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FATIGUE BEHAVIOR OF SILICON CARBIDE WHISKER / ALUMINUM COMPOSITE

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Specimens of an extruded 19.8 vol % SiCw/2124 aluminum alloy composite were subjected to constant amplitude loading of stress ratio 0.1 at room temperature in a laboratory atmosphere. The fatigue crack growth path is tortuous and much of it is nearly parallel to the extrusion direction of the specimen. This is attributable to the SiCw aligned in the extrusion direction. The logarithm of fatigue fracture life, N_f, increases linearly with decreasing stress range, $\Delta\sigma$, within the limits of the applied stress range. The relationship is defined by the equation: $\log N_f = 8.81 - \frac{\Delta\sigma}{1157}$. The observed fractographic features are facets and steps in the initial stage, striations in the subsequent stage, and dimples in the final stage of fatigue.					
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EXPERIMENTAL PROCEDURE

The experimental procedure includes Material and Specimen Preparation, Tension and Fatigue Testing, and Microstructural and Fractographic Examination.

MATERIAL AND SPECIMEN PREPARATION

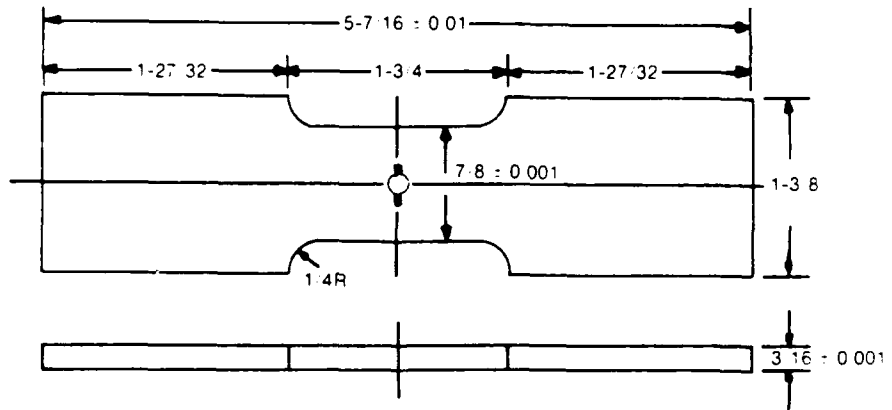
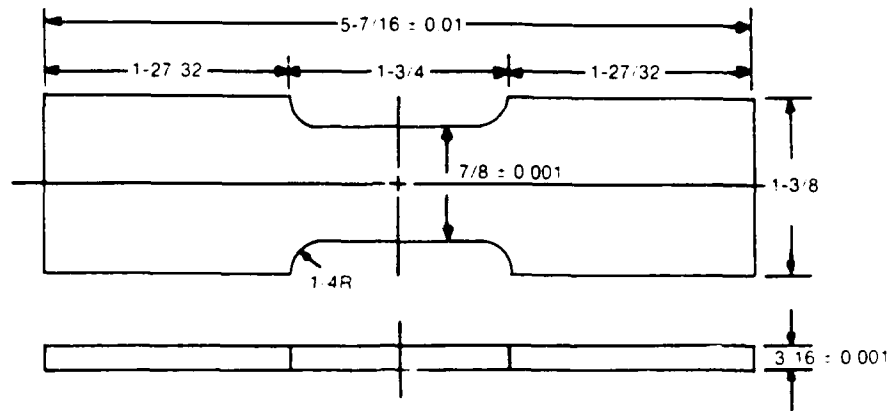
The specimen material was a silicon carbide whisker reinforced aluminum matrix composite, designated SXA24E/20W-T8E510 (19.8 vol % SiCw/Al-3.7 Cu-1.4 Mg), fabricated by Advanced Composite Materials Corp., Greer, SC. This material was initially double extruded from a 12 in. dia. billet to a 4 in. dia. rod, machined to a 3 in. dia. billet, extruded to 0.25 in. x 1.5 in. bar, stretched after solution annealing and cold water quenching, and aged for 10 hours at 320°F. From this material, rectangular tension test and center-cracked-tension specimens were machined, as shown in Figure 1

TENSION AND FATIGUE TESTS

The tension and fatigue tests were conducted at room temperature in a laboratory atmosphere using a closed-loop electro-hydraulic MTS machine. During the tension test, the loading rate was 5,200 lb/min. The fatigue test conditions were stress ratio ($\sigma_{\min}/\sigma_{\max}$) of 0.1, constant amplitude loading of a haversine waveform, and a frequency of 10 Hz.

