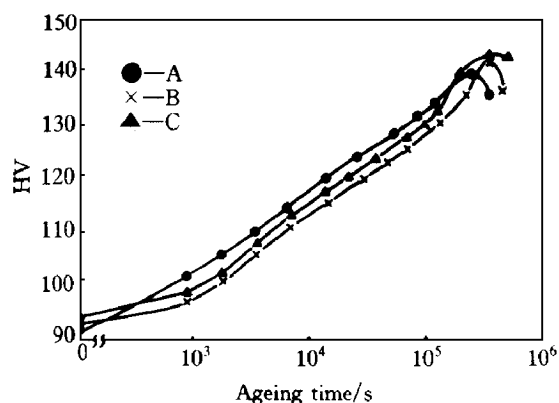
erating voltage of 200 kV.

**Table 1** Chemical compositions of alloys A, B and C ( % )

Alloys	Mg	Li	Ag	Zr	Al
A	5.10	1.56	0	0.13	Bal.
B	5.05	1.63	0.26	0.13	Bal.
C	5.00	1.56	0.52	0.13	Bal.

### 3 RESULTS AND DISCUSSION

The hardness/ageing time curves at 120 °C for the A, B and C alloys are given in Fig.1. It can be seen that the form of the ageing curves of the A, B and C alloys is similar, and only one ageing peak was observed during the whole ageing process at 120 °C. The rate of overage of the C alloy was much slower than that of the B alloy. Compared with the silver-free alloy, the ageing peaks were delayed by additions of silver. It is interesting to note that there is little difference in the peak hardness value between B and C alloys although the silver contained in the C alloy is double that in the B alloy.



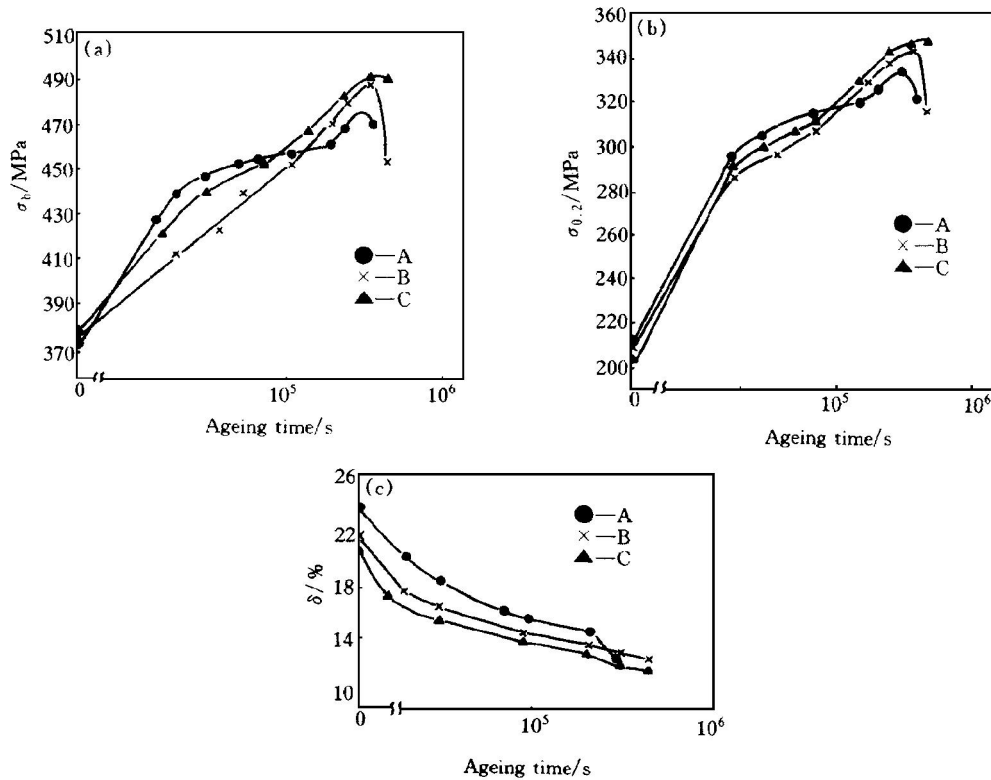
**Fig.1** Hardness/ time (ageing) curves at 120 °C for A, B and C alloys

The tensile properties/ ageing time curves at 120 °C for the A, B and C alloys are shown in Fig.2. It's found that the form of the tensile strength/ageing time curves is similar to the hardnesses/ ageing time curves. The higher peak strength could be achieved by additions of silver, whereas the percentage elongation was reduced,

and the more the silver added, the lower the percentage elongation was, which indicated that the ductility could be declined with the small additions of silver.

