Accelerating effect of whiskers on the ageing process of SiCw/Al composite

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SiCw/Al composites have been studied extensively in many topics, because of their good properties and performance. In general, T_6 treatment was employed to enhance the strength of the composite [1–6]. The ageing kinetics of the composite will be accelerated by whisker addition, which causes highly densified defects [1–3]. The highly densified defects in the composite are due to the great difference of the thermal expansion coefficient between the whisker and aluminium alloy, during the quenching process, which causes residual stress and induces defects [7].

Although the ageing kinetics of the composite and the highly densified dislocation in the composite have been well studied, some concepts have remained unclear. It is not clear whether the nucleation or the growth process was accelerated.

In the study reported here, the morphologies of the precipitation in 6061Al alloy and SiCw/6061Al composite were observed using transmission electron microscopy (TEM), and the mechanism by which the ageing kinetics of SiCw/6061Al composite was accelerated by whisker addition is discussed in this letter.

The SiCw/6061 composite used was fabricated by a squeeze casting method with whisker volume fraction of 20%. The composite and 6061Al were solution-treated at 520 °C for 30 min then quenched into water. The materials were aged at 170 °C and 190 °C, respectively. The ageing kinetics of the composite and 6061Al alloy were characterized by measurement of the Vickers hardness. The specimens of SiCw/6061Al for TEM observation were prepared by the ion milling method with a cooling attachment.

Fig. 1 shows the age-hardening curves of the SiCw/6061 composite and 6061 alloy. It is clear that the ageing process of the composite was accelerated. The composite attained peak ageing at 9 h and 3 h for the ageing temperatures of 170 °C and 190 °C, respectively, but the 6061Al attained the peak ageing at 11 h and 4 h for the ageing temperatures of 170 °C and 190 °C, respectively.

The ageing process of Al–Mg–Si alloy is cluster (Mg–Si–Al vacancy) → GP zone → β'' → β' → β (Mg_2Si) phase [8]. Because β'' precipitate is coherent with the matrix, the deformation field contrast in TEM morphology must be present. β' precipitate is needle-like and semi-coherent with the matrix. So, from the contrast of TEM image, the precipitate can be determined easily. TEM micrographs of peak aged 6061Al are shown in Fig. 2. It can be confirmed that the precipitation in peak aged 6061Al is β''. In Fig. 2, the subgrain boundary is also shown. It can be seen that the density of the precipitates near the subgrain boundary is very small compared with that within the grain, which results

