Fracture Studies of Commercial Polycrystalline Aluminas

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INTRODUCTION

The primary object of this work was to obtain reliable values of K_{1c} for three commercial aluminas, as part of a larger programme aimed at understanding fracture initiation from inherent flaws in unnotched material.

CHARACTERISATION OF MATERIALS

The as-received aluminas had been isostatically cold-pressed and then fired on commercial schedules. In previous experiments, the physical properties were determined, and these are summarised in Table 1.

Alumina	Mean grain size, μm	Density Mg/m^3	Porosity Vol.%	Young's Modulus GN/m^2	Poisson's Ratio
A	3.5	3.66	11	336.8	0.232
B	5.0	3.31	19	226.8	0.221
C	12.0	3.43	21	253.3	0.252

EXPERIMENTAL

Crack Growing

Cracks were initiated in plates by impulsively loading pre-sawn notches using a hardened steel 28° wedge. The latter swung on a stiff pendulum arm, which was fixed to a shaft running in roller bearings. The starter cracks were arrested by a transverse compressive force applied by an engineer's clamp, which was modified for parallel holding. The crack tip position was revealed using methylene blue, a dye penetrant, and crack lengths were measured with a travelling microscope.

Cracks were mostly grown in side-grooved plates, but some ungrooved specimens were also made.

Specimen Geometries

The geometries used were:

(a) single edge-cracked bending
(b) compact tension, and
(c) double cantilever beam cleavage

Type (a) specimens were obtained from ungrooved cracked plates by diamond sawing(1). The span:depth (S:W) ratio was 6 on a span of 1.8 cm, and the specimen breadth was nominally equal to the crack length(2). Type (b) specimens were 2.5 cm square, with a thickness one-quarter of the width. Type (c) specimens were 2 cm high by 5 cm long, and the thickness:width ratio was again 0.25. In all the grooved plates, the groove depth was one-quarter of the plate thickness. In type (b) and (c) specimens, loading holes 0.475 cm diameter were drilled symmetrically about the crack-line using a diamond core drill.

Fracture Toughness Tests

For room temperature tests in air, type (a) and (b) specimens were fractured with crack lengths in the range $0.1 \leqslant a/W \leqslant 0.6$. For type (c) specimens, the relative crack length is expressed in terms of the cantilever arm height, t, and for these, toughness tests were conducted in the range $1.5 \leqslant a/t \leqslant 4$ (3).

The fracture toughness was also measured in water at temperatures up to the boiling point, in silicone oil up to 220°C, and in air to 450°C.

Microstructural Observations

Optical micrographs were obtained from relief-polished surfaces of the aluminas. A thin tensile specimen, intended for in-situ fracturing in the transmission electron microscope, was made using the ion-beam machining technique. Micrographs were obtained at 800 kV as the specimen was pulled to fracture in an AEI EM7 microscope.

RESULTS

Toughness Test in Air at Room Temperature

The values of K_Q for the bending and the compact tension configurations were calculated using the compliance calibration factors given in reference(4), and the standard expressions for K. The equation used for computing K values from double cantilever beam (DCB) results was:

$$K_I = \frac{Pa}{Wt^{3/2}} \left(3.467 + 2.135 \frac{t}{a}\right) \qquad \dots (1)$$

where P is the crack extension load and W is the thickness of the plate(3). To obtain K_I from a side-grooved plate result, the right hand side of equation (1) was multiplied by a factor $\frac{b}{W}$, where b was the fracture web width(5).

Fig. 1 demonstrates that the bend test method did not produce a valid K_{1c} result for this material. However, the compact tension and DCB tests did (Figs. 2 and 3 respectively), even though the K_{1c} values were not coincident.

Environmental K_{1c} Results

These are summarised in Fig. 4, and it is evident that water induces a drastic reduction in K_{1c}, whilst the value in oil is very similar to the air result. The oil and air values show a similar temperature dependence.

Microstructural Observations

Optical micrographs revealed a glassy phase in each alumina, existing mostly at the grain boundaries.

The transmission microscope experiments produced no positive evidence of dislocation motion at the crack tip, even in the minor phase grains.