MICROSTRUCTURAL AND FRACTOGRAPHIC EXAMINATION

The specimen planes, perpendicular and parallel to the extrusion direction, were polished, etched by Keller's reagent, and examined in an Advanced Metals Research 1000 scanning electron microscope, operated at an accelerating voltage of 20 kV. The fractographic examination of tension-fractured and fatigue-fractured specimens was also carried out using the same scanning electron microscope.



Geometry of Center Notch



Dimensions in Inch

Figure 1. Specimens
 (a) Rectangular Tension Test Specimen
 (b) Center-Cracked-Tension Specimen for Fatigue Test

RESULTS AND DISCUSSION

The results and discussion are divided into five parts: Microstructure, Tensile Strength, Crack Growth Path, Fractography, and Fatigue Fracture Life.

MICROSTRUCTURE

The scanning electron micrographs of the specimen planes, perpendicular and parallel to the extrusion direction, are shown in Figures 2 (a) and (b), respectively. In the plane perpendicular to the extrusion direction, shown in Figure 2 (a), many white dots which are the transverse section images of SiC whiskers can be seen. In the specimen plane parallel to the extrusion direction, shown in Figure 2 (b), many white rods which are the longitudinal images of SiC whiskers are observed. Such a micrographic feature indicates that the SiC whiskers are aligned in the extrusion direction. From the micrographs, the size of the SiC whisker is measured to be between 0.1 and 1 μm dia. and 1.5 to 11 μm long. The short SiC whiskers are attributable to possible breakage during the composite fabrication process of blending, consolidation, and extrusion.

TENSILE STRENGTH

The determined ultimate tensile strength and 0.2% offset yield strength of the specimen material of LT orientation are 87.8 ksi and 83.5 ksi, respectively.

CRACK GROWTH PATH

In the tension test specimen, the crack growth path is transverse to the loading (or extrusion) direction. No significant deflection in crack growth path is noticeable, as shown in Figure 3.

In the center-cracked-tension specimen for fatigue testing, two fatigue cracks emanate initially from the two opposite tips of the center notch, shown in Figure 4. Subsequently, without appreciable growth, these cracks deflect about 100° in opposite directions and grow towards the opposite ends of the specimen, respectively. As a result, the two crack paths are parallel to each other and inclined about 10° to the longitudinal (or loading) direction. In the final overload fracture stage, the two cracks deflect transversely towards the opposite edges of the width-reduction-portion. Such a tortuous fatigue crack growth path is not changed by reducing the specimen thickness from 3/16 in. to 1/16 in. The tortuousness of the fatigue crack growth path is attributed to the alignment of SiC whiskers in the extrusion direction.

A somewhat similar deflection of the fatigue crack growth path is also observable in specimens with straight or semi-circular single edge notches, shown in Figure 5 (a) and (b).

FRACTOGRAPHY

The fractographs of a tension tested specimen are shown in Figure 6. The transverse fracture surface is entirely covered by dimples. Some of the dimples contain SiC whiskers, debonded partly or mostly, indicating microvoid nucleation at SiC whiskers. Those whiskers are fractured transversely and do not have any longitudinal crack.

