THE STRUCTURE AND MECHANICS OF CELLULAR MATERIALS IN NATURE

L. J. Gibson

Department of Materials Science and Engineering
Massachusetts Institute of Technology
Cambridge MA 02139 USA
ljgibson@mit.edu

A wide range of natural materials exploit a combination of cellular and composite microstructures for increased mechanical efficiency. Wood, for instance, is made up of a honeycomb-like cellular structure with composite cell walls, with cellulose fibres reinforcing a matrix of lignin and hemi-cellulose. The cellular structure of wood gives it performance indices for bending stiffness and buckling that are close to those of the best engineering material, unidirectional carbon fibre composites.

Palm stems, too, have a cellular structure. In contrast to the roughly uniform microstructure of wood, palm stems have a radial gradient in density, increasing toward the periphery of the stem. As the palm grows and increases its height, the diameter of the stem remains roughly constant while the cell wall thickness (and cell density) at the outer perimeter of the stem increases. The radial density gradient increases the equivalent flexural rigidity of the stem compared with that of distributing the solid as a uniform, average density. Bamboo stems are hollow and the stem wall is made up of a radially varying volume fraction of almost solid fibers in a matrix of porous, low density cells. Again the radially varying volume fraction of fibres increases the flexural rigidity of the bamboo.

Plant stems have a structure that botanists refer to as the "core-rind" structure: a core of low density cells surrounded by a cylindrical shell of much higher density cells. Porcupine and bird feather quills also have this structure, with an outer solid cylindrical shell supported by an inner foam-like core. The foam-like core in both plant stems and animal quills acts as an elastic foundation supporting the outer cylindrical shell, increasing its resistance to local buckling, from either axial compression or bending.

Some marsh plants, such as the iris and the cattail, have tall, relatively narrow flat leaves with noticeable ribs on the outside surfaces of the leaves, running along their length. Examination of the cross-section of such leaves indicates that they have a classic engineering sandwich structure: the nearly fully dense ribs form fiber-composite faces separated by a low density core of parenchyma cells. The separation of the relatively stiff faces by the low density core increases the moment of inertia of the cross-section with little increase in weight, increasing their ability to resist bending and buckling.

References

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