Effect of 0.5% silver on the age hardening behaviour of an Al–Li–Cu–Mg–Zr alloy

Central-South University of Technology, Department of Materials Science and Engineering, Changsha, Hunan 410083, People’s Republic of China

It has been known that a small addition of silver to Al–Cu–Mg alloys aged at a temperature between 120 and 250 °C can increase the response of age hardening and modify the associated microstructures [1, 2]. For example, in Al–Cu–Mg alloys that lie in the α + S region of the ternary phase diagram at the ageing temperature, silver stimulates the precipitation of finely dispersed T phase (Al₆(Cu, Ag)Mg₄) [3]. For ternary alloys with high Cu:Mg ratios, if silver is added to these alloys a fine distribution of very thin, hexagonal plate-like precipitates is formed on {1 1 1} planes. This precipitated phase has been designated Ω phase by Polmear and co-workers [4–6]. There is strong evidence that these precipitates lead to the increased hardness of these alloys, and improvement in both room and elevated temperature tensile properties. A more recent example is weldalite 049 alloy developed by Martin Marietta Corporation [7]. The ultrahigh strength of 049 alloy apparently results from the refinement of T₁ precipitates due to the presence of small amounts of silver and magnesium in this alloy [8, 9].

The purpose of this letter is to report the results of the effect of addition of 0.5% silver on the age hardening of an Al–Li–Cu–Mg–Zr alloy with lower Cu and higher Li contents than 049 alloy, based on hardness measurement and transmission electron microscope (TEM) observations.

The alloys were prepared using high-purity materials in an argon atmosphere. The chemical compositions of the alloys tested are shown in Table I. The ingots were homogenized, scalped, then hot rolled and cold rolled to 2 mm sheets. Solution treatment was carried out in a salt bath at 530 °C for 30 min. Quenching was normally in cold water. Some specimens were aged at 190 °C for various periods immediately after quenching. Some specimens were aged at 170 °C for 2 h and then aged at 190 °C for various periods. Others were cold rolled by 8% after quenching and then aged at 170 °C for 2 h and at 190 °C for various periods. The specimens were examined by hardness measurement and by observation using TEM.

Fig. 1a shows the hardness/time curves aged at 190 °C for both silver-containing and silver-free alloys. With increasing ageing time, hardening increased to the peak hardness values and then decreased. The hardness increment of the silver-containing alloy throughout the whole period of ageing at 190 °C was significantly greater than that of the silver-free alloy. This implies that 0.5% Ag added to the alloy increased the hardening component during ageing at 190 °C.

Fig. 1b shows hardness/time curves for double ageing conditions. It can be seen that after ageing at

<table>
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<th>Li</th>
<th>Cu</th>
<th>Mg</th>
<th>Ag</th>
<th>Zr</th>
<th>Al</th>
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<td>bal</td>
</tr>
<tr>
<td>2</td>
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<td>2.18</td>
<td>0.80</td>
<td>0.51</td>
<td>0.15</td>
<td>bal</td>
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Figure 1 Hardness/ageing time curves for the (O) silver-free and (●) silver-containing alloys: (a) aged at 190 °C; (b) aged at 170 °C for 2 h and then aged at 190 °C; (c) cold rolled by 8% and aged at 170 °C for 2 h and then aged at 190 °C.
170 °C for 2 h, hardness values increased significantly compared with as-quenched specimens. However, during the initial stages of subsequent ageing at 190 °C, hardness values were not increased but were decreased. After ageing at 190 °C for 20–40 min the hardness values exhibited minimum values and after passing the minimum values hardening was again increased up to a maximum and then decreased. This implies that there is reversion behaviour in both alloys during the initial stages of ageing at 190 °C after ageing at 170 °C for 2 h. As with single ageing shown in Fig. 1a, the silver-containing alloy has a greater response to age hardening.

For the specimens cold rolled prior to double ageing, the ageing curves also exhibit the same characteristic as with double ageing (Fig. 1c). There are minimum hardness values in the initial stages of final ageing at 190 °C. However, the differences in hardness recorded for the two alloys were less significant than those obtained without cold working prior to ageing. This is similar to the results for Al–Li–Cu alloy reported by Wiets and Polmear previously [2]. This implies that cold working prior to ageing offsets the effects of silver on the response to age hardening of the alloys used in this investigation.

TEM observations indicated that in the two alloys the precipitation of 6' phase was rapid, and the addition of silver had no significant effect on 6' precipitation. This is attributed to the fact that 6' precipitates could form rapidly from the supersaturated solid solution by homogeneous nucleation during or right after the water quench. This preferred nucleation is common in Al–Li-based alloys. The dark field image in Fig. 2 shows the homogeneously distributed 6' particles for the silver-containing specimen aged at 170 °C for 2 h. The dissolution of 6' particles was not observed in the reverted temper.

In the condition without prior cold working, small amounts of S' particles, precipitated on the dislocations, were present for the silver-free alloy aged to peak hardness (Fig. 3a). However, in the silver-containing alloy, finely dispersed precipitates were observed for the same ageing treatments. The morphology and dispersion of these precipitates were completely different from the lath-shaped S' particles (Fig. 3b). These small particles are T phase. A small amount of lath-shaped S' precipitates was also present in the silver-containing alloy. For the specimens with prior cold working, the effect of silver on the precipitation of T phase is less significant. In both alloys aged to peak hardness at 190 °C, large amounts of S' precipitates were observed. Fig. 4 shows bright field micrographs of S' phase in silver-free alloy which was cold rolled by 8% prior to ageing. No Ω phase was observed in the alloys investigated. Precipitation of the copper-rich Ω phase would require high Cu:Mg ratios: as the Cu:Mg ratios are low, the formation of Ω phase is unlikely in the composition ranges of the alloys studied.

It has been known that in some Al–Cu–Mg alloys GPB zones form at lower ageing temperature and cause additional hardening [10, 11]. It is suggested that during pre-ageing at 170 °C, the formation of fine 6' precipitates and GPB zones caused greater age hardening than with as-quenched specimens. In the range of ageing temperatures and Li content...