The fractographs of a fatigue fractured specimen are shown in Figure 7. In the immediate vicinity of the center notch tips, numerous white dots (transverse section images of SiC whiskers) and cavities of various sizes are seen in the matrix. The dimensions of their diameters are similar to those of SiC whiskers. It appears that these cavities have been formed by those SiC whiskers which were pulled out



(a)



(b)

Figure 2. Scanning Electron Micrographs
(a) Plane Perpendicular to Extrusion Direction
(b) Plane Parallel to Extrusion Direction

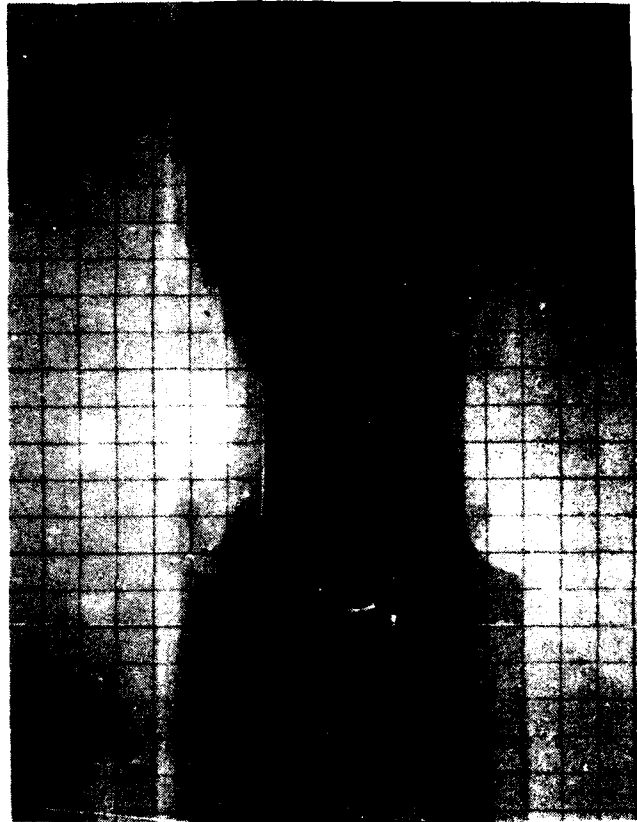
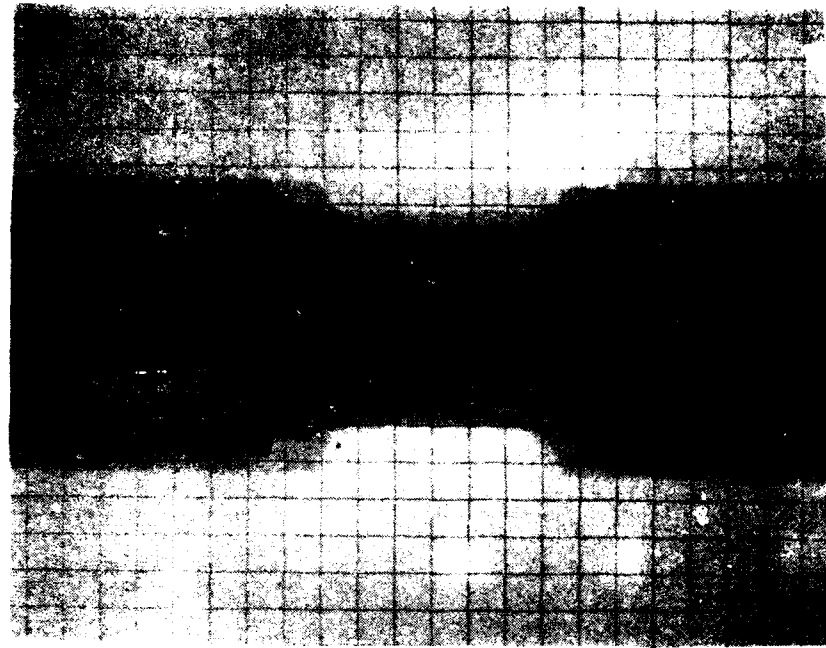
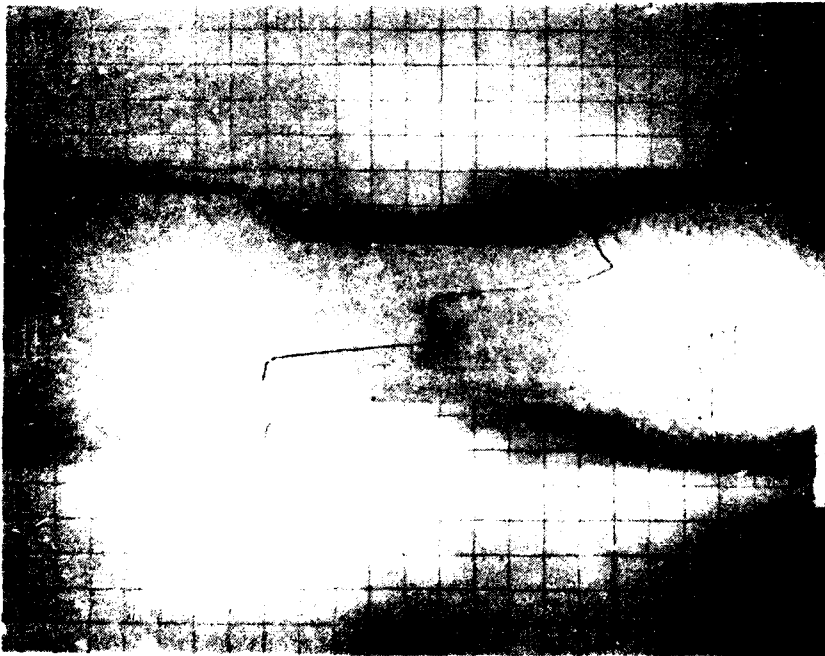


