Fracture Mechanics under Combined Loading Modes of an Aluminium Matrix - Boron Fiber Composite.

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INTRODUCTION

The applicability of fracture mechanics expressions to composites containing a low yield strength ductile metal matrix must contend with possible complications due to gross yielding and internal interface failures. In the present paper, we describe the experimental aspects of the fracture behaviour of boron reinforced pure aluminium subjected to pure and combined tension/torsion loadings (nominally modes I and III). The variables studied included the effects of notch length and combined loading path dependency.

EXPERIMENTAL

Unidirectionally aligned fiber composite plates of V_f 0,3 were prepared by vacuum hot pressing layups of alternate layers of boron fiber (100μm diameter) and aluminium foil (99,4%). Pressing conditions varied slightly to produce two series of specimens with different shear moduli G_{12} (see Table).

Composite	Series	T(°C)	P(hbar)	t(h)	G_{12} (hbar)
B-Al	170	~560	2,5-3	1	4200 ±200
V_f 0,3					
13 layers	240	~550	2,5-3	1	3000 ±200

Blanks 8mm wide x 60mm long were cut from 1.9mm thick plates with a diamond cutting wheel.

By EDM techniques, double edge notched DEN specimens Fig.1 were prepared with an as-cut notch root radius of 15-20 μm ; additional fatigue cracking proved unsuccessful. Mechanical testing was performed on an Instron machine and a combined tension-torsion machine. Load-deformation and load-torque plots were obtained with the aid of strain gage extensometers and an X-Y recorder.

RESULTS AND DISCUSSION

(i) Notch Sensitivity (Mode I)

For series 170, the effect of notch length/specimen width ratio 2a/w on the ultimate stress is shown in Fig.2. The normalized results reveal that the pure aluminium matrix composites are less notch sensitive than the alloy matrix composites (1). This is attributed to matrix ductility which, although an intrinsic property, was aided by matrix-matrix bond failure, Fig.3.

(ii) Effect of Notch Depth on K_c (Mode I)

Compliance calibrations for mode I loading were found to be irreproducible. Consequently, K_I was calculated from the usual width-corrected expression for DEN specimens (2). In the expression, the crack length utilized was that of the longer of the two original notch lengths. Although very little stable crack propagation was observed, as reported by others (1)(3), stability increased slightly with 2a/w. The results, Fig.4, reveal an apparent dependency of K_c on 2a/w. This has been reported for single edge notch B-Al(6061)(4) and center-notched BSiC-Al (6061)(1), but was found not to exist in a brittle resin matrix composite fractured parallel to the fibers (5). The observations (1)(3) of no K_c dependency on thickness over the range 0.7 - 2.5 mm for well bonded composites suggest that triaxial stresses within multilayer fiber arrays may be sufficient to provide plane strain conditions. For weak bonds, plane strain may be dependent more on the internal interface strengths.

The higher K_c values of the series 240 specimens was coupled with lower fibre-matrix and matrix-matrix bond strengths. This is consistent with the measured G_{12} values.

(iii) Combined Tension/Torsion Loading

Wu (6) has pointed out that meaningful combined loading fracture assessments must include a determination of the loading path dependency. The effect of 3 different loading paths was determined at four points or "windows" lying between the pure modes for the series 240 material. In each case, a similar path dependency was found, the form of which is shown in Fig.5. Audible "pings" attributed to fibre breaks were detected early in the tests.

K_I was determined analytically as above. For the parallel shear mode, the strain energy release rate G_{III} is given by

$$G_{III} = \frac{M^2}{bw}\left(\frac{\partial C}{\partial 2a/w}\right)_{2a_o}$$

were M is the moment and C the specimen compliance. The latter was determined from calibrations curves. Due to uncertainties in the conversion G_{III} to K_{III}, the results are reported here as a double normalized plot, Fig.6. The absolute values were G_{IIIC} pure = 0.55 x 10^{-2} daJ/cm^2 and K_{IC} = 49.2 hbar$\sqrt{mm}$.

Fractographic examination showed that crack propagation under pure shear mode loading had been influenced by mode I forces, Fig.7. In addition pure mode I failures displayed substantial fibre pullout and matrix-matrix bond failure, Fig.8. Consequently, mode II failure was inherent in these composites. For any one window, radial path fractures displayed the most pullout.

CONCLUSIONS : Considerable analytical work is needed to successfully describe the fracture behaviour of ductile matrix weakly bonded composites.

