Surface energy measurements from Griffith cracks in boron fibres

In a previous report [1], fracture of boron fibres, nucleated at so-called proximate voids, was studied experimentally and compared to Griffith's law for brittle fracture

$$\sigma_f = \left(\frac{4E\gamma}{\pi 2c}\right)^{1/2}, \tag{1}$$

σ_f is the measured fracture stress, E the experimental Young's modulus, γ is the surface energy and $2c$ is the measured major axis of the proximae void acting as a Griffith crack.

A logarithmic plot of experimentally obtained $2c - \sigma_f$ points approximately followed the straight line

$$\ln 2c = q - 2 \ln \sigma_f \tag{2}$$

From Equation 1 the material characteristic constant q is obtained as

$$q = \ln\left(\frac{4E\gamma}{\pi}\right). \tag{3}$$

q can be numerically estimated from the experimental $2c - \sigma_f$ plot, which yields the experimental surface energy

$$\gamma = \frac{\pi}{4E} \cdot e^q \tag{4}$$

The active parts of the proximate voids can in principle be approximated by ellipsoids, transverse sections of which are revealed in SEM micrographs of fracture surfaces (see Fig. 1). The transverse cross-section ellipse has major and minor axes $2C$ and $2c$ respectively as demonstrated in Figs. 1 and 2. Under the influence of an axial tensile stress, however, the axial cross-section ellipse (dashed in Fig. 2) represents the Griffith geometry and has the major axis $2c$ equal to the minor axis of the transverse cross-section ellipse (Fig. 1). These particular crack nucleation conditions are typical of the fibre geometry only, and unlike the situation in a plate or slab. In the previous work [1], the quantity $2C$ was (erroneously) applied in Equation 2, yielding an overestimated γ value. A new series of measurements of $2c$ has, however, now been performed, on an extended experimental sampling. The obtained $\ln 2c - \ln \sigma_f$ plot is reproduced in Fig. 3. The full line represent a least square adjustment to the experimental points of a line, the equation of which is

$$\ln 2c = 8.4 - 2.1 \ln \sigma_f. \tag{5}$$

The two dashed lines are drawn so as to include all the points and with the exact Griffith direction coefficient -2. As can be seen, the agreement with Griffith's law is good. From the two dashed lines the surface energy interval (in $\mathrm{J\,m^{-2}}$)

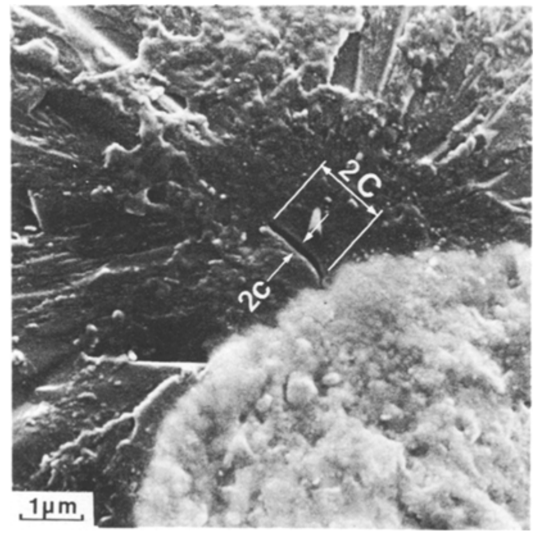

Figure 1 20 kV SEM micrograph of proximate void initiated fracture, indicating the major ($2C$) and minor ($2c$) axes of the transverse cross-section ellipse.

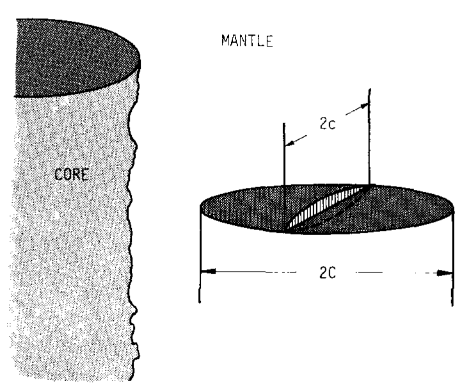

Figure 2 Schematic representation showing the transverse (shadowed) and axial (dashed) cross-section ellipses, characteristic of a proximate void. The transverse cross-section ellipse has major and minor axes $2C$ and $2c$ respectively.

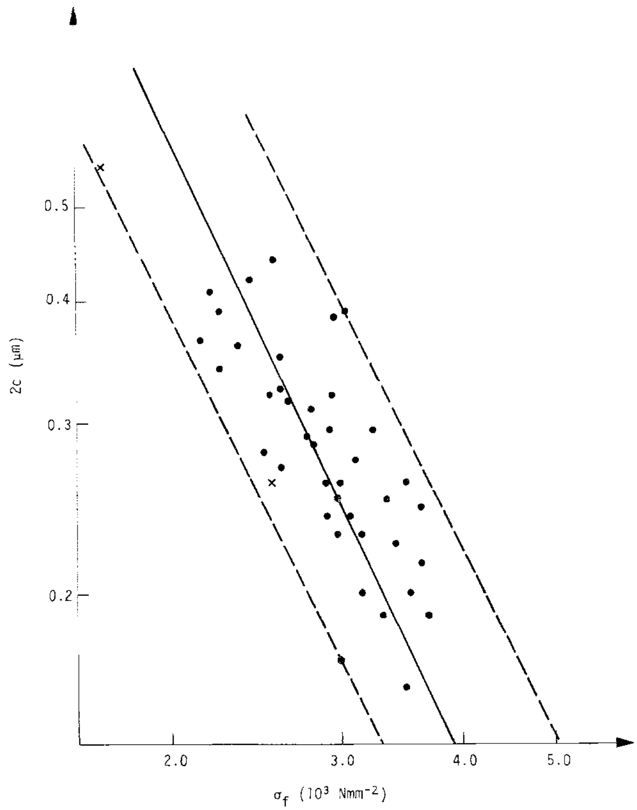

Figure 3 Logarithmic plot of experimental $2c - \sigma_f$ points. The full line represents a linear least-square fitting. The dashed lines have the direction coefficient -2 and correspond to the extreme γ values. The values marked X correspond to Layden [5].

$$2.77 \leqslant \gamma \leqslant 6.43 \qquad (7)$$

is obtained. These values are of the same order of magnitude as the values for tungsten available in literature [2, 3]. The present method represents one of very few possibilities of measuring surface energies in brittle solids.

γ values, based on measurements of fractured fibres, sometimes appear high, compared to values obtained by bulk measurements [4]. A possible explanation is the systematic measurement error caused by the confusion between relevant major and minor axes reported here.

References

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