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Microstructure of wood-fibre–plaster composites

R. S. P. COUTTS, J. V. WARD
CSIRO, Division of Chemical and Wood Technology, Private Bag 10, Clayton, 3168, Victoria, Australia

Gypsum plaster products are widely used in the Australian building industry; however, the cost of reinforcing these products with fibres of glass or sisal is increasing. New plaster products using wood-pulp fibres as the reinforcement have been described in earlier publications [1, 2]. Mechanical testing of these materials demonstrated that the samples possessed sufficient flexural strength (> 25 MPa) and fracture toughness ($> 3\,kJ\,m^{-2}$) at 10% (by mass) wood fibre so as to be very useful building products.

A study of the microstructure of fractured surfaces was undertaken to understand better the mechanisms taking place during load to failure. Earlier scanning electron microscopic (SEM) studies of wood fibre-reinforced cement systems [3, 4] had suggested that fibre fracture was important in generating fracture toughness energy; the belief [5] that fibre pull-out was the predominant micromechanism was thus challenged.

The wood fibres used in this study were from commercial *Pinus radiata* kraft lap pulp obtained from the N.Z. Forest Products Ltd, Kinleith Mill, New Zealand. The wood fibre-reinforced plaster (WFRP) composites were prepared by a slurry/vacuum dewatering technique described in an earlier publication [2]. Samples (of dimensions 125 mm × 40 mm) were tested in flexure (three-point bend test) at a loading rate of $0.5\,mm\,min^{-1}$ (sample thickness 6 mm, span 100 mm) on an Instron testing machine (Model 1114); fracture was completed by hand. Flexural strength and fracture toughness values were calculated as reported in an earlier study [2].

To enable close examination of individual fibres, samples containing low mass-fractions of the reinforcing fibre were studied. All fracture surfaces were coated with gold under vacuum and the fracture surfaces examined under a Cambridge S250 Mark III scanning electron microscope operating at either 5 or 10 kV.

The fracture surface of the matrix material is relatively even because of the brittle mode of failure of plaster (fracture toughness, $0.05\,kJ\,m^{-2}$ [2]) (see Fig. 1). At high magnification it can be seen that the matrix material is a reasonably porous substance made up of very crystalline material with relatively random alignment of the crystals (see Fig. 2) which leads to the high void volume.

When a relatively low level of wood fibre (2% by mass) is introduced into the matrix material, a composite is formed which has a ten-fold increase in the value of fracture toughness ($0.52\,kJ\,m^{-2}$ [2]). SEM studies of the WFRP fracture surface (see Fig. 3) show that it is very uneven, which suggests a much greater fracture surface energy was generated. At high magnification it can be seen (Fig. 4) that the fibres have been both fractured and pulled out of the matrix during loading to failure and considerable energy was thus consumed.

Investigations with wood fibre-reinforced cement systems had shown that composites containing 8 to 10% fibre (by mass) could generate fracture toughness values of excess of 20 times that of the matrix material [6]. This behaviour had been attributed to the fact that when the wood fibres fracture they do so in a unique manner. Wood fibres are hollow tubes composed of layers of cellulosic fibrils embedded in a matrix of hemicellulose and lignin [7]. Most of the cell wall material is contained in what is called the S_2 layer, the fibrils of which form a spiral wrap around the fibre. Page *et al.* [8] showed that when single wood cells were tested in tension, some of them showed a pseudo-

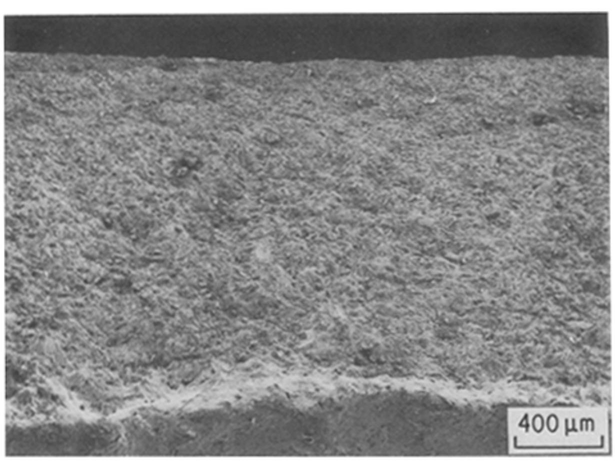

Figure 1 Even fracture surface observed for brittle matrix.