TEM investigations indicated that homogeneous distribution of  $\delta'$  precipitates present in both silver-containing and silver-free alloys. There was no significant difference in the distribution and morphology of  $\delta'$  particles between the silver-containing and silver-free alloys. However, in the same aged condition the size of  $\delta'$  particles in the silver-containing alloys appeared to be smaller than that in the silver-free alloy, and it seemed that the more the silver was added, the finer the  $\delta'$  phase was. As for the silver-free A alloy, its  $\delta'$  particles after ageing for 80 h was even bigger than that of the B alloy aged for 100 h (see Fig.3). It seems that the existence of the silver may prevent the growth of the  $\delta'$ , this may lead to the delay of the ageing peak for the B and C alloys and the slow overage of the C alloy. The slow growth of  $\delta'$  phase may be associated with the fact that the addition of silver slows the rate of the lithium atoms diffusion. On one hand, because silver atoms and magnesium atoms have high combining energy with vacancies<sup>[10]</sup>, they may trap a lot of vacancy after quenching, consequently the number of vacancies trapped by the lithium atoms is reduced. On the other hand, as for  $\delta'$  phase, in order to grow up, they either rob silver atoms and magnesium atoms of vacancies, or get over the obstacle of the combination of silver atoms/ vacancy or magnesium atoms/ vacancy, thus it is difficult for lithium atoms to diffuse, and the growth of  $\delta'$  particles is slower.

The X-Ray diffraction results (see Table 2 and 3) showed that the S phase ( $\text{Al}_2\text{MgLi}$ ) could be precipitated in B and C alloys, and only in the C alloy T phase ( $\text{Mg}_{32}(\text{Al}, \text{Ag})_{49}$ ) was present. This indicated that in the Al-Mg-Li-Ag alloy the T phase could be precipitated only when containing more silver. As Wheeler *et al*<sup>[11]</sup> pointed out the Al-Mg alloys with even small additions of silver should consequently be regarded as ternary precipitation hardening alloys, here the Al-Mg-Li alloys with additions of silver could also be considered as quaternary



**Fig.2** Tensile properties/ time (ageing) curves at 120 °C for A, B and C alloys  
(a) —Tensile strength; (b) —0.2 % proof stress; (c) —Elongation

**Table 2** X-Ray diffraction of B alloy aged at 120 °C for 100 h

No.	$2\theta/^\circ$	$D/\text{nm}$	INTEG.I	Phase( $hkl$ )
1	21.753	4.1023	82	S(422)
2	23.068	3.8523	62	S(511)
3	31.263	2.8586	109	S(711)
4	38.408	2.3417	5872	S(822)
5	43.309	2.0874	84	S(931)
6	44.648	2.0278	6620	S(933)

precipitation hardening alloys. The existence of  $T$  phase in the Al-Mg-Ag alloys was reported by Auld *et al*<sup>[12]</sup>, which can contribute to the marked age hardening<sup>[13]</sup>. In the Al-Mg-Li-Ag-Zr alloy the  $\delta'$ ,  $S$  phase and  $T$  phase could be precipitated, and it seems reasonable to attribute the high level of age hardening and strengthen-

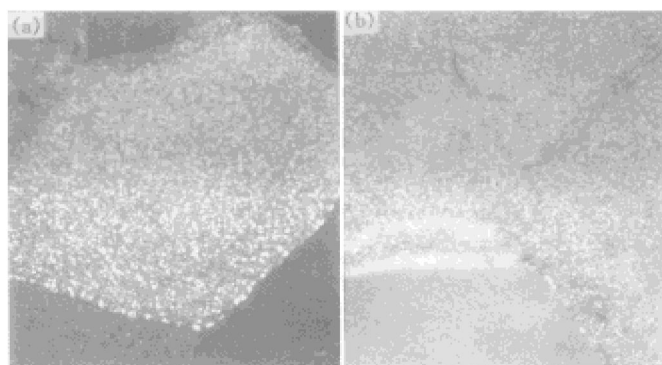
ing in the alloy mainly to their presence. The precipitation of  $T$  phase may lead to the slower overage of C alloy, for the precipitation of  $T$  phase can compensate for the softening during the overage stage.

#### 4 CONCLUSIONS

(1) Small quantities of silver may modify the ageing characteristics of the Al-Mg-Li-Zr alloys, and the higher peak hardness and strength could be achieved by small additions of silver.

(2) The ageing peak was delayed by the additions of silver, and the more the silver was added, the slower the rate of overage softening was.

(3)  $T$  phase can be precipitated in the Al-Mg-Li-Ag-Zr alloy containing 0.52 %Ag.



**Fig.3** Central dark field image of  $\delta'$  phase  
(a) —A alloy aged 80 h at 120 °C ; (b) —B alloy aged 100 h at 120 °C

**Table 3** X-Ray diffraction of C alloy aged at 120 °C for 100 h

No.	$2\theta/^\circ$	$D/\text{nm}$	INTEG.I	Phase( $hkl$ )
1	21.737	4.085 1	366	$S(422)$
2	22.972	3.868 2	280	$T(321)/S(511)$
3	25.050	3.551 8	155	$S(440)$
4	35.801	2.506 0	248	$T(530, 433)$
5	36.623	2.451 6	201	$T(600, 442)/S(733)$
6	38.342	2.345 6	12 780	$T(611, 532)/S(822)$
7	41.089	2.194 9	186	$S(842)$
8	42.147	2.142 2	201	$T(631)/S(664)$
9	44.550	2.032 1	20 934	$T(710, 550)/S(933)$
10	45.910	1.975 0	263	$T(721, 633)/S(1020)$
11	64.803	1.437 5	4 801	$T(941, 853)$
12	68.568	1.367 4	160	$T(1031, 952)$
13	77.843	1.226 0	9 078	$T(1060, 866)$
14	81.996	1.174 1	804	$T(1222, 1064)$

growth of  $\delta'$  phase during ageing.

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(4) The additions of silver may prevent the