The mechanical properties (elastic, plastic, creep, and fracture) of cellular solids or foams are related to the properties of the cell wall material and to the cell geometry. The properties are well described by simple formulae. Such materials occur widely in nature and have many potential engineering applications.

I. INTRODUCTION

When modern man builds large load-bearing structures, he uses dense solids: steel, concrete, glass. When nature does the same,* she generally uses cellular materials: wood, bone, coral. There must be good reasons for this. It is, almost certainly, that cellular materials permit the simultaneous optimization of stiffness, strength, and overall weight in a given application. Cellular solids are nature’s equivalent of the I-beam.

Man-made foams are common enough, of course: cushioning, insulation, padding, packaging are all functions filled by cellular solids. Nature uses them in these ways, too: orange peel to protect the orange, cork bark to insulate the tree. But while nature has, for aeons, used cellular materials to support large loads, man, until recently, has used only wood—a natural cellular solid—in this role. His ability to design and optimize his own cellular structures is still limited.

In this article, I would like to summarize the understanding—some of it old, some more recent—of the mechanical behavior of cellular solids. The engineering potential of cellular materials is considerable, but its realization requires new and innovative methods of design, unfamiliar to traditional engineers.

*To give an idea of the scale of some natural “structures”, a large dinosaur was about the length and weight of a 25-seater aircraft; a large redwood tree is about the height of a 30-floor building (100 m) and weighs around 2500 tonnes.
II. THE STRUCTURE OF CELLULAR SOLIDS

Making foams is not difficult. Most polymers can be foamed easily, and techniques exist for doing the same thing with ceramics and glasses. Even metals can be formed into foams.

A. Isotropic and Anisotropic, Open, and Closed-Cell Foams

What do they look like? Figure 1 shows man-made cellular solids: polymers, ceramics, and metals; Figure 2 shows natural cellular materials: cork, wood, sponge, coral, bone, and cuttle bone. They show that some foams are almost isotropic, meaning that their structure and their properties have no directionality. Others are anisotropic: their structure is axisymmetric (like cork) or orthotropic (like wood); and their properties reflect this. Man-made foams tend to be almost isotropic. Natural cellular solids are rarely so; a single piece of cork or bone differs in strength and stiffness by a factor of 2 or more along two directions at right angles. Wood is more anisotropic still: many woods are 10 times stiffer and stronger when loaded along the grain than across it. So we cannot ignore the directionality of cell structures;