Cork: Structure, Properties, Applications

Lorna J. Gibson

Ever since people have cared about wine, they have cared about cork to keep it sealed in bottles. *"Corticum abstrictum pice demovebit amphorae ..."* (Pull the cork, set in pitch, from the bottle) sang the Roman poet Horace in 27 B.C., to celebrate the anniversary of his miraculous escape from death from a falling tree. In Roman times, corks used to seal bottles were covered in pitch; it was not until the 1600s that a method for stoppering bottles with clean corks was perfected by Benedictine monks at Hautvillers in France. Cork's elasticity, impermeability, and chemical stability means that it seals the bottle without contaminating the wine, even when it must mature for many years. The Romans also used cork for the soles of shoes and for floats for fishing nets. According to Plutarch (A.D. 100), when Rome was besieged by the Gauls in 400 B.C., messengers crossing the Tiber clung to cork for buoyancy.

Cork is the bark of the cork oak, *Quercus suber*, which grows in Mediterranean climates. Pliny, in his *Natural History* (A.D. 77), describes it: "The cork-oak is a small tree, and its acorns are bad in quality and few in number; its only useful product is its bark which is extremely thick and which, when cut, grows again." All trees have a thin layer of cork in their bark; *Quercus suber* is unusual in that, at maturity, the cork forms a layer many centimeters thick around the trunk of the tree. The cell walls of cork are covered with thin layers of unsaturated fatty

Robert Hooke's book *Micrographia* amazed readers with its detailed drawings such as this one of cork showing the roughly rectangular cell shape in one plane and the roughly circular cell shape in the perpendicular plane. The lower drawing is of sensitive plant (*Mimosa pudica*), whose touch-induced leaf movement Hooke studied. For more images and insight on *Micrographia* from this article's author, please view this YouTube video: https://www.youtube.com/watch?v=zFfVtziLhg4

Cork is harvested from managed cork oak (*Quercus suber*) forests such as this one in Portugal.

acid (suberin) and waxes, which make them impervious to air and water, and resistant to attack by many acids.

Cork Under the Microscope

Cork occupies a special place in the history of microscopy and of plant anatomy. When English scientist Robert Hooke perfected his microscope, around 1660, one of the first materials he examined was cork. What he saw led him to identify the basic unit of plant and biological structure, which he called the "cell" (from *cella,* Latin for small chamber). His book, *Micrographia,* published in 1665, records his observations, including the comment that, "I no sooner descern'd these (which were indeed the first *microscopical* pores I ever saw, and perhaps, that were ever seen, for I had not met with any Writer or Person that had made any mention of them before this) but me thought I had with the discovery of them, presently hinted to me the true and intelligible reason of all the *Phenomena* of Cork." Hooke's detailed drawings of cork show the roughly rectangular cell shape in one plane and the roughly circular cell shape in the perpendicular plane. Hooke noted that the cell walls were arranged "as those thin films of Wax in a Honey-comb."

Modern scanning electron micrographs of cork show additional detail. In the plane in which the cells look rectangular, we see that the cell walls are wavy, rather than straight, and in the perpendicular plane, the cells are roughly hexagonal prisms, with the waviness in the cell walls along the length of the prism axis. The dimensions on the unit cell are microns, or micrometers (μm); for comparison, a human hair is roughly 50 microns in diameter.
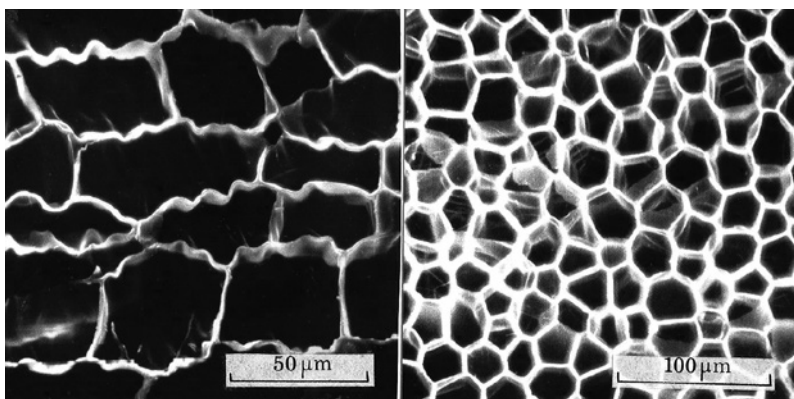

Scanning electron micrographs of cork cells in the same two perpendicular planes as in Hooke's drawings, showing the corrugations in the cell walls (from Gibson et al., 1981).