Figure 3. Crack Growth Path in Tension Test Specimen



(b)



(a)

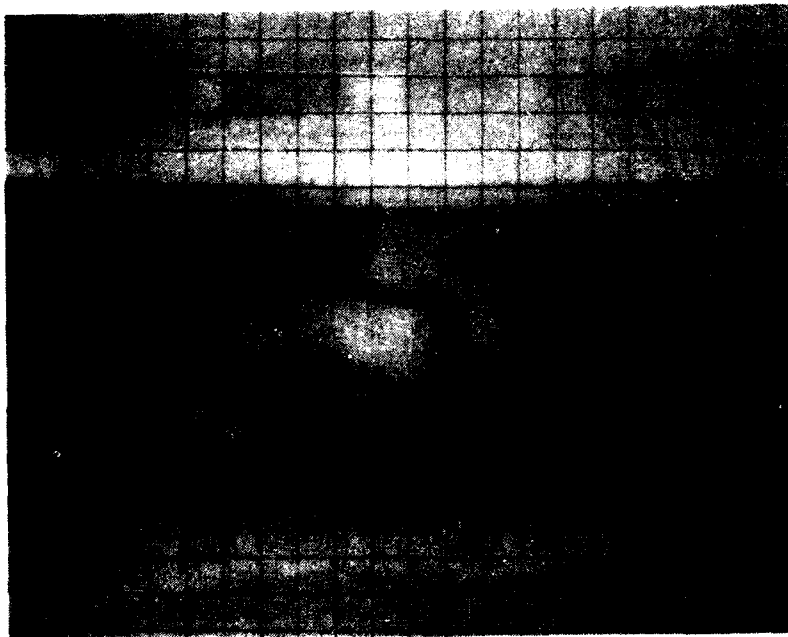
Figure 4. Fatigue Crack Growth Path in Center-Cracked-Tension Specimen

(a) Specimen Thickness: $3/16$ in.

(b) Specimen Thickness: $1/16$ in.



