Study of precipitation and deformation characteristics of the aluminium-lithium alloy by X-ray double crystal diffractometry

J. CHAUDHURI, V. GONDHALEKAR, A. INCHEKEL, J. E. TALIA
The Institute for Aviation Research, The Wichita State University, Wichita, Kansas 67208, USA

The X-ray double crystal diffractometry technique was utilized to follow the ageing and deformation characteristics in the aluminium–lithium (Al–Li) alloy. This non-destructive method is extremely sensitive to measure the strain and dislocation density within individual grains through X-ray rocking curves. For ageing at 200° C, optimum ageing needed for maximum hardness was 32 h. Dislocation multiplication was responsible for reduction of hardness beyond 32 h ageing. In addition, when the specimen was deformed in tension, both compressive and tensile residual strains were found within individual grains.

1. Introduction

Al–Li alloys have gained considerable importance in aerospace and automobile industries over the past few years because of their low density–high modulus and low density–high strength characteristics. For lithium additions up to 4 wt %, each weight per cent lithium added to an aluminium alloy reduces the density by approximately 3% and increases the elastic modulus by approximately 6%.

When Al–Li alloys containing more than 1 wt % lithium are quenched from the single-phase field and aged at temperatures below the metastable solvus line, homogeneous precipitation of the metastable phase δ' (Al_3Li) occurs. The δ' phase is a superlattice with a Cu_3Au (Li_2) type structure. Owing to the structural similarity and close match between the lattice parameters of the solid solution (i.e. matrix) and the δ' precipitate, a homogeneous distribution of coherent precipitates results. The improvements in the elastic modulus and density of the alloy occur irrespective of lithium being present in the solid solution or δ' precipitate. However, the improvement in strength accompanies the nucleation and growth of the δ' precipitate [1, 2].

The X-ray double crystal diffractometry technique offers an excellent possibility for measuring micro-deformations and microdefects within individual grains. This method is non-destructive and rapidly performed, and does not need any sample preparation. It is well suited to study the mechanical properties of materials and is particularly useful when the degree of deformation is small.

In this article, the precipitation hardening characteristics of the Al–Li alloy, as analysed by the the X-ray double crystal diffractometry technique, is reported. In addition, the X-ray double crystal diffractometry method was also applied to study the deformation mechanisms in this alloy.

2. Experimental procedure

Kaiser 2090 Al–Li (2.8 wt % Li) alloy was used in the present study. Because for X-ray measurements the minimum size of the grain is required to be approximately 50 μm, the sheet specimens were at first deformed 0.7% and annealed at 550° C for grain growth, and then were quenched to room temperature. Subsequent ageing treatments were performed at 200° C.

After each ageing treatment, the Vickers microhardness of the specimens was measured using a Leco microhardness apparatus. At the same time, X-ray analysis was performed in a different area of the specimens using a Blake Industries double crystal diffractometer in (+ −) parallel arrangement and Cu$K\alpha$ radiation [3]. The X-ray beam size used was 0.5 mm × 0.5 mm. A perfect crystal of germanium (1 1 1 surface) was used as the first crystal and X-ray rocking curves of the (0 0 2) reflection were obtained from individual grains of the specimens. The details of the X-ray rocking curve analysis technique and its application to polycrystalline materials is described elsewhere [3, 4]. Both the peak intensity (PI) and full width at half of the maximum intensity (FWHM) are measures of lattice misalignment caused by strains and/or dislocations. As the lattice misalignment increases, the peak intensity decreases and FWHM increases.

For the deformation experiment, the specimens were deformed under tension in a MTS machine at 0.8% increments until they failed. The X-ray rocking curve analysis was performed at each stage of deformation.

3. Results and discussion

Fig. 1 shows the variation of microhardness with ageing time. The strength or hardness increase associated with the δ' precipitates is due to their

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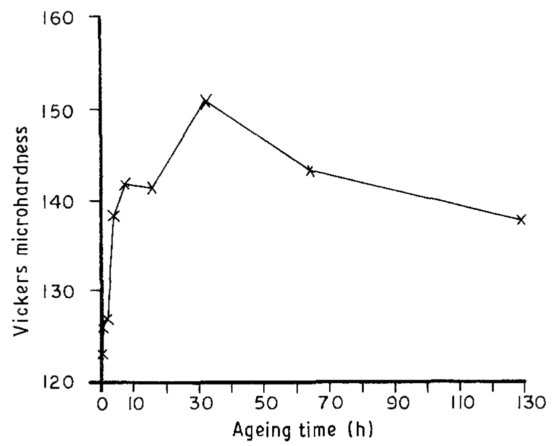

Figure 1 Variation of microhardness of 2090 Al–Li alloy with ageing time.