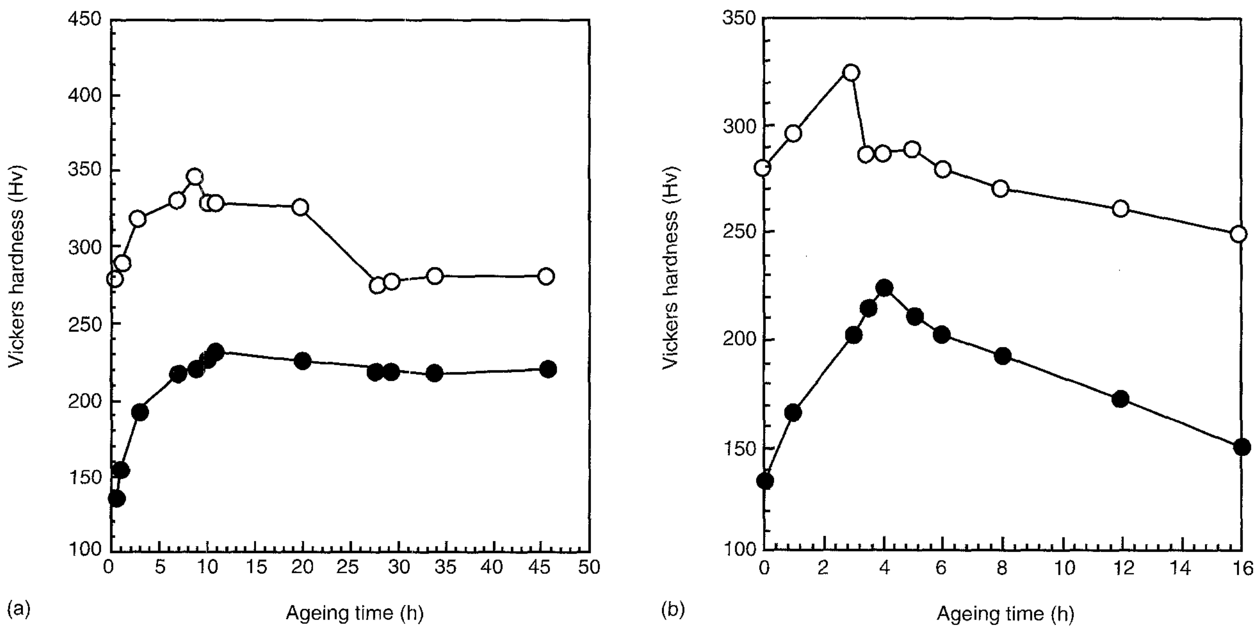

Figure 1 Age-hardening curves of (●) the 6061Al and (○) the composite aged at (a) 170 °C and (b) 190 °C.

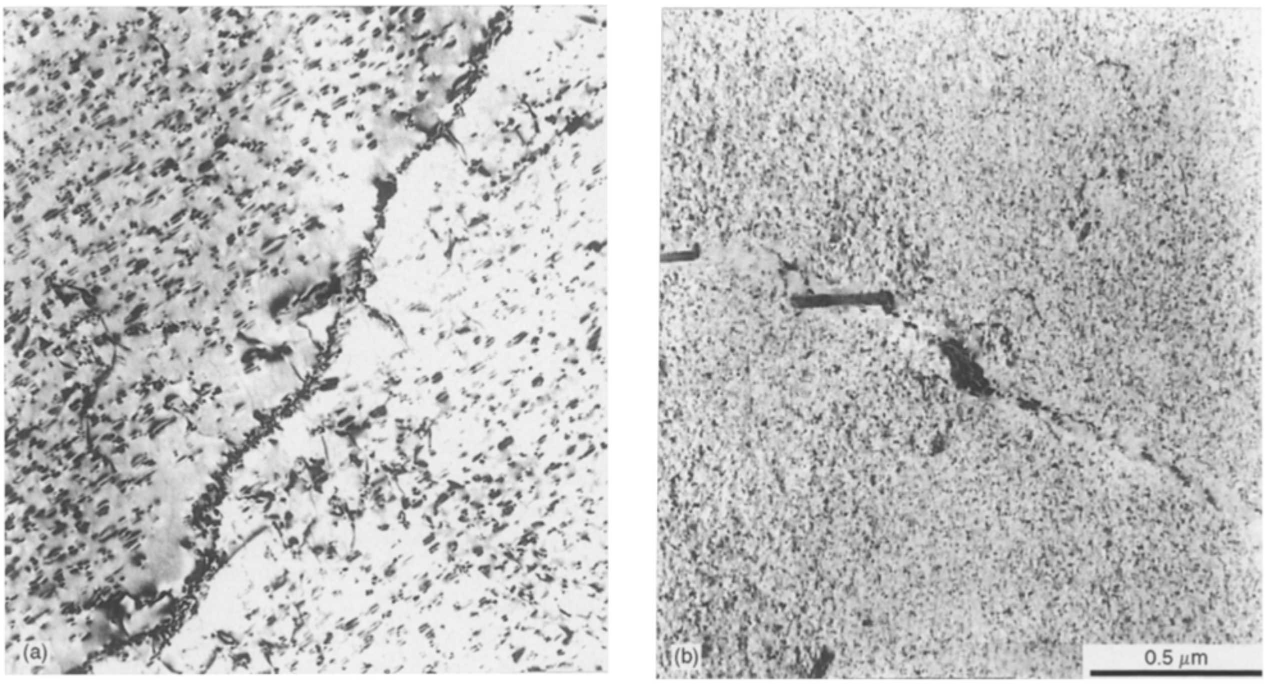

Figure 2 TEM micrographs of the peak aged 6061Al aged at (a) 170 °C and (b) 190 °C.

from the vacancy being absorbed by the grain boundary. This result is in agreement with previous studies, i.e. the nucleation of the precipitates in Al–Mg–Si alloy is related to the presence of vacancies.

Fig. 3 shows TEM micrographs of the as-quenched SiCw/Al composite; the highly densified dislocation can be found easily. Another feature of the dislocation state in the composite is that the many dislocations are helical; it may be suggested the helix dislocation is due to the vacancy being absorbed by screw dislocation.