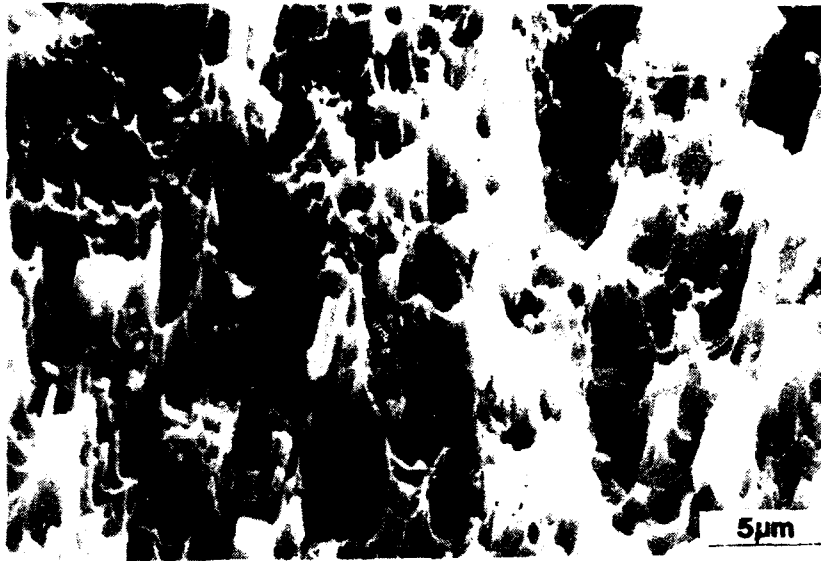
(b)



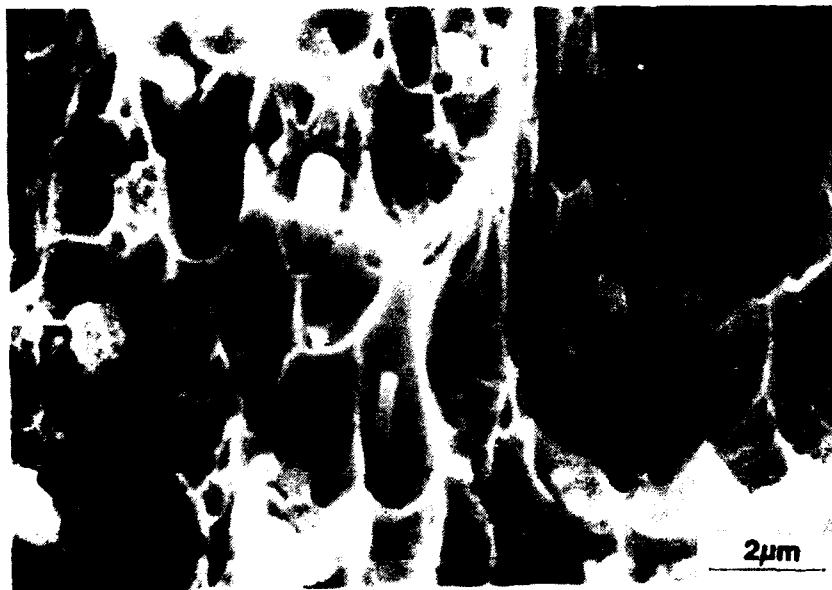
(a)

Figure 5. Fatigue Crack Growth Path in Single Edge Notch Specimen
(a) Straight Edge Notch Specimen
(b) Semi-Circular Edge Notch Specimen

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(a)



(b)

Figure 6. Fractographs of a Tension Tested Specimen



Figure 7. Fractographs of a Fatigue Fractured Specimen

during the cracking process. The matrix also shows facets and steps but no visible striation. After the deflection of the crack path to a nearly longitudinal direction, white rods (longitudinal images of SiC whiskers) and striations are visible in the matrix, indicating fatigue crack growth. Those SiC whiskers have smooth longitudinal surfaces with scattered debris-like-particles but no evidence of any cracking, Figure 8. Such a smooth longitudinal surface is probably due to debonding of the SiC whiskers during fatigue crack growth. Therefore, it is evident that the fatigue crack grows parallel to or along the longitudinal interfaces of the aligned SiC whiskers but not through them. As the crack grows further in the same direction, visible striations are fewer and fainter. Near the transverse deflection, the SiC whiskers are still seen as white rods, and dimples are present in the matrix, indicating overload fracture

From the observed features of the crack path and the fractograph, it is apparent that:

