EFFECT OF PARTICLE SIZE AND AGEING ON THE FATIGUE BEHAVIOUR OF AN ALUMINIUM BASED METAL MATRIX COMPOSITE

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Fatigue crack propagation tests have been carried out on an 8090 aluminium matrix reinforced with 20wt% of 3 and 23μm particulate SiC. The results clearly show that increased ageing time results in a deterioration in the resistance to fatigue crack propagation for both reinforcement particle sizes. From fracture surface examination this appears to be associated with heterogeneous precipitation at the Al/SiC interface. It is also concluded that there is a complex dependence of fatigue crack growth resistance on reinforcement particle size.

INTRODUCTION

There has been a limited amount of work on the effect of particle size (Davidson (1) and Shang et al (2)) and ageing condition (You and Allison (3) and Christman and Suresh (4)) on the fatigue crack growth characteristics of aluminium based composites reinforced with discontinuous SiC. Little effect of ageing on fatigue has been reported over a range of growth rates for particulate (3) and whisker (4) reinforced composites. This effect has been attributed to the suppression of the planar slip by the presence of SiC, which results in low growth rates in underaged unreinforced Al-Li based alloys. Work on the effect of particle size on the fatigue crack growth properties of an Al-Zn-Mg-Cu based composite (2) indicated that coarser distributions of reinforcement can promote roughness induced closure mechanisms reducing crack growth rates at low stress intensity ranges.

There is a need, therefore, for a systematic study of the effects of particle size and matrix ageing condition on the fatigue response of composite materials of this nature.

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EXPERIMENTAL

The material for the study consisted of an 8090 matrix (Al-2.3Li-1.2Cu-0.7Mg-0.1Zr,wt%) reinforced with 20wt% of nominally 3μm or 23μm particulate SiC. The composite was produced by BP using a powder metallurgy route involving hot isostatic pressing, hot forging and finally rolling to a plate thickness of 15mm. Examination of the composite microstructure revealed a homogenous particle distribution with little evidence of particle cracking during processing.

The plate material was solution treated at 530°C for 2 hrs followed by cold water quenching. All ageing treatments were carried out at 170°C and from hardness data the peak and overaged conditions were found to correspond to 5 and 50 hrs respectively. Due to lithium loss during mechanical processing and heat treatment the surfaces of the billets were machined off and single edge notch bend specimens of dimensions 12.5x12.5x100mm taken from the T-S orientation. The fatigue tests were performed in accordance with E647-88 in four point bending at a frequency of 20 Hz and a load ratio of R=0.1. Crack length was monitored using a dc potential drop technique.

RESULTS

The variation in fatigue crack growth (FCG) rate with ageing condition for the two composites is shown in Figures 1 and 2. For both reinforcement distributions artificial ageing results in a deterioration in FCG resistance with increasing ageing time. There is no significant effect of ageing, however, on the value of threshold, ΔK_{th}. Fracture surface examination (Figure 3) showed no evidence of a change in the mechanism of crack propagation with ageing as is observed in unreinforced Al-Li alloys. In general, for all the conditions tested, planar slip was suppressed by the addition of reinforcement. Isolated areas of crystallographic FCG appeared at near threshold growth rates in all ageing conditions, probably associated with areas of unreinforced matrix. Detailed examination of the Al/SiC interface around fractured particles in the 23μm material revealed the presence of voids which became more numerous as the ageing time increased (Figure 4).

The effect of particle size on the FCG properties in the peak aged condition is illustrated in Figure 5. These data show the same trend with particle size as all the ageing conditions investigated. In the near threshold region the FCG rate is higher and the value of ΔK_{th} lower in the 3μm composite. In this regime the fatigue crack tends to avoid the reinforcement in both composites. In the Paris regime the FCG rates in both composites are very similar, although some instances of particle fracture are observed in the 23μm SiC, but this is rare for the 3μm reinforcement (Figures 3 and 6). The area fraction of fractured SiC on the fatigue fracture surface of peak aged specimen of the 23μm composite was found to range from 6% at ΔK=5 MPa√m to 11% at ΔK=13 MPa√m. At stress intensities approaching static failure the 3μm material again shows greater rates of FCG than observed in the 23μm material. This is associated with the lower fracture toughness of the 3μm ($K_{IC} \approx 11$ MPa√m) compared to the 23μm composite ($K_{IC} \approx 16$MPa√m) in the peak aged condition.

