

Effect of tensile stress on microstructure evolution of Al-Cu-Mg-Ag alloys

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Abstract: The effect of tensile stress on thermal microstructure evolution of Ω phase in an Al-Cu-Mg-Ag alloy with high Cu/Mg ratio and higher Ag content was investigated by transmission electron microscopy (TEM). The samples were aged at 200 °C for 1 h (T6 condition), then thermal exposed at 250 °C for 100 h with and without a tensile stress (130 MPa), respectively. The results indicate that Ω precipitates uniformly disperse in the matrix as a major precipitate after artificially aging at 200 °C for 1 h (T6 condition). Exposed at 250 °C for 100 h without stress, Ω precipitates dissolve dramatically. Whereas, during stress exposure they coarsen unexpectedly rather than dissolve into matrix. It can be deduced that the stress retards the redissolution of Ω phase.

Key words: Al-Cu-Mg-Ag alloy; Ω phase; thermal exposure; tensile stress

1 Introduction

Al-Cu alloy has been widely used for structural materials because of their good age hardening characterizations and high temperature creep resistance with the precipitation of GP zones and θ' plates on $\{001\}_{\text{Al}}$ planes. Additional trace elements of Mg and Ag have been found to induce the finely dispersed Ω precipitate on $\{111\}_{\text{Al}}$ planes, replacing the conventional GP zones and θ' plates on $\{001\}_{\text{Al}}$ planes[1]. The effect of the trace elements on Ω precipitation has been shown by atom probe field ion microscopy (APFIM) study[2] as Mg-Ag clusters formed at the beginning of aging, then Cu atoms aggregated into the clusters to form Ω nuclei on $\{111\}_{\text{Al}}$ planes. Ω precipitates appear to maintain coherency along the $\{111\}_{\text{Al}}$ planes at temperatures up to 200 °C, which is facilitated by segregation of Mg and Ag atoms to the precipitate-matrix interface during growth of Ω (Fig.1)[1, 3].

Considering strain energy, SUH et al have pointed out that the incorporation of Mg and Ag decreases the strain energy for the nucleation of Ω on $\{111\}_{\text{Al}}$ plane [4, 5]. Some research conclusions[6–11] showed that precipitation process could be modified dramatically on

coupled elastically stress with temperature during aging (namely, stress aging), which helped to modify and control the species, quantity, shape, size, distribution and orientation of precipitates, and finally, to improve the mechanical properties of materials. Stress aging technology has been utilized in some aluminum alloys for a few years[7–12]. Since the Ω precipitate exhibits basically the stoichiometric composition ratio of Al_2Cu compound and consequently changes into the stable θ phase, the evolution of Ω and θ' precipitates should be closely related with the mutual constituent Cu atoms in GP zones, θ' and Ω . The stress effect on GP zones has been examined by ETO et al[13]. The preferential nucleation of Ω and θ' plates under external stress has been reported[14, 15], nevertheless, stress effect on the thermal microstructure evolution of Ω phase has been uncertain.

In this work, stress exposure is performed to investigate the microstructure evolution of Ω phase in an Al-Cu-Mg-Ag alloy after peak-aging treatment. The relative density change between Ω and θ' plates depends on the respective stress sensitivities of Ω and θ' plates. The thermal microstructure evolution of Ω and θ' plates is qualitatively investigated by TEM observations. The exposure methods (the combination of the stress and

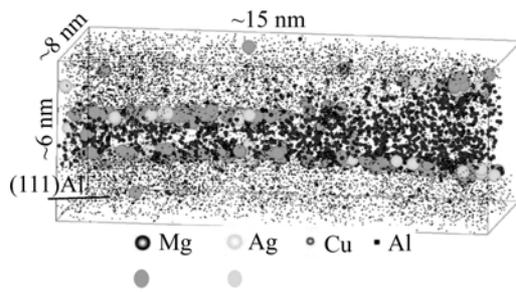


Fig.1 3DAP elemental mapping of $\{111\}$ plates in Al-Cu-Mg-Ag alloy and Mg-Ag co-clusters around Ω plates

stress-free exposure after peak-aging condition, respectively at elevated temperature) are performed to study the effect of the stress on the microstructure evolution of Ω phase in an Al-Cu-Mg-Ag alloy with high Cu/Mg ratio and higher Ag content.

2 Experimental

The nominal chemical composition of the alloy was Al-6.5Cu-0.4Mg-1.0Ag (mass fraction, %). Samples were solution treated at 515 °C for 6 h and then quenched into cold water rapidly. The quenched samples should be put into furnace as quickly as possible in order to prevent from natural aging. All the samples were aged at 200 °C for 1 h (T6 condition), then exposed at 250 °C for 100 h. This treatment compared with exposure at 250 °C for 100 h concurrently under a tensile stress of 130 MPa, the external stress applied on the samples was perpendicular to the rolling direction. Thin foil specimens for TEM (transmission electron microscopy) were prepared in a twin jet electron-polisher using a solution of 30% nitric acid and 70% methanol (volume fraction) at about -25 °C. TEM foils were examined using a Tecnai G² 20ST microscope operating at 200 kV.