DISCUSSION

The inability of the single edge-cracked bend specimen to provide a valid K_{1c} result for alumina is probably due in part to differences in crack length across the width of the beam. This is particllarly serious at low a/W values, where the proportional error in crack length will be large ($\simeq$10%). Since G increases rapidly at these small a/W values, a beam containing such a misaligned crack can have very different G values across its breadth.

The 5% discrepancy between the two sets of valid K_{1c} results is attributable to the large compliance of a DCB specimen. A marked deviation from linearity on the load:deflection record was always detectable prior to the onset of rapid crack propagation, and this is taken to be clear evidence of slow growth. The stiffer compact tension test showed no such feature. On the microstructural scale, the slow growth could be due to a stress corrosion mechanism, due to chemisorption of atmospheric water at the crack tip. The effect is well known in glass and sapphire$^{(6)}$.

Finally, the absence of evidence for dislocation motion at a propagating crack tip leaves open the problem of why polyphase aluminas, such as A, B and C have a somewhat higher K_{1c} (20 → 30%) than pure material of the equivalent grain-size.

The conclusions at present are based upon only two in-situ fracture tests, so more experimental work is required.

ACKNOWLEDGEMENTS

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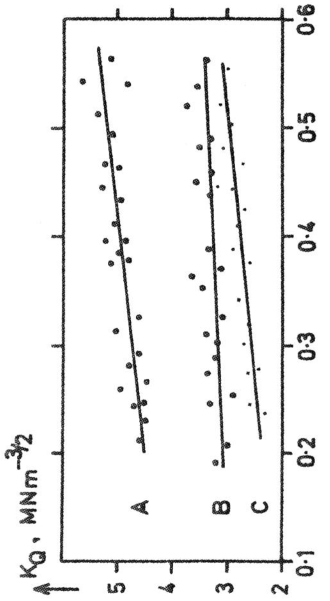

Fig.1 K_Q: a/W for three-point bend

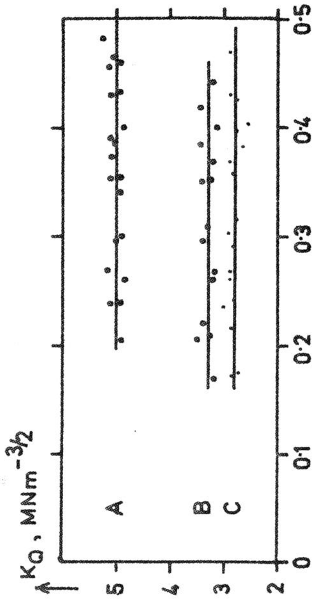

Fig. 2 K_Q: a/W for compact tension

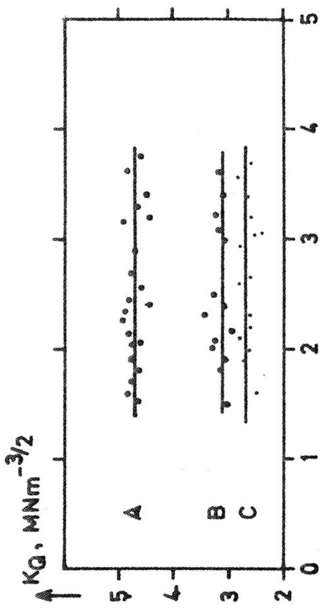

Fig.3 K_Q: a/t for DCB

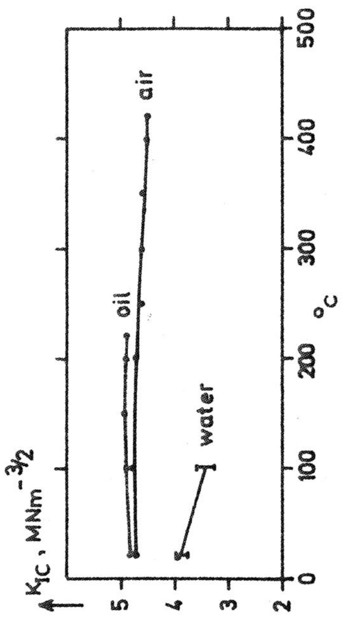

Fig. 4 K_{IC}: Temperature for alumina A in air, Silicone oil, and water