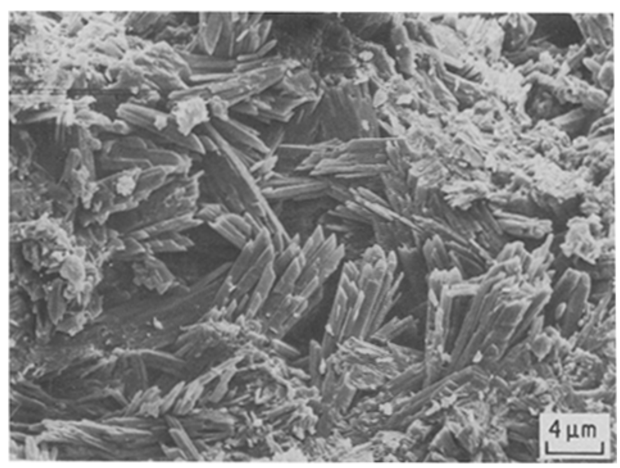

Figure 2 High magnification of fractured matrix showing disordered crystalline packing.

Figure 3 Uneven fracture surface of WFRP (4% fibre by mass), suggesting considerable increase in fracture energy.

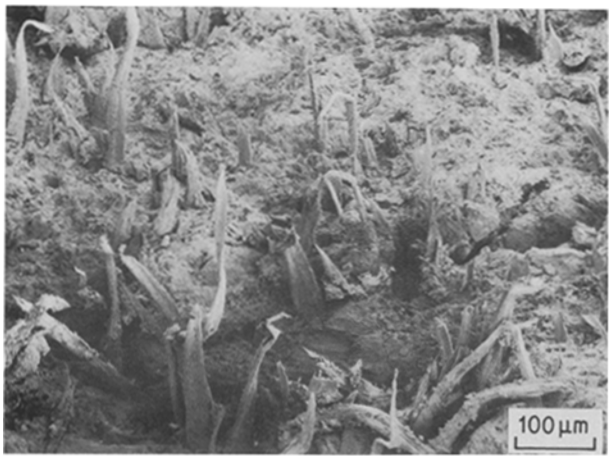

Figure 4 High magnification of WFRP fracture surface, showing fibres both fractured and pulled-out from the matrix.

plastic behaviour which curiously resembled that of a ductile metal. This behaviour was ascribed to "tension buckling". That is, the helically wound hollow fibre is elastically unstable, and when loaded in tension will collapse and elongate with a very large irrecoverable absorption of energy.

From the results obtained with single fibres one would expect that a composite reinforced with such fibres will have a high fracture energy, provided that the matrix does not restrict the buckling behaviour. Fig. 5 shows a number of fibres that have failed in tension by what seems to be a buckling of the fibre.

Figure 5 Fibres failed in tension with some showing "buckling".

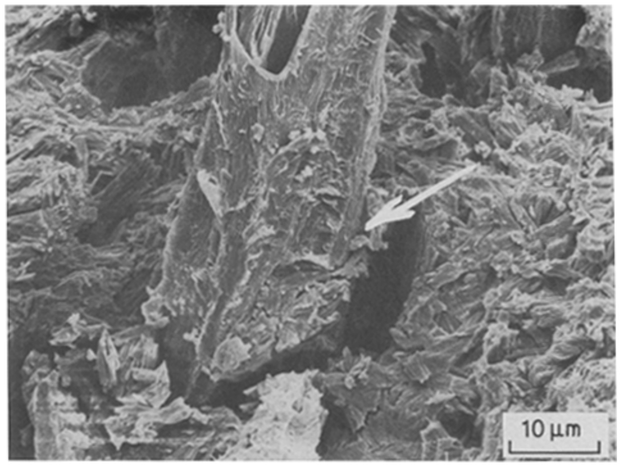

Figure 6 Matrix is shown (arrow) strongly bonded to lower part of a fibre broken in tension, with total removal of outer layer of fibre above fracture plane.