DISCUSSION

Harris et al (5) observed the same trend in FCG behaviour as a function of ageing in unreinforced 8090 as seen here for composites. In the unreinforced alloy in under and peakaged conditions the shearing of ordered Al_3Li encourages localised planar slip and an irregular facetted appearance to the fracture surface. This results in crack tip shielding in the form of roughness induced closure. Slower rates of FCG in the underaged material may also be associated with greater slip reversibility since dislocation looping of precipitates becomes more dominant in the peakaged condition. On overageing the precipitation of further phases, notably S' (Al_2CuMg), inhibits planar slip, by promoting cross slip, and thus reduces roughness induced closure.

The addition of SiC to an aluminium alloy has been shown to have three important consequences:

i) Arsenault and Shi (6) measured a high matrix dislocation density due to the differential thermal expansion of the SiC and the matrix,

ii) Humphreys (7) suggested nucleation from the damage zone at the Al/SiC interface may result in a finer recrystallised grain size in reinforced materials, and

iii) a reduction in slip band length as the reinforcement particles behave as dispersoids (1).

All of these effects will contribute to the suppression of planar slip in the composite.

Investigation of ageing effects in the 3µm reinforced composite by Knowles and King (8) suggests that some form of matrix weakening, adjacent to SiC particles occurs as a result of ageing. From Figure 4 it is apparent that as ageing time increases void density at the Al/SiC interface in the 23µm composite also increases. Clearly this could be the proposed matrix weakening effect. Gilmore and Bowen (10) have observed precipitates at the Al/SiC interface in 8090 containing 3µm reinforcement but have not identified them. It is possible that these precipitates may be the brittle T_2 phase. Liu et al (9) observed precipitates at the Al/SiC interface as a result of ageing which were thought to contribute to failure of the interfacial region in monotonic crack propagation tests on an overaged Al-Zn-Mg-Cu alloy.

Since the same trend in FCG behaviour as a function of ageing is observed in both composites it is probable that the same mechanism observed above is also operating in the 3µm composite. The presence of a reinforcement particle in the damage zone ahead of a fatigue crack tip results in load transfer to the particle and a large stress gradient across the interface (Davidson (11)). The Al/SiC interfacial strength was estimated by Flom and Arsenault (12) and reported to be approximately equivalent to the strength of the reinforcement particles. Since the mechanism of crack advance observed in this work is the failure of the matrix adjacent to the interface it seems reasonable to assume the presence of brittle or void nucleating precipitates in this region would increase the rate of crack advance.

The effect of particle size in the low growth rate regime of the FCG curve (Figure 3) could be a result of increased roughness induced closure (2) or the reduced slip band length in the 3µm composite (1). The FCG behaviour in the Paris regime requires explanation, however, since such behaviour has not been observed before. Two major effects of particle size will be:

i) a larger ceramic particle will have a lower strength and therefore be more prone to fracture as observed by Flom and Arsenault (13), and

ii) in the composite with the coarser distribution of SiC there will be less grain boundary area and less Al/SiC area (7) and this may affect the extent of the effect of local intefacial weakening.

The experimental observations show that particle fracture occurs in the 23μm composite and it might be expected that this brittle mode of failure would increase the FCG rate. However, since the area fraction of fractured SiC on the fracture surface is less than the average volume fraction it is proposed that the fracture of carbides only occurs if they are particularly weak or in a favourable orientation. This does not imply the fatigue crack is not attracted to reinforcement,however, but simply that failure of the matrix adjacent to the interface will occur unless the particle is sufficiently weak to make fracture an easier process. The experimental observations of fatigue behaviour in the Paris regime can only be explained if the two effects of increased particle size listed above cause insignificant changes in the rate of FCG or if the two factors cancel each other out.