1. During slow crack growth under fatigue loading, most of the crack path is nearly parallel to or along the longitudinal interfaces of the aligned SiC whiskers. The corresponding fractographic features are facets, steps, and striations. In this period, the maximum stress intensity factor K_{max} is less than the critical stress intensity factor of the material K_C , i.e. $K_{max} < K_C$. Accordingly for $K_{max} < K_C$, the crack grows in a direction nearly parallel to or along the longitudinal interface of the aligned SiC whiskers.
2. During the tensile fracture or the overload fracture following the slow fatigue crack growth, the crack path is transverse to the aligned SiC whiskers. The corresponding fractographic features are dimples, some of which are nucleated at SiC whiskers. In this region, $K_{max} \geq K_C$. Accordingly, for $K_{max} \geq K_C$, the crack cuts through the aligned SiC whiskers transversely.

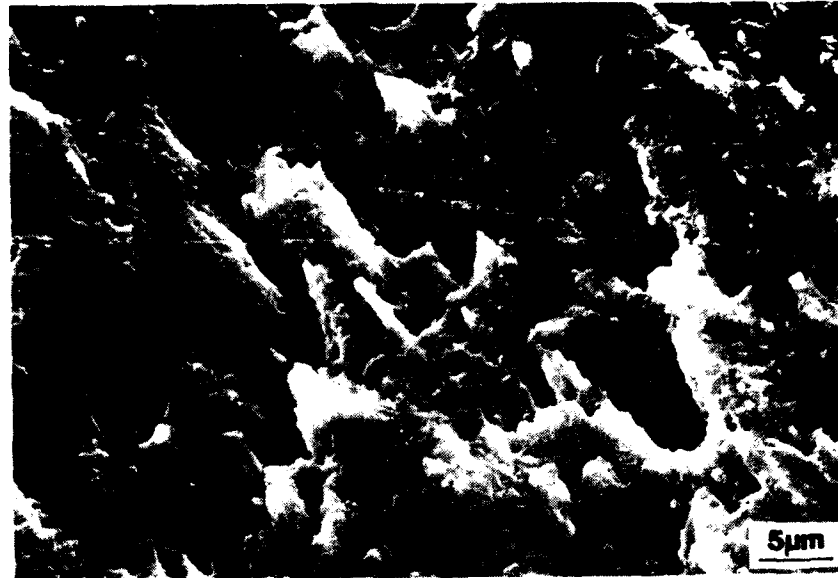
FATIGUE FRACTURE LIFE

Due to the tortuousness of the fatigue crack growth path, it was not possible to measure the increasing crack size and define its growth rate. Consequently, only the fatigue fracture life was determined and its relationship with the applied stress range was established. A plot of stress range versus logarithm of fatigue fracture life is shown in Figure 9. The plot is a straight line and is defined by the question:

$$\Delta\sigma = 10190 - 1157 \cdot \log N_f \quad (1)$$

$$\text{or } \log N_f = 8.81 - \frac{\Delta\sigma}{1157} \quad (2)$$

where $\Delta\sigma$: stress range (psi)
 N_f : fatigue fracture life (cycle)



(a)



(b)