Because of the random orientation of the reinforcing fibres in the matrix; under any given load, fibres will experience shear, tensile or compressive forces. Thus, various micromechanics take place at the same time.

Fig. 6 shows a fibre that has failed under tensile load very close to the fracture surface of the specimen and was obviously well bonded to the matrix before being stressed. This fibre appears to retain an uncollapsed lumen (hollow centre of fibre). It can be seen that debonding between fibre and matrix has taken place (see arrow). The matrix material is attached to the fibre near the surface but above the place of fracture the fibre is free of matrix and has fractured by tensile failure.

The normal occurrence with WFRP materials, as observed under the SEM, is that the fibres are well coated with a layer of matrix material suggesting that the bond between wood fibre and plaster matrix is stronger than the bonds holding the crystalline material together within the matrix. Fig. 7 shows a coated fibre and at high magnification (Fig. 8) the small crystals can be seen attached to the fibre surface

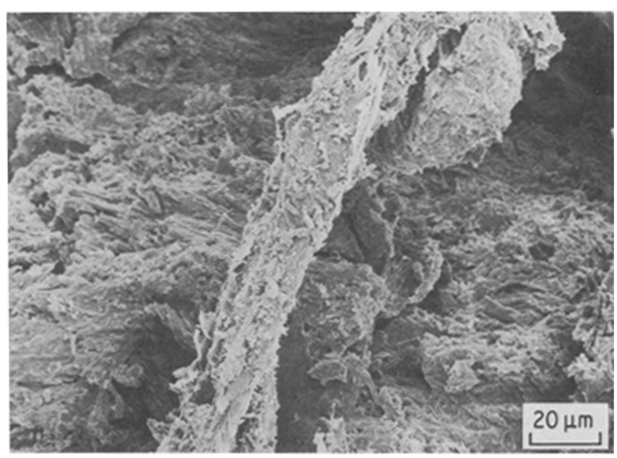

Figure 7 A fibre lifted from the surface of the fracture plane has considerable matrix attached.

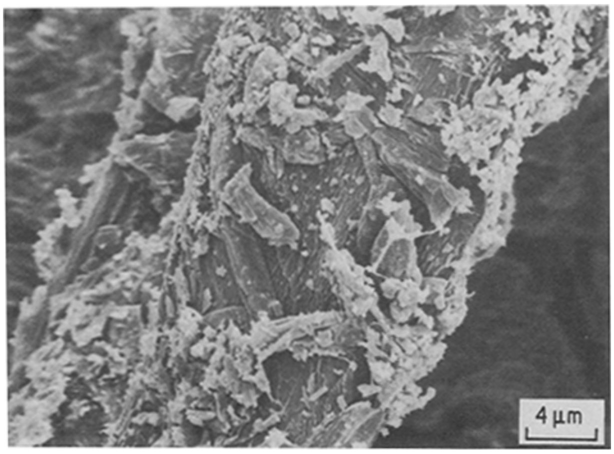

Figure 8 At high magnification crystals of matrix are shown strongly attached to fibre, suggesting fibre-to-matrix bonding is stronger than matrix to matrix bonding.

and interlocking with other crystals as they grow to form a coating on the fibre.

In conclusion, addition of wood fibre reinforcement (e.g. 10% by mass) can produce composites with flexural strength values greater than 27 MPa and fracture toughness values of 3.0 kJ m^{-2} [2]. Examination of the fracture surfaces of the WFRP composites shows that the reinforcing fibres can be stressed to failure, the main mechanisms taking place when the composite is tested in flexure being both fibre fracture and fibre pull-out. The fibres that do not fracture tend to be strongly coated with a layer of matrix material suggesting a strong interfacial bond between wood fibre and plaster – a stronger bond than that between the crystalline material making up the matrix.

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