3 Results and discussion

Fig.2 shows the microstructure of artificially aged samples at 200 °C for 1 h (T6 condition), which contains Ω and θ' plates with fine and uniform dispersion of Ω precipitate dominating in the matrix. For this investigated alloy, abundant Mg and Ag dissolve to form Mg-Ag clusters as the nucleation sites for Ω plates due to their high binding energy. These clusters form at 200 °C when there is “excess” silver relative to soluble Mg and a greater than equilibrium volume fraction of Mg-Ag clusters.

It has been established that plate-like precipitates thicken by a ledge nucleation and propagation mechanism[16]. The excellent coarsening resistance of the Ω plates aged at 200 °C observed in the study by HUTCHINSON et al[17] was shown by conventional

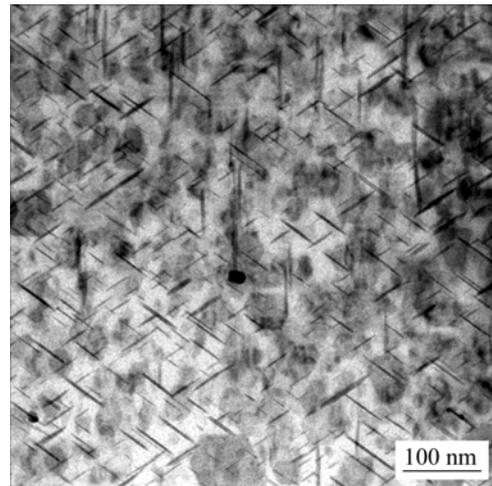


Fig.2 Representative micrograph taken near $[110]_{\alpha}$ zone axis illustrating matrix θ -type precipitation after artificially aging at 200 °C for 1 h (T6 condition) in samples

transmission electron microscopy to be the result of a lack of growth ledges arising from a prohibitively high barrier to nucleation and that for coherent plates, strain energy considerations controlled the ease at which these thickening ledges nucleated for discrete plate thickness, so the Ω plates will not thicken at 200 °C for aging time up to 1 h.

The microstructures of exposed samples at elevated temperature 250 °C for 100 h with and without tensile stress of 130 MPa after aged at 200 °C for 1 h are represented in Fig.3. Ω plates coarsening takes place in thermal stress exposed material (Fig.3(a), (c) and (e)). Ω plates disperse uniformly when the magnitude of TEM is lower (Fig.3(a)). In the higher magnitude TEM photograph much thicker Ω plates (Fig.3(c)) than that at age condition can be seen (Fig.2). It also can be seen that wider PFZs (precipitate free zones) and equilibrium phase exist in the grain boundaries (Fig.3(e)). The accelerated coarsening of precipitates observed in the present investigations could possibly be caused by a solute drag effect where the substitutional atoms are carried by migrating dislocations. During stress exposure, the movement of free dislocations introduced by external tensile stress occurs.

Therefore an increased mobility of Cu atoms caused by moving dislocations can explain the stress accelerated coarsening of Ω plates. Another possible mechanism is that a higher dislocation density is maintained during stress exposure as compared to isothermal exposure. If it is true, higher effective pipe diffusion fluxes and faster particle coarsening can be expected.

Meanwhile, “free” solute atoms in the matrix that be not used to nucleate when aged at 200 °C, are available which have not yet to participate in the normal precipitation process. Such solute may be expected to