Figure 8. Morphology of a Fatigue Crack Growth Area

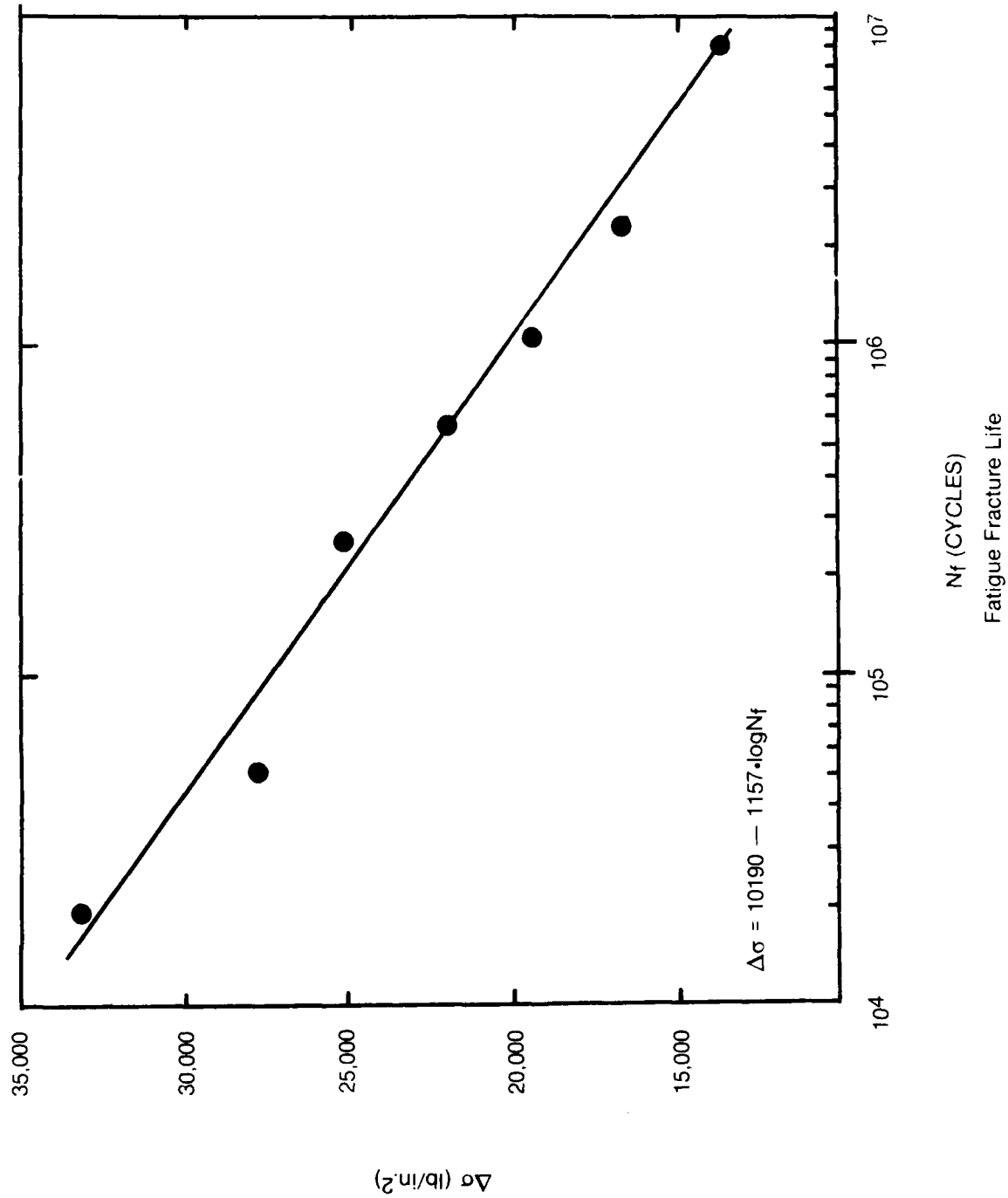


Figure 9. Variation of Fatigue Fracture Life with Stress Range

CONCLUSIONS

1. The SiC whiskers in the extruded 19.8 vol. % SiCw/2124 aluminum alloy composite are aligned in the extrusion direction.
2. During slow fatigue crack growth under the loading condition of $K_{\max} < K_C$, the crack growth path is nearly parallel to or along the longitudinal interface of the aligned SiC whiskers. In this stage, fatigue striations are developed on a nearly longitudinal matrix crack plane.
3. During the tensile fracture or the overload fracture following slow fatigue crack growth under the loading condition of $K_{\max} \geq K_C$, the crack growth path is transverse to the aligned SiC whiskers. In this stage, dimples are formed in the matrix.
4. The logarithm of fatigue fracture life, N_f , increases linearly with decreasing stress range, $\Delta\sigma$. This relationship is defined by the equation:

$$\log N_f = 8.81 - \frac{\Delta\sigma}{1157}$$

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