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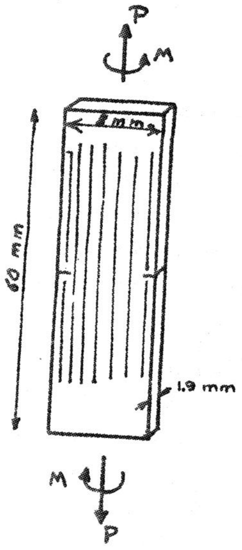

FIG. 1 Double edge notch specimens with axial fibers.

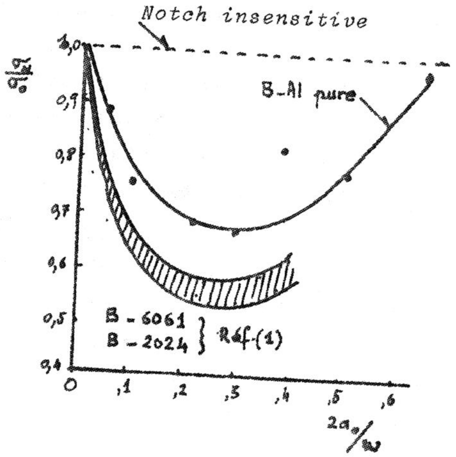

FIG. 2 Normalized net fracture stress as a function of 2a/w .

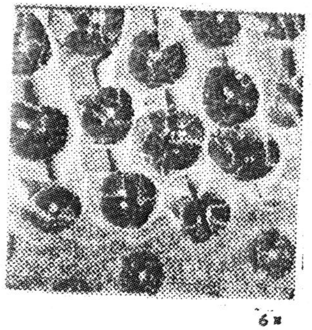

FIG. 3 Necked matrix and split fibers in conjunction with matrix - matrix bond failure.

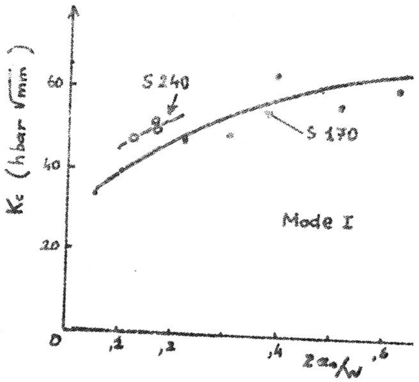

FIG. 4 K_c as a function of 2a/w for mode I failure.

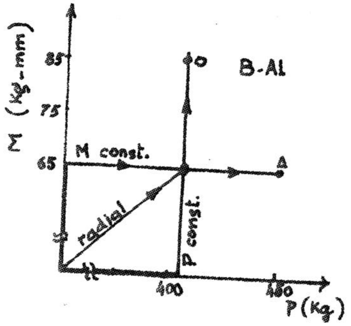

FIG. 5 Combined loading fracture "window" for different loading paths.

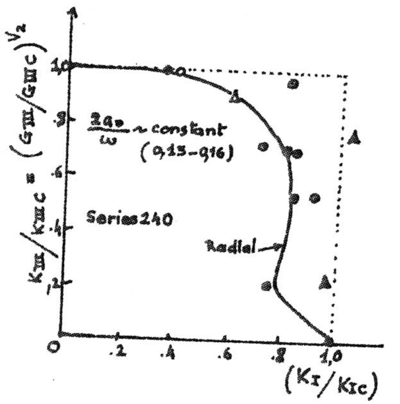

FIG. 6 Interaction between normalized stress intensity factors for modes I-III.

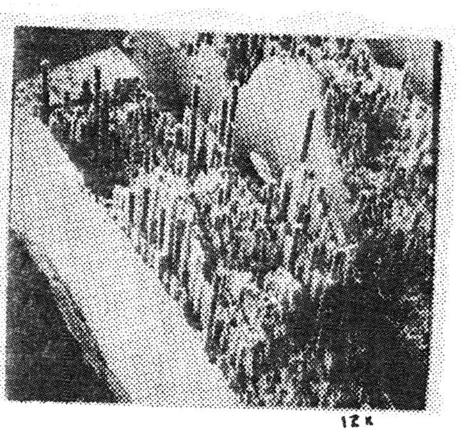

FIG. 7 Fracture surface of pure torsional loading failure.

FIG. 8 Fracture surface of pure tension loading failure.