Chapter 1
Introduction

Abstract In natural world, a number of porous materials are observed, for example, woods, animal bones, leaves, and stalks. These holes or pores carry out the functions of supply, lightweight property, fluid permeability, keeping warm ability, masticability, etc. Wood, trabecular bone, and bamboo are all anisotropic; their mechanical properties depend on the direction of loading. Natural cellular materials exploit anisotropy to increase their mechanical efficiency, placing material where it is most needed to resist the applied loads. Throughout this book, we shall see the way in which porous materials exploit anisotropy to give unique functional performance.

Keywords Bamboo • Cancellous bone • Cellular materials • Natural biomaterials • Solidification defects

1.1 Porous Materials Widespread in Natural World

When we look around the natural world, we notice that a number of porous materials are existent such as woods, animal bones, leaves, and stalks. Besides, artificial materials such as foods, clothes, and buildings are not immaculate, but porous. Figure 1.1 shows the microstructure of several cellular materials [1]. Wood and cork are honeycomb-like cellular materials with prismatic cells like the hexagonal cells in a bee's honeycomb. Sponge and cancellous tissue consist of connected ligaments, while a coral and a bone of cuttlefish consist of stacked rectangular cells. On the other hand, leaves are network of round cells and stems of plants have also similar shape, but these are cross section of bundles of many tubes. As shown in Fig. 1.2, the bones are much familiar to our human body [1]. Most bones are an elaborate construction, made up of an outer shell of dense, compact bone, enclosing a core of porous cellular, cancellous, or trabecular bone. Most of the configuration minimizes the weight of bone while still providing a large bearing area, a design which reduces the bearing stresses at the joint [1]. In a sense these bones are

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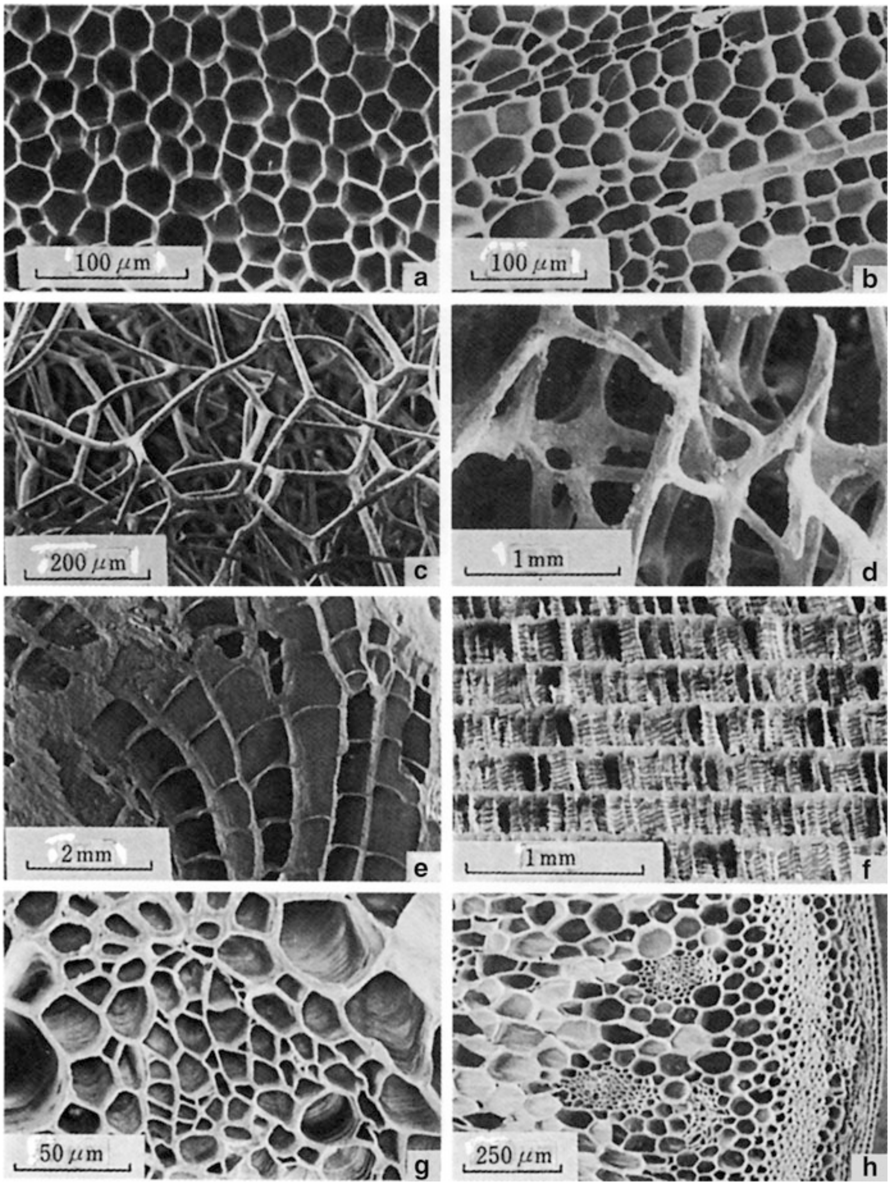