The final fracture of the composites in the peak aged condition occurred by ductile failure of the matrix with extensive particle cracking in the 23μm material (Figures 7 and 8). It is generally reported that microvoid nucleation is the critical step in the fracture of particulate composites (7,13). The effect of particle size on plane strain fracture toughness as measured here is in line with a deformation mechanism proposed by Humphreys (7). The increase in particle size from 3 to 23μm results in an increase in interparticle spacing and therefore the plastic relaxation of dislocation build up at the reinforcement is easier. The critical strain for void nucleation is likely to occur at a higher stress in the 23μm composite in line with the fracture toughness value of 16 MPa√m compared to 11MPa√m in the 3μm material in the peak aged condition.

SUMMARY

The rate of FCG in 8090 reinforced with 20wt% SiC is a function of particle size and matrix ageing condition . The effect of ageing on the fatigue performance of both composites appears to be related to precipitation at the Al/SiC interface. The next step in this investigation will be to characterise precipitation at the interface as a function of particle size and ageing time.

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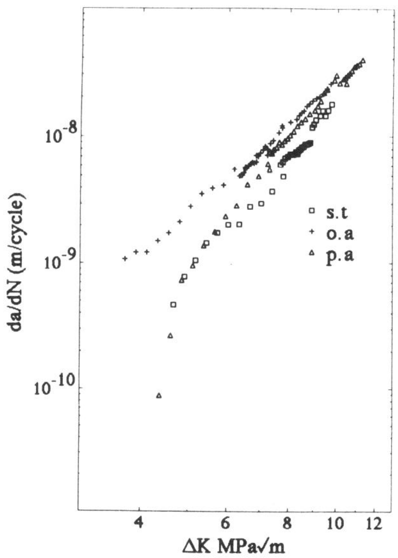

Fig. 1 da/dN vs ΔK as a function of ageing for the 3μm composite

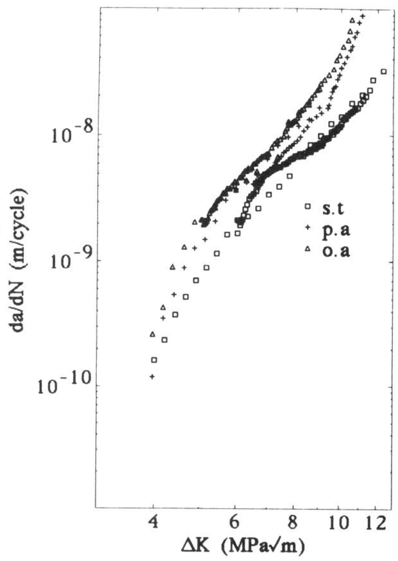

Fig. 2 da/dN vs ΔK as a function of ageing for the 23μm composite

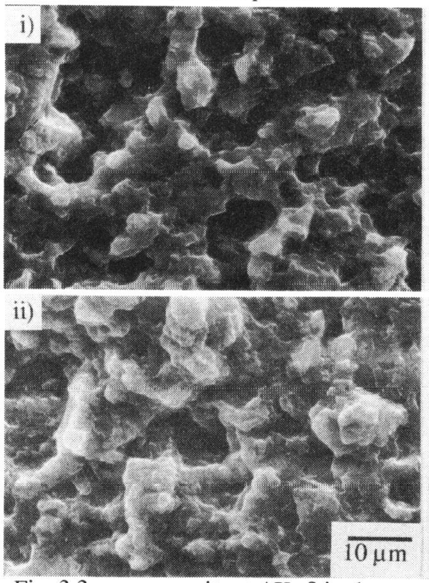

Fig. 3 3μm composite at ΔK=8 in the i) solution treated, ii) overaged condition

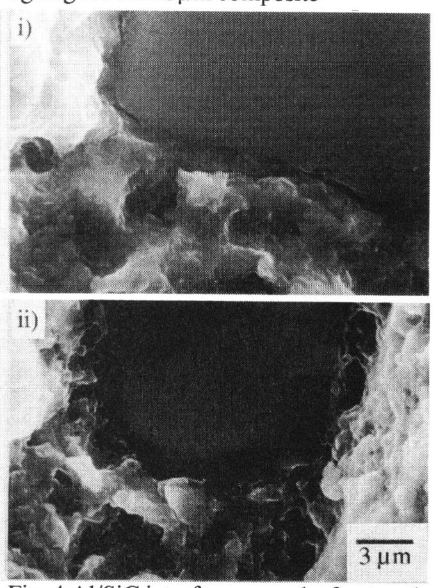

Fig. 4 Al/SiC interface around a fractured particle, i) solution treated, ii) overaged