Fig. 4 shows the TEM morphology of the composite aged at 170 °C for 10 min. Although the precipitate in the composite aged at the initial stage was β'' phase, the density of the β'' precipitate was quite small compared with that in the 6061Al composite (see Fig. 2). This result indicates that the nucleation process of the precipitate in the composite is not accelerated by the whisker addition. On the contrary, the nucleation of the precipitate in the composite is restrained. Thus the ageing process of the composite with whisker addition must be contributed by another mechanism.

Fig. 5 shows the TEM morphology of the peak aged composite. From the contrast of the TEM image, the precipitation in the aged composite can be determined. The precipitation in the composite peak aged at 170 °C was β'' phase, and the density of the β'' phase was small compared with that in the peak aged 6061Al. However, the size of β'' phase in

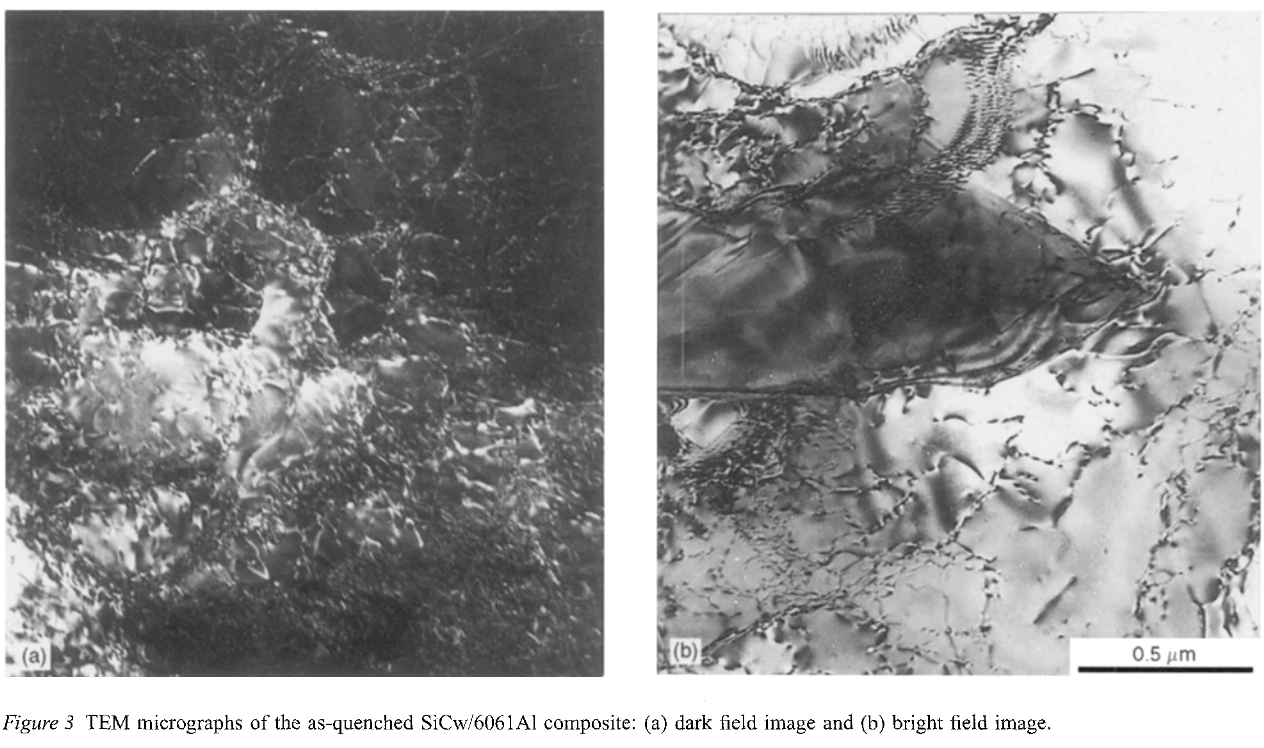

Figure 3 TEM micrographs of the as-quenched SiCw/6061Al composite: (a) dark field image and (b) bright field image.

Figure 4 TEM micrograph of the composite aged at 170 °C for 10 min.

the composite peak aged at 170 °C was coarser than that in 6061Al peak aged at 170 °C. It can be suggested that the nucleation process in the composite is restrained, but the growth rate of the precipitation in the composite is increased compared with the 6061Al. When the ageing temperature was 190 °C, the precipitation in the peak aged composite was β' phase with a lower density. The results indicate that the ageing sequence of the composite was accelerated by the whisker addition.