Fig. 1.1 Natural cellular materials: (**a**) cork, (**b**) balsa, (**c**) sponge, (**d**) cancellous bone, (**e**) coral, (**f**) cuttlefish bone, (**g**) iris leaf, and (**h**) stalk of a plant (Reprinted with permission from [1] © 1997 Cambridge University Press)

considered as functionally gradient materials; the outer immaculate skin layer holds strength and the porosity of the bone increases as the depth from the top surface is inward. It is more interesting that the bones of birds that fly in sky are much lighter weight, just like a tube, and more porous than those of animals that crawled on

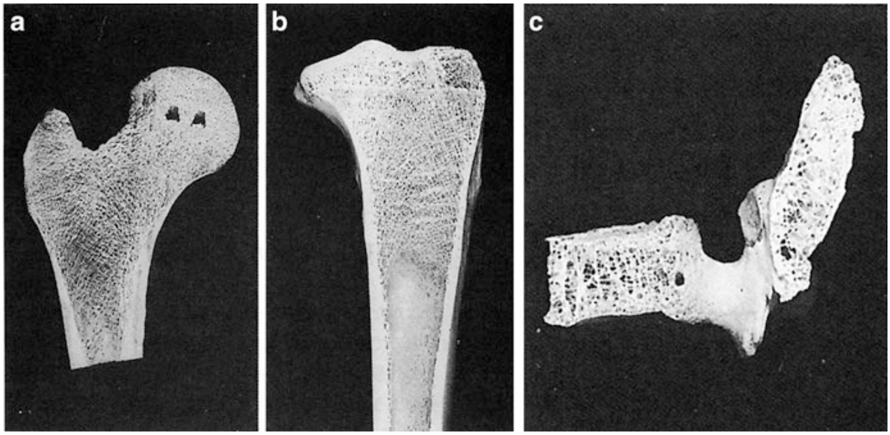

Fig. 1.2 Cross-sectional views of (**a**) the head of a femur, (**b**) the tibia, and (**c**) a lumbar vertebra. In each case, there is an outer shell of almost fully dense compact bone surrounding a core of porous, low-density, cancellous bone (Reprinted with permission from [1] © 1997 Cambridge University Press)

the ground as shown in Fig. 1.3 [http://www3.famille.ne.jp/~ochi/kaisetsu-01/05-te-ashi.html]. Thus, it may be considered that such natural biomaterials are one example to be designed as advanced materials. We, researchers who are investigating metallic and inorganic advanced materials, should learn various ideas from natural environment, in particular, the biomaterials in nature. These holes or pores carry out the functions of channels of supply, lightweight property, fluid permeability, keeping warm ability, masticability etc. Superficially, bones look fairly solid, but deceptive.

It is no exaggeration to say that most of various parts of industrial products are manufactured by casting or powder sintering techniques. In these processes, casting defects and sintering defects such as gas pores are usually considered as harmful defects to impede an efficiency or functional properties of the manufactured products. Therefore, it is said to be indispensable for high performance of the products to manufacture high-density materials with a porosity as small as possible. Figure 1.4 shows cross-sectional view of rimmed steel ingot [2]. The top part of the ingot has large shrinkage cavity, which is caused by volume reduction during solidification (not appear in this photo). Inside the ingot, there are a number of cylindrical pores which are called casting (solidification) defects. Such defects are known to be formed by evolution of hydrogen bubbles, carbon monoxide gas bubbles, etc. In particular, in the bottom part, some longer elongated pores are observed. Such long pores are grown and elongated in the direction of solidification. This book focuses attention to formation of the elongated solidification defects, properties of metals with the elongated defects, and utilization of such elongated defects in metals.

Fig. 1.3 Cross sections of a bone of a bird that flies in sky (Reprinted with permission from [http://www3.famille.ne.jp/~ochi/kaisetsu-01/05-te-ashi.html] © Nature Photo Gallery, Shinji Ochi)

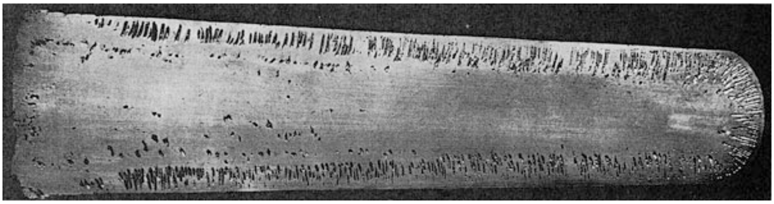

Fig. 1.4 Cross-sectional view of rimmed steel ingot. Two typical solidification defects are observed; top part is shrinkage cavity and surroundings are gas pores [2]

Up to the present, for example, penetrated pores can be used for filtering materials and large surface area resulted from high porosity can be utilized as electrode materials. However, if the porous materials whose mechanical strength does not become inferior significantly can be produced, wide and various applications to lightweight structural, functional materials, transportation materials, etc., could be possible prospectively. The porous materials with directional pores may meet these demands.