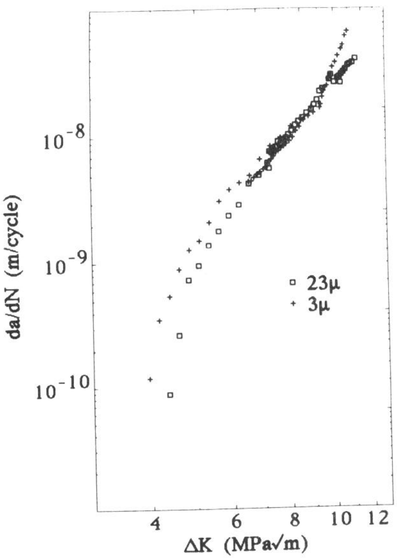

Fig. 5 da/dN vs ΔK for the 3 and 23μm composites in the peakaged condition

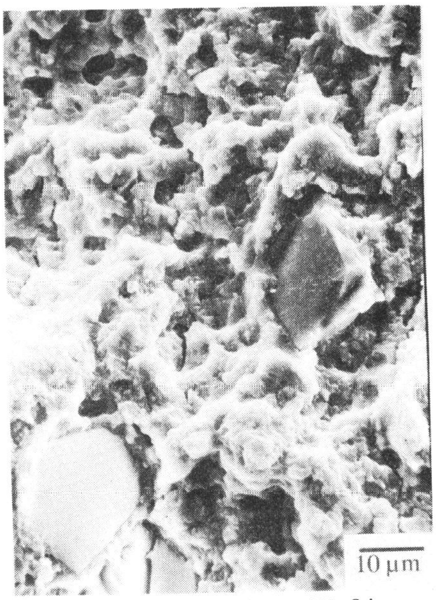

Fig. 6 23μm comoposite at ΔK=8 in peakaged condition

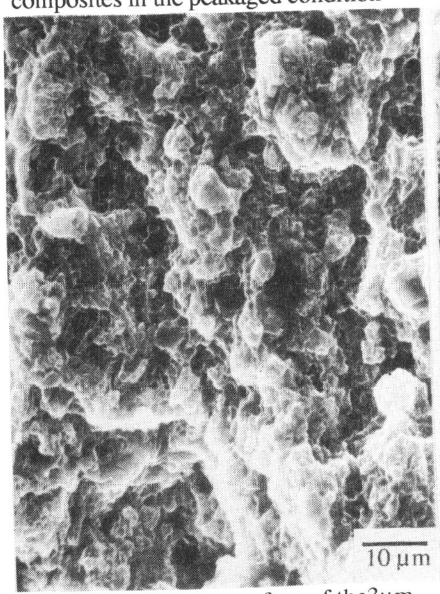

Fig. 7 Final fracture surface of the3μm composite in the peakaged condition

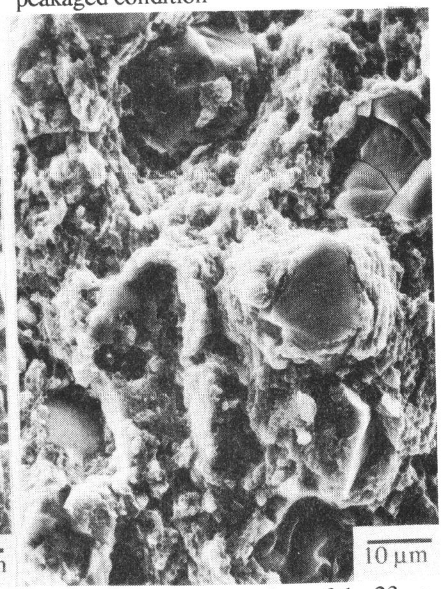

Fig. 8 Final fracture surface of the 23μm in the peakaged condition