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Effect of stress on microstructures of creep-aged 2524 alloy

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Abstract: Microstructures of creep-aged 2524 (Al−4.3Cu−1.5Mg) aged at 170 °C with various stresses (0, 173 and 250 MPa) were studied on a creep machine. Ageing hardness curves under various stresses were plotted and the corresponding microstructures were characterized by transmission electron microscopy (TEM). The results show that the value of peak hardness is increased, while the time to reach the peak hardness is reduced under an external stress. Meanwhile, the length of *S*(Al_2CuMg) phase is shorter and the number density of *S* phases is larger in the creep-aged alloy. The predominant contribution to the peak hardness can be ascribed to the GPB zones with an elastic stress.

Key words: creep-age; *S* phase; GPB zone; hardness; dislocation; stress orientation effect

1 Introduction

In order to reduce the cost in the manufacture of airplane, age-forming was explored and studied to meet this requirement. It has drawn much attention as it can decrease the manufacturing processes by combining both ageing treatment and the forming process with elastic stress applyed to the alloy sheet during the ageing process [1]. This technology has been successfully applied to airplane [2]. The mechanism of age-forming of binary Al−Cu alloy has been investigated [3−7]. And it was found that the elastic stress can induce stress orientation effect on the precipitate in this alloy. However, there are few reports on the age-forming of ternary Al−Cu−Mg alloy. In previous work, the effects of plastic stress on the microstructure and mechanical properties of 2524 alloy were investigated, which can lead to a higher hardness and shorter time to peak hardness. Meanwhile, *S* phases contribute to the peak hardness [8]. In the present study, creep-age forming was employed to study the effect of elastic stress on the microstructures and properties of commercial alloy 2524 during isothermal ageing at 170 °C.

2 Experimental

The chemical composition of the commercial 2524 alloy used in this work is listed in Table 1. The specimens were punched from as-received sheet with 4 mm in thickness. Temperature dependence of yield strength was determined to be 251 MPa at 170 °C using an Instron machine. Then the samples with gage length of 22 mm were aged at 170 °C with a creep machine under various constant stresses. The stresses applyed to the alloy were 0, 173 (~70%$\sigma_{0.2}$, $\sigma_{0.2}$=251 MPa at 170 °C) and 250 MPa(~$\sigma_{0.2}$). Vickers hardness measurement was carried out with 450SVDTM on the aged specimens under a load of 48 N for dwell time of 20 s. Thin foils were prepared by electro-polishing in a twin-jet Tenupol with a 33% nitric acid solution in methanol operated at −25 °C and 13.8 V. FEI CM20 TEM operated at 200 kV was employed to observe the microstructures.

3 Results and discussion

3.1 Hardness curves

Figure 1 depicts the ageing hardness curves of 2524

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Table 1 Chemical composition of 2524 commercial alloy (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Cr
0.02	0.1	4.34	0.62	1.45	<0.005

Ni	Zn	Zr	Ti	Al
<0.005	0.02	<0.005	0.01	Bal.

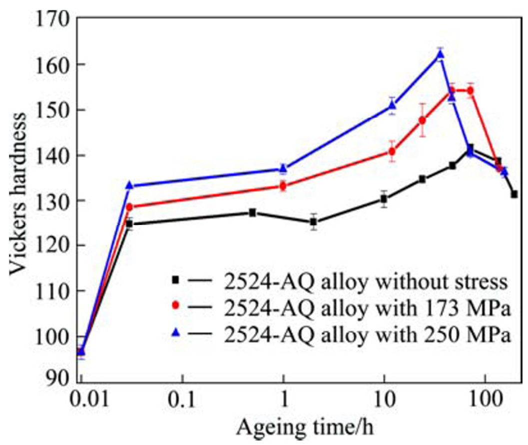

Fig. 1 Hardness curves of creep-aged alloy under various stresses at 170 °C

alloy aged at 170 °C with and without stress during the ageing process. All of the curves are separated into two stages: rapid hardening and second hardening which is consistent with other authors [9−12]. It is generally accepted that the rapid hardening is due to the clusters and the second hardening is ascribed to the GPB zones in this series alloy. When the three groups of samples are shortly aged for 2 min, rapid hardening occurs and the value is increased rapidly compared with the as-quenched condition. Obviously, the hardness value of the creep-aged sample is larger than that of sample conventionally aged at 170 °C. Meanwhile, the hardness value is greater with a larger stress applied to the aged alloy. After leveling for a period, the hardness value begins to ascend the second peak hardness. When applying an external elastic stress on the alloy, the hardness value increases and the time to reach peak hardness decreases compared with the conventional-aged sample. While the peak hardness is much larger and peak time is even shorter under stress of 250 MPa. As for 250 MPa around the yield strength of the alloy responding to the ageing temperature, the increment of the hardness could ascribe to the work hardening effect and the precipitation strengthening. In terms of the alloy under a stress of 173 MPa, the increment of the hardness can be due to the precipitation strengthening. Both will be discussed by associating with microstructures later. In all, the trend of the hardness curves of the alloy applied with elastic stresses is the same with the curves of that under plastic stresses in Ref. [8].

3.2 Microstructures

3.2.1 Microstructural evolution in conventionally aged and creep aged samples

The evolution of the microstructures aged at 170 °C for various time was examined by TEM with the incident beam parallel to ⟨001⟩ as shown in Fig. 2. A stress of 173 MPa is applied to the alloy to compare the samples without stress. Figure 2(a) shows the typical bright field (BF) TEM image of 2524 alloy aged at 170 °C for 2 min without stress. A few dislocation loops can be observed in this shortly aged sample. However, besides dislocation loops, helical dislocations generate in creep-aged sample aged under 173 MPa for 2 min in Fig. 2(b). The dislocation loops or helical dislocations are on {110} plane. The increased dislocations in Fig. 2(b) indicate that the elastic stress can accelerate the formation of dislocations. When the alloy is solution treated and then rapidly quenched, a lot of supersaturated vacancies can be reserved in the matrix. Some dislocation loops can form due to the condensation and collapse of extra vacancies [13]. With an external stress applying on the ageing alloy, the migration of vacancies can be accelerated and the formation of dislocations is facilitated. Thus the number density of dislocations is higher with an external stress applying on the alloy.

With prolonging ageing time to 0.5 h as shown in Fig. 2(c) and Fig. 2(d), it can be seen that the microstructures are similar to those aged for 2 min from the BF TEM images. A few dislocations are present in the conventionally aged alloy and more dislocations are in the creep-aged alloy. Turning to the diffraction pattern, some streaks in both images indicate the presence of the precipitation of $S(Al_2CuMg)$ phase. However, no other precipitates could be detected in this condition. The precipitate sequence in Al−Cu−Mg alloy which is in the region of α+S phase is generally regarded as: solid solution → pre-precipitate stage → GPB zones + S→S [9]. Generally speaking, S phases prefer to nucleate on dislocations and then grow heterogeneously on dislocations. With increasing ageing time, the S phase will grow into lath along ⟨001⟩ direction on {120} plane.

The corresponding microstructures of the ascending stage to peak hardness are shown in Fig. 2(e) and Fig. 2(f). Figure 2(e) illustrates the typical BF TEM image of the 2524 alloy aged at 170 °C for 24 h. S phase can be seen to grow into lath and thicken. While the other strengthening precipitates, GPB zones, could be obviously observed in bright field image and also can be detected in diffraction pattern. Similarly, GPB zones could also be seen in creep-aged sample under a stress of 173 MPa in Fig. 2(f). GPB is nowadays regarded as the predominant precipitates contributing to the peak hardness in the peak-aged Al−Cu−Mg alloy other than