Fracture energy of plant fibres

Recent work by Jeronimidis [1] and Gordon and Jeronimidis [2] has demonstrated the way in which the work of fracture (γ_F) for timber achieves the exceptionally high value of around 10^4 J m^{-2}. In our experiments we have observed critical strain energy release rates, G_c, ($= 2\gamma_F$) of around 10^5 J m^{-2} for pre-notched plant fibres extracted from bow string hemp (*Sansevieria metallica*). This present work is, as far as we are aware, the first reported attempt to follow a compliance calibration method [3] for the estimation of critical strain energy release rates in individual plant fibres.

The fibres, which lie parallel to the major axis of the leaf, were carefully extracted by hand and then deformed in tension using a specially designed microtensometer [4]. Only fibres having diameters of 74 ± 2 μm and lengths of 22 ± 2 mm were used in this experiment. Prior to straining, small notches perpendicular to the fibre axis were carefully introduced using a sharp razor blade. The depth of these notches was estimated by viewing the notched fibres in an Olympus Optical transmission microscope. All tests were carried out at ambient conditions (28° C and 70% r.h., approximately).

These fibres deform in a linear elastic manner throughout straining. By examination of the load–deflection record for each fibre it was possible to measure the elastic complicance (extension per unit force) at various notch depths for these otherwise geometrically similar fibres. The results are illustrated in Fig. 1. Superimposed upon the datum points is the compliance calibration curve which was obtained by fitting a second degree polynomial to the results. The equation for this curve was found to be:

$$C = 0.170 + 1.26 \times 10^3\, a + 2.46 \times 10^7\, a^2 \quad (\mathrm{m\,kN^{-1}}). \qquad (1)$$

In this expression C equals compliance and a equals notch depth. Some of the fibres were pulled to failure and values for the critical strain energy release rates, G_c, were calculated according to the well-known equation [3]:

$$G_c = \frac{P^2}{2b}\left(\frac{\partial C}{\partial a}\right)_{a=a^*}. \qquad (2)$$

In this expression C equals compliance and a equals release rate, P is failure load, b is taken as the fibre diameter, and $\partial C/\partial a$ is evaluated from Equation 1 using the particular value of notch depth, a^*, in that specimen. Values of G_c calculated from the failure loads of specimens having notch depths in the range 4 to 40 μm are shown in Fig. 2. The mean value for G_c is 1×10^5 J m^{-2} with a standard deviation of 0.4×10^5 J m^{-2}. The error bars shown on Figs. 1 and 2 were calculated by consideration of the errors involved in the measurement of fibre geometry (including notch depth) and in the measurement of loads applied to specimens.

Given the rather difficult nature of the experiment with regard to ensuring complete uniformity of the extraction, handling and geometry of the fibres, it is felt that the scatter represented in Fig. 2 is not excessive. It is likely that this scatter more

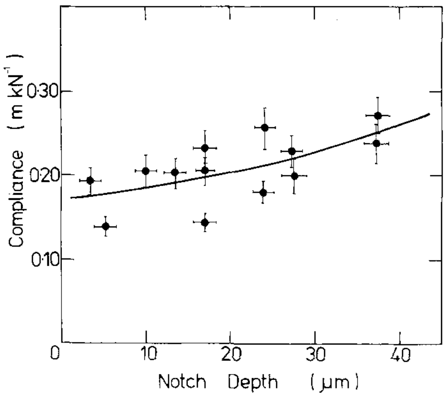

Figure 1 Elastic compliance, C, plotted against notch depth, a.

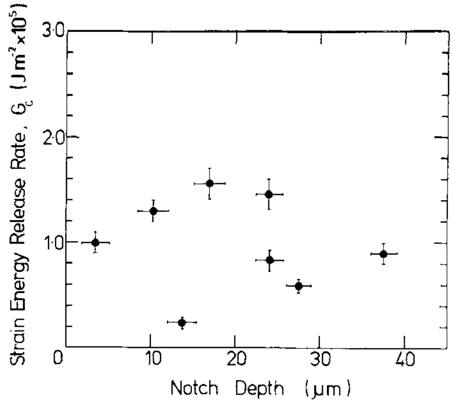

Figure 2 Strain energy release rate, G_c, plotted against notch depth, a.

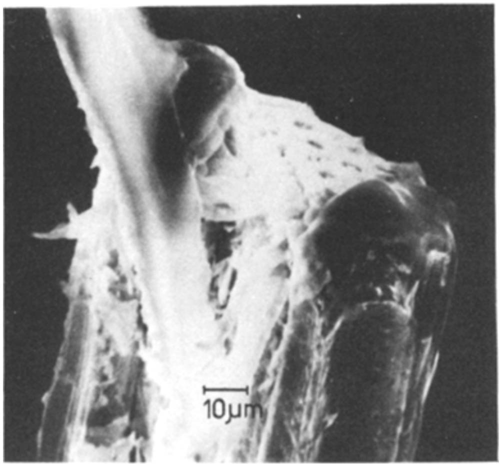

Figure 3 Fractured plant fibre showing cell delamination and cell wall buckling.

closely follows variations in the microstructure of individual fibres. We have observed that each fibre consists of a bundle of about 35 single cells, each cell being about 10 to 20 μm diameter. The cells are held together in the fibre by a mixture of lignin, cellulose and hemicellulose [5]. Page *et al.* [6] have shown that individual cellulose cells may be deformed in tension by as much as 20%, due to the "unconstrained" buckling of the cell walls into the lumen. Similar observations of cell wall buckling have been made by Jeronimidis [1]. This effect has been attributed to the way in which the cellulose microfibrils are wound in the cell walls in a predominantly helical manner [2]. Examination of the fracture surfaces (e.g. Fig. 3) of our notched fibres reveals that the cells undergo lateral separation ahead of the notch (under the action of tensile stresses in the plane of the notch [7]) such that they are then able to deform in the "unconstrained" manner, thus allowing large tensile strains to be achieved in the region of the notch tip. This behaviour is essentially similar to that described by Gordon and Jeronimidis [2] for the failure mechanism of pitchpipe (*Pseudotsuga taxifolia*).

Since the post-buckling deformation is non-elastic it therefore contributes significantly to the energy absorbed as the fracture propagates through the specimen. This energy-absorbing process presumably involves the separation of the helically wound microfibrils and ultimately failure of the microfibrils themselves. Clearly, the adoption of the helical arrangement of reinforcing microfibrils forms the basis of a complex mechanism for the achievement of such high strain energy release rates to obviate the possibility of catastrophic failure within the plant material. Such effects appear to be widespread in nature and would appear to offer great scope for application to synthetic materials.

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Effect of magnetic field on reduction of cobalt oxides

In 1972, Skorski [1] noted an increase in the reduction rate of haematite (Fe_2O_3) in a strong magnetic field at 180 and 300° C. Magnetic fields of 500 and 1400 G (emu g^{-1}) were used. Rowe *et al.* [2] reported on the reduction of the two intermediate iron oxides, magnetite (Fe_3O_4) and wüstite (FeO) to metallic iron at 385 and 490° C, respectively. The reduction of magnetite was shown to be enhanced under the influence of a strong magnetic field whereas that of wüstite was decreased.

Having become convinced that a strong magnetic field can have an appreciable effect on the reduction rate of metal oxides, we now turn our attention to the oxides of cobalt, another ferro-