Natural structures such as bones have a gradient in density, rather than two distinct solid and cellular components. For example, bamboo epitomizes this (Fig. 1.5); the volume fraction of dense fibers increases radially toward the periphery of the stem. Bamboo is also tubular, again increasing the bending stiffness of its cross section. Wood, trabecular bone and bamboo are all anisotropic; their mechanical properties depend on the direction of loading. Natural cellular materials exploit anisotropy to increase their mechanical efficiency, placing material where it is most needed to resist the applied loads. In tree, for instance, the highest stresses, resulting from bending in the wind, act along the length of the trunk and branches. Wood is much stiffer and stronger in this direction, along the grain, than across it, as a result of its honeycomb-like cellular microstructure as well as the composite nature of the

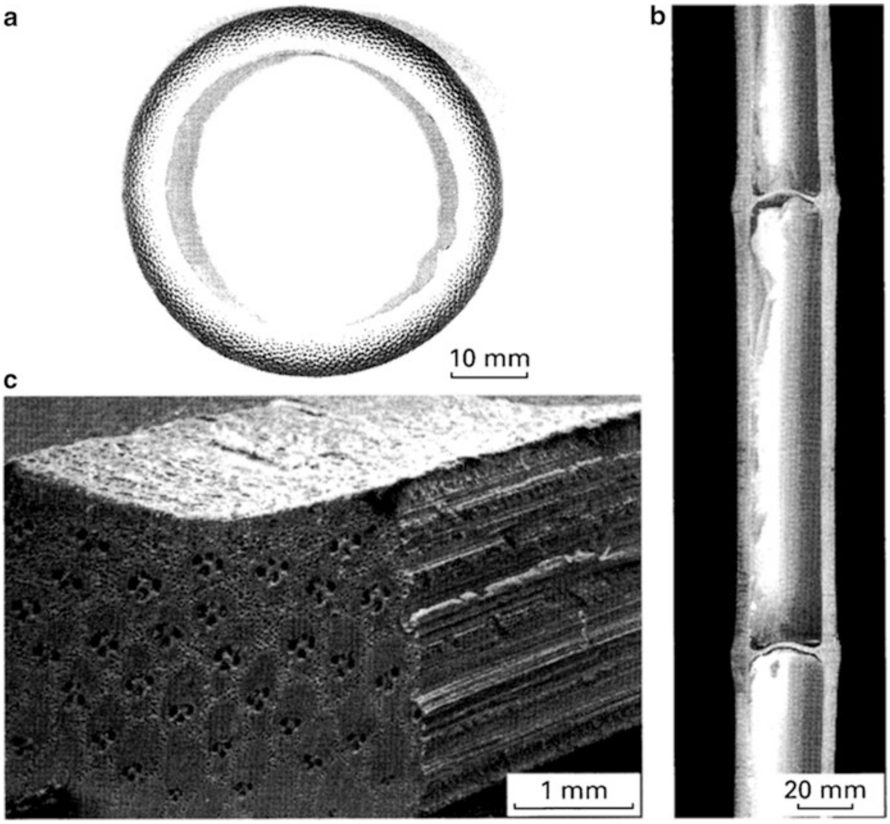

Fig. 1.5 (**a**) A cross-section of bamboo, showing the tubular (**b**) structure. (**b**) A longitudinal section of bamboo, showing the more or less evenly spaced diaphragms. (**c**) Scanning electron micrograph of a cross-section of bamboo, showing the radial density gradient. (Reprinted with permission from [3] © 2010 Cambridge University Press

solid cell wall material. Bone grows in response to applied loads; the trabeculae in human vertebrae, for instance, which are subjected primarily to compressive loading from the weight of the body, align in the vertical direction, increasing the stiffness and strength in that direction. Throughout this book, we shall see the way in which porous materials exploit anisotropy to give exceptional mechanical performance.

This book is divided into three parts. The first part summarized the various fabrication methods of cellular and foamed metals (Chap. 2), fabrication methods of porous metals with directional pores, in particular explaining various casting techniques and various gas-supplying techniques including the historical background (Chap. 3). Furthermore, nucleation and growth mechanism of pores in metals in Chap. 4 and control methods of pore size and porosity in metals in

Chap. 5 were described. Then we described the details of fabrication techniques of various materials through various fabrication methods in Chap. 6. In the second part, mechanical properties (Chap. 7) and various physical and chemical properties (Chap. 8) and processing techniques (Chap. 9) are explained. Finally, in the third part, various applications to heat sinks, vibration-damping materials, golf putter, and medical devices are described somehow in details in Chap. 10. In Chap. 11, the conclusions are summarized.

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