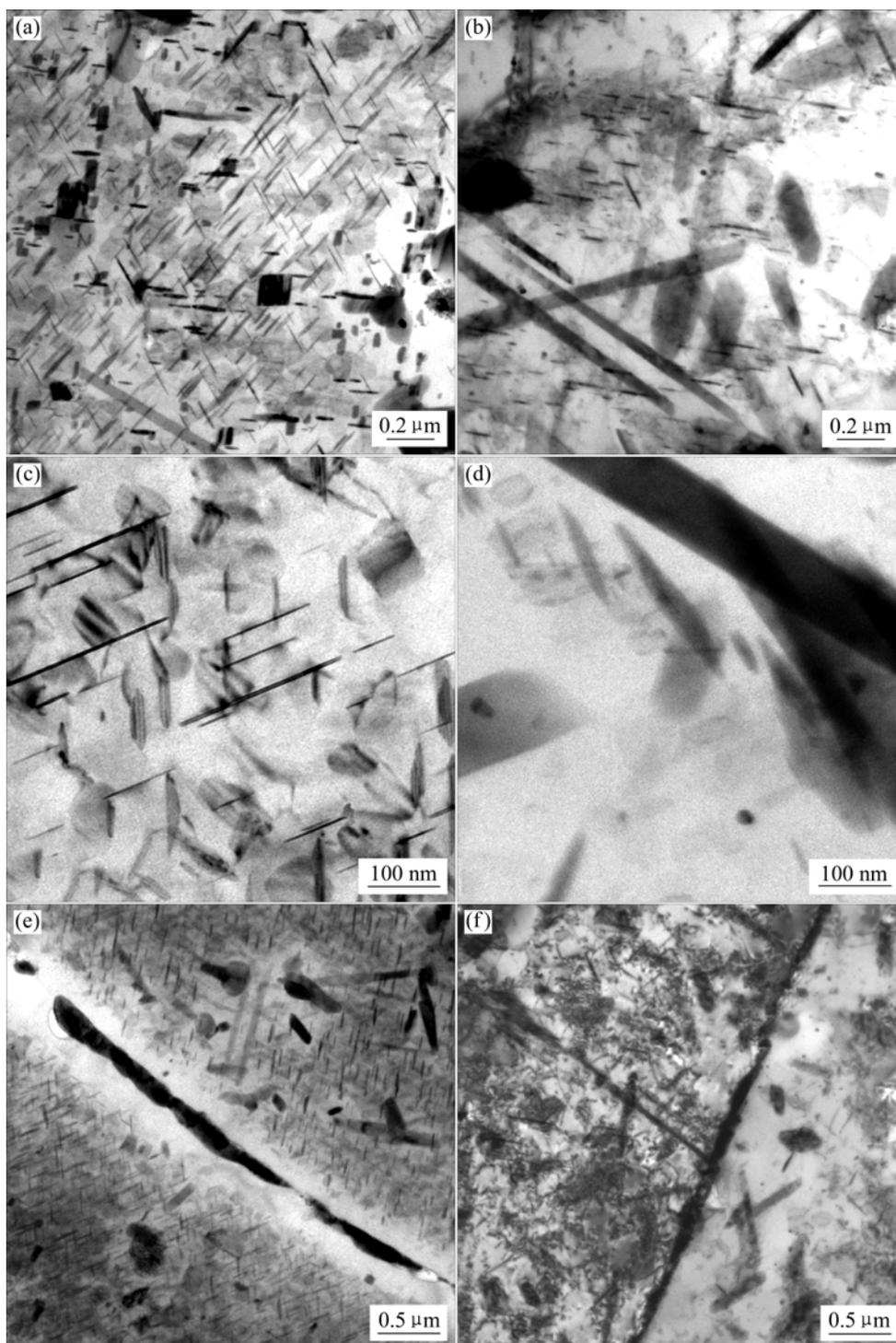


Fig.3 Representative micrographs taken near $[110]_{\alpha}$ zone axis illustrating precipitation after exposed at elevated temperature 250 °C for 100 h after artificially aging at 200 °C for 1 h (T6 condition) in samples: (a), (c) and (e) stress condition; (b), (d) and (f) stress-free condition

interact with mobile dislocations, which will impede their motion and affect deformation behavior[5]. This solute may also facilitate dynamic growth during exposure with stress.

Fig.3(b), (d) and (f) show the microstructures of samples which are aged at 200 °C for 1 h and then exposed at 250 °C for 100 h with stress-free. Ω plates

dissolve sacrificially to matrix with the rise of thermal exposure time at 250 °C. The lower magnitude TEM photograph (Fig.3(b)) shows a smaller number of Ω plates that do not dissolve completely. Ω plates are easy to dissolve at 250 °C, for the diffusion rate of atoms is faster at high temperature. On the other hand, Ag and Mg atoms at Ω /matrix interfaces occur to redistribute and

Ag-Mg co-clusters are broken up so that Cu atoms flow to matrix. Another explanation is that when exposure at 250 °C for 100 h Ω plates take place to coarsen, however, Ag-Mg co-clusters are not big enough to enwrap the growing Ω plates. Therefore the “guard-walls” are broken up. Then redissolution happens. In the grain boundaries (Fig.3(f)) the PFZs are not as wide as that in the stress exposure condition.

To correlate the microstructure of stress-free exposure with that of stress exposure, alterations of Ω precipitates are caused by stress which suppress the redissolution of Ω and promote the successive growth of it.

4 Conclusions

1) Majority of Ω precipitates is decomposed during the thermal exposure without stress.

2) During stress exposure, Ω precipitates grow unexpectedly rather than dissolve into matrix. The stress plays a role of retarding the decomposition of Ω phase rather than accelerating the growth of them.

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