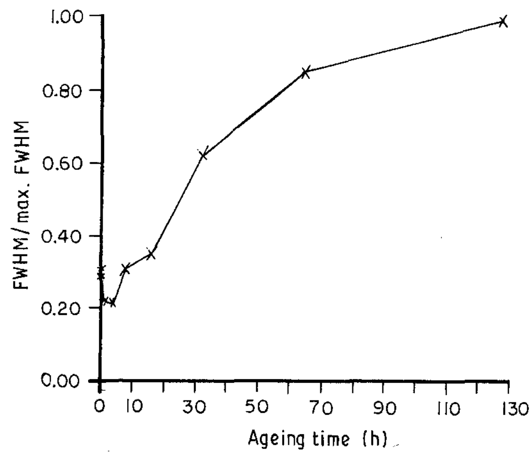

Figure 3 Variation of FWHM/maximum FWHM with ageing time.

resistance to dislocation motion. Kelly gave a thorough review of strengthening mechanisms in two-phase alloys by the second-phase particles [5]. For shearable precipitates, such as Al_3Li, this depends mainly on coherency hardening, which is the elastic coherency stress surrounding a particle that does not fit in the matrix exactly. It can be seen in Fig. 1 that the maximum hardness was obtained at 32 h ageing, because the maximum coherency occurred at that time. Ageing longer than 32 h led to coarsening of the precipitates, which was accompanied by a gradual loss of coherency and hence a decrease in hardness.

The ratios of peak intensity to maximum peak intensity and of FWHM to maximum FWHM, as averaged over a number of grains, are shown in Figs 2 and 3, respectively. At the beginning, the peak intensity was increasing, because more volume fraction of the matrix was coming into reflection as the precipitate particles were leaving the matrix. The decrease in peak intensity after 8 h ageing was due to the lattice misalignment caused by coherency strains, while the lattice misalignment due to dislocation multiplication caused the peak intensity to decrease beyond 32 h ageing.

Also, it can be seen in Fig. 3 that the FWHM increased with the increasing coherency strain. The FWHM values should decrease due to the reduction in coherency strain after 32 h ageing. In contrast, the FWHM values increased, which indicated that dislocation multiplication occurred for ageing beyond 32 h. In addition, the strengthening mechanism, due to entanglement of dislocations, was responsible for smaller slopes in the microhardness, peak intensity and FWHM curves after 64 h ageing.

The density of dislocation, D, can be calculated from the FWHM

$$D = \frac{(\mathrm{FWHM})^2}{9\boldsymbol{b}^2} \qquad (1)$$

where $\boldsymbol{b}$ is the Burgers vector. Excess dislocation densities after 32 h of ageing, as calculated, are shown in Fig. 4.

Figs 5 and 6 show the variations in FWHM and peak intensity with deformation in two grains ((0 0 2) reflection), respectively. From the shift of the rocking curve peak position of the (0 0 2) reflection, $\Delta\theta$, the normal strain, ε, can be calculated from the Bragg diffraction condition

$$\varepsilon = \frac{\Delta d}{d} = -\cot\theta\,\Delta\theta \qquad (2)$$

where d is the interplanar spacing, Δd is the change in interplanar spacing and θ is the Bragg angle. The residual strains as calculated are plotted in Fig. 7. It can be seen that, although the specimen was deformed in tension, the residual strain was always compressive in one grain and sometimes compressive and sometimes tensile in the other grain. This was a consequence of the interaction among the different grains in polycrystalline materials. Similar findings in zircaloy have

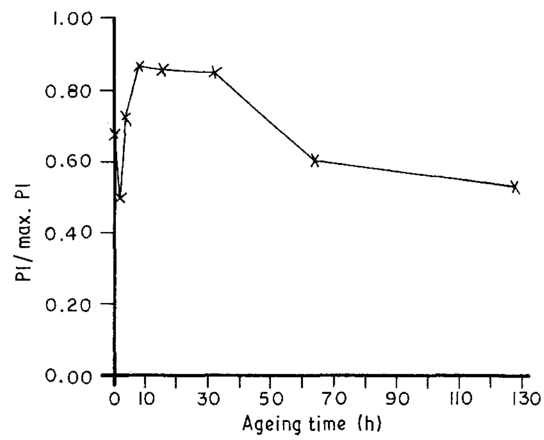

Figure 2 Variation of peak intensity/maximum peak intensity with ageing time.

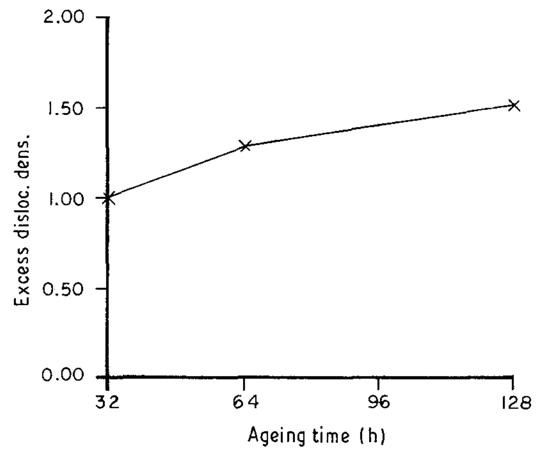

Figure 4 Excess dislocation density, compared with the dislocation density at 32 h ageing, plotted against time.

