NEWS AND VIEWS

Calculating the strength of wood

A group of mechanical engineers has provided a rational framework for understanding what is known of the strength of all kinds of wood. The methods should be more widely applied.

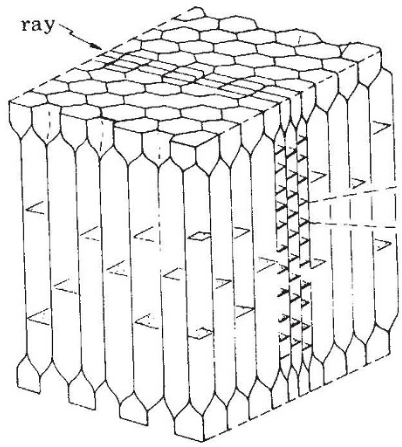
That wood is in some sense strong has been known since antiquity. Surprisingly, the reasons why have only in the past few weeks been made clear.

The construction industry probably includes few avid readers of the *Proceedings of the Royal Society,* either series A (physics) or B (biology), which is why something must be done to draw attention to the remarkable circumstances that this most august journal has now published what seems to be the first convincing explanation of the mechanical strength of wood. For what it is worth, the analysis (by K.E. Easterling, R. Harrysson, L.J. Gibson and M.F. Ashby, the first two from the University of Luleå in Sweden and the others from the Department of Engineering at the University of Cambridge) turns up in series A of *Proc. R. Soc.* (**383,** 31-41, 1982). The paper, which owes something to an earlier study of the structure of cork (L.J. Gibson, K.E. Easterling and M.F. Ashby, *Proc. R. Soc.* **377,** 99-117; 1981) and to some newly reported investigations of the cellular structure of balsa wood, is a splendid illustration of what mechanical engineers can accomplish (if they are permitted) for biologists.

Living trees are of course aggregates of cells, most of them filled with cytoplasm, some of them seasonably capable of photosynthesis. The wood derived from trees that is used in the construction industry is, however, best thought of in quite different images, as a three-dimensional structure made from the walls of empty cells, themselves made largely from cellulose with a measured and nearly constant density of about 1.5×10^3 kg m^{-3}, and with tensile strengths and other mechanical properties that can in principle be measured (but which in practice appear to depend on the orientation of the cellulose microfibrils within the cell walls). So, ever since the shapes of wood cells were first described by microscopists, it should have been a relatively simple task for mechanical engineers to figure out just how strong a particular wood should be. Alternatively, just as aeronautical engineers are forever trying to puzzle out what kind of honeycomb structure will provide the most resistance to some specified force (bending, twisting, crushing . . .) for the least use of material, so people should have been on the look-out for wood-cell structures promising desirable mechanical properties.

It will be interesting to see whether an attempt (not yet carried out) to predict the ideally strong wood would point to the cellular structure of a balsa wood now described — a three-dimensional network of cells with hexagonal cross-section with pointed ends and with an aspect ratio (of length to breadth) of about sixteen. In practice, the circumstances (see figure) are more complicated. In balsa wood, bundles of hexagonal needles oriented along the axis of the tree are lumped together around each annual growth ring, but are also separated from each other in blocks by layers of differently shaped cells running out in sheets from the centre of the tree (and which, when seen in the cross-section of a tree, not merely a balsa tree, are called rays). One important complication is that individual cells may have stiffening cellulose membranes perpendicular to the axis of the cell (and of the tree). What Easterling *et al.* have done is to calculate the mechanical properties of such structures.

The results of the analysis are surprisingly straightforward, but consistent with what has been found empirically about the strength of wood. Take, for example, the calculation of the Young's modulus of wood compressed tangentially. The only way in which the wood cells can be deformed is by the bending of the angles by which the walls are joined, which can be related to the Young's modulus (in that direction) of the materials of which the walls themselves are made. Indeed, the tangential Young's modulus turns out to be the Young's modulus of the cell-wall material multiplied by the factor $4/\sqrt{3}(t/l)^3$ where t is the thickness of the hexagonal cell wall and l the length of the hexagonal side. Simple geometrical arguments lead to the conclusion that the tangential Young's modulus of balsa wood should be proportional to the cube of the physical density of the



Schematic representation of bundles of columnar hexagonal cells within a balsa growth-ring (from Easterling et al.*) Cell height = 0.6 mm (approx), diameter = 0.035 mm.*

wood. The same line of argument suggests that the radial modulus, corresponding to compression along a radius from the centre of the tree, is twice as large, but that the axial modulus should be proportional to the first power of the density of the bulk wood, not to its cube.

The remarkable feature of the comparison between prediction and observation now reported is not that the numerical values (calculated and observed) differ by factors which are sometimes as large as four or five but that they are in the same ball-park. Curiously enough, the mechanical engineers seem to be better able to predict the crushing strength of balsa wood, perhaps because the dominant factors in their calculations are estimates of the collapse strength of the exceptional pieces of the cell structure, the hexagonally prismatic pointed ends of balsa wood cells, for example. The outstanding achievement of the argument, however, about which more could with advantage have been said, is that the variation of the mechanical properties of balsa wood with density calculated from first principles provides scaling laws that appear to accommodate not merely this exceptional material but other kinds of wood as well.

That the scaling laws for the strength of wood should have a rational basis is comforting but unsurprising. What else would one expect? The interest of this study, however, is that it shows that in the investigation of biological materials (of which wood is one) even the macroscopic methods of mechanical engineering can be applied successfully to estimate the mechanical properties of microfibrillar structures, bundles of cellulose molecules and the like. Bone is another such material to which attention has now turned. No doubt there will be many others. □

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