On the basis of this study, the nature of the effect of whiskers on the ageing kinetics of SiCw/Al composite can be discussed. Because of the difference between the thermal expansion coefficients of the whisker and matrix alloy, residual stress must be induced during the quenching process, resulting in enhancement of the defect density in the matrix of the composite. The defects can be divided into two types, dislocation and vacancy (because the high stacking fault energy of aluminium alloy, the stacking fault, can be ignored). From TEM observation, it was found that the vacancies were absorbed by screw dislocation (see Fig. 3). Many studies [8] have indicated that the precipitate is closely related to the presence of vacancies. In this point of view, the nucleation process of the composite is restrained by lower vacancy density. The size of the precipitates in the composite (see Fig. 4) is larger than that in 6061Al alloy (see Fig. 2), which means that the growth rate of the precipitates in the composite is accelerated by the whisker addition. Because the highly densified dislocation exists in the matrix of the composite, the dislocation is very beneficial for the diffusion of the Mg and Si atoms.

According to the above study, the main conclusions are as follows. Firstly, the ageing process of the composite was accelerated by whisker addition. Secondly, the nucleation process of the precipitates was restrained, because the vacancies were absorbed by the highly densified dislocation in the matrix of the composite. Thirdly, the growth rate of the precipitates was increased by the highly densified dislocation in the matrix of the composite.

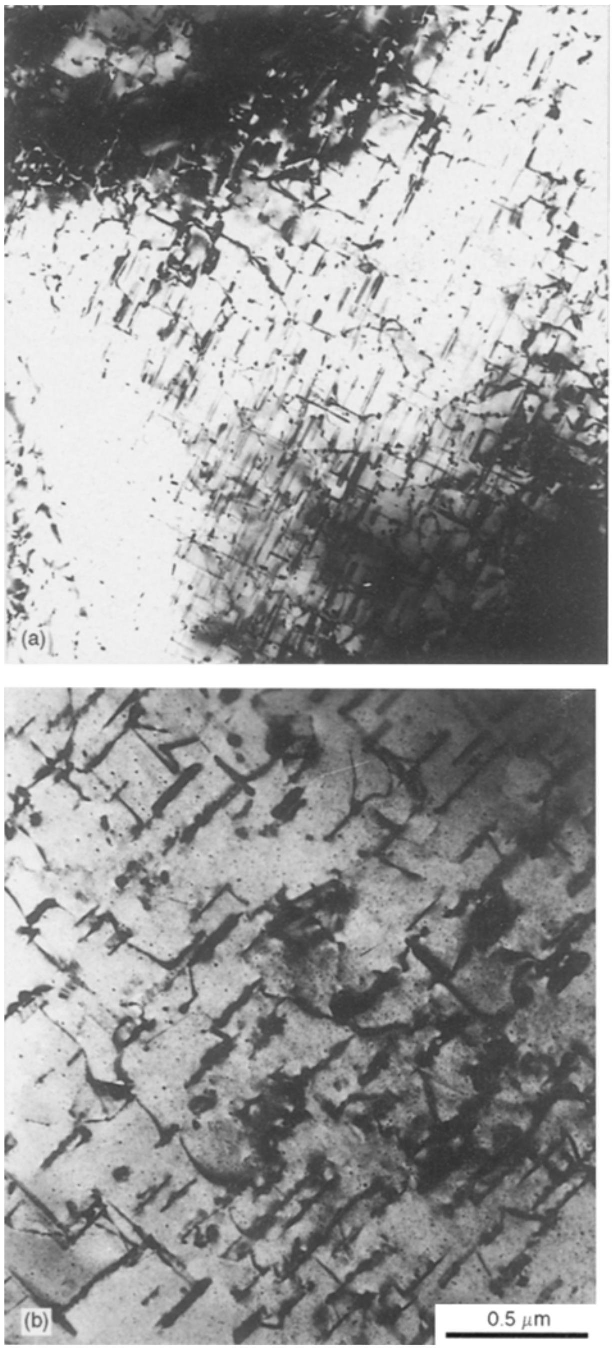

Figure 5 TEM micrographs of the peak aged SiCw/6061Al composite aged at (a) 170 °C and (b) 190 °C.

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Received 2 October
and accepted 6 December 1995