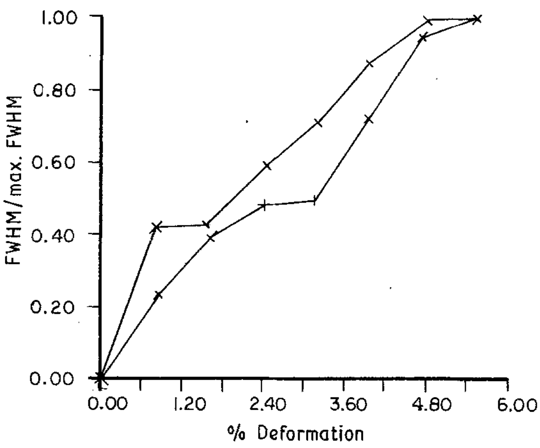

Figure 5 FWHM/maximum FWHM plotted against deformation. (—+—) Grain 1, (—×—) grain 2.

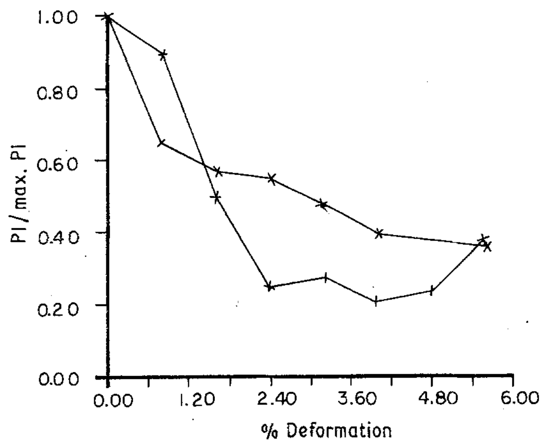

Figure 6 Peak intensity/maximum peak intensity plotted against deformation. (—+—) Grain 1, (—×—) grain 2.

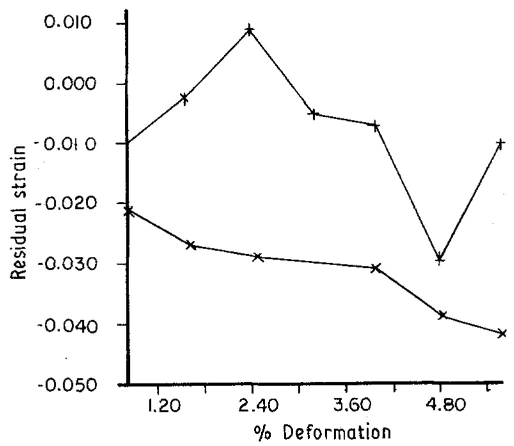

Figure 7 Residual strain plotted against deformation. (—+—) Grain 1, (—×—) grain 2.

been reported by Brown [6]. It is clear from Fig. 7 that the grains were strained more at the beginning than at the later stage of deformation. This is again partly because of the interaction of strains among different grains. Another factor which was responsible for the reduction of the slope of strain against deformation curve after 1.6% deformation was the relaxation of part of the strain in the form of dislocations. Also, the FWHM increased and peak intensity decreased continuously with deformation because the lattice misalignment increases with the increasing strain and dislocation density.

4. Conclusions

It has been shown that X-ray double crystal diffractometry can be used successfully to follow the kinetics of ageing and deformation in Al–Li alloys. For maximum hardness, the optimum ageing needed for 2090 Al–Li alloy was found to be 32 h. Dislocation multiplication occurred beyond 32 h ageing. The reduction in hardness slowed down after 64 h ageing due to the entanglement of dislocations. The residual strains in individual grains were both compressive and tensile when the specimen was deformed under tension. In addition, the grains were strained less at the later stage of deformation because of the constraints to further deformation by the neighbouring grains and the relaxation of strains in the form of dislocations.

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References

1. E. A. STARKE Jr, T. H. SANDERS and I. G. PALMER, *J. Metals* **33** (1981) 24.
2. B. NOBLE and G. E. THOMPSON, *Metal Sci. J.* **5** (1971) 114.
3. B. K. TANNER, "X-ray Diffraction Topography" (Pergamon, 1976) p. 47.
4. R. N. PANGBORN, S. WEISSMANN and I. R. KRAMER, *Metall. Trans.* **12A** (1981) 109.
5. P. M. KELLY, *Int. Metall. Rev.* **18** (1973) 31.
6. B. S. BROWN, *J. Metals* January (1988) 56.

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