A NOTE ON THE CELL-WALL STRUCTURE OF SOFTWOOD TRACHEIDS

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(Received 12 January 1976)

ABSTRACT

Molecules of hemicellulose in walls of softwood tracheids are birefringent and lie essentially parallel to cellulose molecules. These hemicelluloses perform a structural function in providing a link between cellulose and lignin, and consequently should be considered as "coupling agents" between them. Models of the softwood tracheid cell wall should recognize this structural role for hemicelluloses.

Additional keywords: Cell-wall models, cellulose, hemicellulose, lignin.

The cell wall of softwood tracheids is generally considered to consist of an array of crystalline cellulosic elementary fibrils, 35Å in diameter and of indefinite length, embedded in a matrix of hemicellulose and lignin. The detailed molecular disposition of this matrix is not known, in spite of its importance to wood and wood-pulp technology. Recently, useful insights into the mechanical properties of wood fibres (Cave 1968; Cowdrey and Preston 1966; Mark 1967; Page et al. 1972) have come from consideration of the analogy between the structure of the wood cell wall and that of a fibre-reinforced plastic composite. In this analogy the cellulosic fibrils play the role of the reinforcing fibres and the hemicellulose and lignin, the matrix. The purpose of this note is to point out that pursuit of this analogy can lead to a profitable speculation on the structure of the matrix.

A living tree withstands considerable stresses not only from its own growth but also from wind and gravity during its lifetime. Clearly the cell wall has a structure that is strong in its wet state. In contrast, fibre-reinforced composites, and particularly glass fibre-reinforced epoxy resins, exhibit poor strength retention when exposed for long periods to wet conditions (Sterman and Marsden 1968). Strength is lost because moisture migrates along the hydrophilic glass surfaces, reduces the glass-epoxy bond strength and facilitates crack growth. A technology has developed that overcomes this deficiency (Wong 1968). It uses a so-called "coupling agent," generally a short-chain molecule, one end of which is linked covalently to the glass fibre, the other to the matrix. It seems that, because of the hydrophilic nature of cellulose, the composite wood cell wall would also require a coupling agent to provide it with wet strength. It is suggested here that the hemicellulose plays this role.

It is proposed that the hemicellulose molecules are substantially parallel to the cellulosic fibrils and attached to them by hydrogen bonding and Van der Waals' forces. Since the homopolymers, xylan and mannan, of the common softwood hemicelluloses are known to crystallise, it is possible that the more complex native molecules of glucomannan and glucuronoxylan may cocrystallise at least for one molecular thickness onto the cellulosic fibrils. Such crystallised molecules would be expected to withstand stress in the wet state. The side chains, branches and chain ends, together with steric hindrances would clearly prevent perfect crystallisation so that portions of the hemicellulose molecules would extend into the matrix. There they would either be linked covalently to the lignin, or embedded in it and held by physical forces. A model of the proposed structure is shown in Fig. 1.

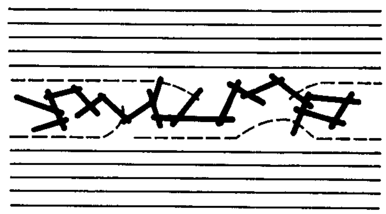

FIG. 1. Proposed model for the structure of the softwood tracheid cell wall.

The model finds support from several observations.

(a) There is evidence that the hemicellulose molecules are oriented parallel to the fibrils (Liang et al. 1960; Marchessault and Liang 1962; Preston 1964). This evidence has been strengthened by a recent finding that the hemicelluloses of softwood, *in situ*, have a birefringence equal to that of cellulose (Page et al. 1976), and must therefore be almost perfectly oriented.

(b) Although the question of a covalent link between hemicellulose and lignin is disputed, there is some evidence in its favour (Merewether 1960). However no modern authors have proposed a covalent link between cellulose and lignin.

(c) No plants exist that contain only lignin and cellulose, implying perhaps that lignification serves no purpose if hemicelluloses are absent.

(d) The proportion of cellulose to hemicellulose in wood generally agrees with a model in which the hemicelluloses form a single cocrystallised layer around the fibrils.

It is freely admitted that this model is not appreciably different from those proposed by several previous authors (Fengel 1970; Frey-Wyssling 1959; Marchessault 1964; Preston 1964). In particular, it is quite similar to the model of Albersheim (1975), who has shown, working with primary walls of sycamore cells, that the hemicellulose, xyloglucan, cocrystallises onto the cellulose and forms, with other hemicelluloses, a cross-linked structure between the fibrils. The concept developed here of the hemicellulose as coupling agent between the cellulose and lignin does, however, seem to add a rationale to models of the structure of softwoods that has hitherto been lacking.

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