Cork Tree vs Cork Oak

The Arboretum's cork tree (*Phellodendron* spp.) collection lies south of the Hunnewell Visitor Center along Meadow Road, as seen in the photo below. There are 18 *Phellodendron* specimens comprising 5 taxa, all native to Asia, in the collection.

While the bark of cork trees has a similar compliant feel as that of the true cork oak (*Quercus suber*), it is not used as a source of cork. These scanning electron micrographs of two perpendicular planes in *Phellodendron* bark show more irregular cells compared with those of *Quercus suber* (seen on page 24). Cork oak is only cold hardy through USDA hardiness zone 8 (average annual minimum temperature 10 to 20°F [-12.2 to -6.7°C]) so there are no specimens at the Arboretum.
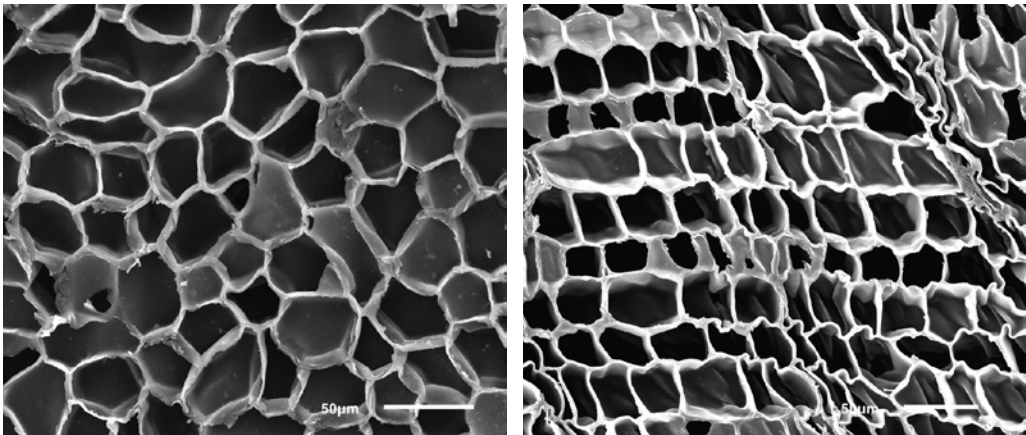
How Cork Works

Cork is roughly 15% solid and the rest is air. Its density is typically about 15% that of water: its low density, combined with the closed cells that do not allow water to enter, gives cork its great buoyancy. The low volume fraction of solid, along with the relatively compliant cell wall material, gives rise to its compressibility.

The waviness or corrugations in the cell walls of cork leads to an unusual behavior: if pulled along the prism axis, the corrugations in the cell walls straighten out, with little change in the transverse dimension (like the bellows of an accordion unfolding). In contrast, if you pull on most materials they get narrower in the transverse direction (think of pulling on a rubber band, for example). And if a cube of rubber is compressed some amount in one direction, it will expand out sideways by nearly half that amount in each of the other two transverse directions. When compressed along the prism axis, the corrugations in cork's cell walls simply fold up, again producing no change in the transverse dimension. It is this property, along with the compressibility of cork, that makes it easy to insert cork into a bottle and gives a good seal against the glass neck of the bottle.

Cork makes good gaskets for the same reason that it makes good bungs for bottles: it is compressible, accommodating deformation, and its closed cells are impervious to liquids. Thin sheets of cork are used, for instance, as gaskets between sections of woodwind instruments. The sheet of cork is always cut with the prism axis normal to its plane, so that when the two sections of the instrument are mated, the cork does not expand around the circumference of the section and will not wrinkle.

Cork makes an admirable flooring material because it is comfortable to walk on (thanks to its compressibility), it holds warmth, and it doesn't become slippery, even when wet. Cork holds warmth because it transfers heat poorly. In porous, cellular solids such as cork, heat transfer occurs by conduction (through the solid or gas), by convection (as gas on the warmer side of a cell rises and that on the cooler side falls, setting up convection currents), or by radiation. Gases have lower thermal conductivities than solids (by a factor of up to a thousand) so


COURTESY OF AMORIM

Sheets of cork oak bark rest in front of the tree they were harvested from.


KESSLER AND SONS MUSIC

Cork gaskets are used at the tenon joints of clarinet sections.

the high volume fraction of air within the cells reduces heat transfer by conduction through cork. Convection currents, carrying heat from one side of a cell to the other, are suppressed for cell sizes less than about 1 millimeter (for small cell sizes, the buoyancy force associated with hot air rising is counteracted by drag of the air against the walls of the cells). And heat flow by radiation also depends on cell size—the smaller the cells, the more times the heat has to be absorbed and reradiated, reducing the rate of heat flow. So the high volume fraction of air in cork and its small cells contribute to its ability to hold warmth.
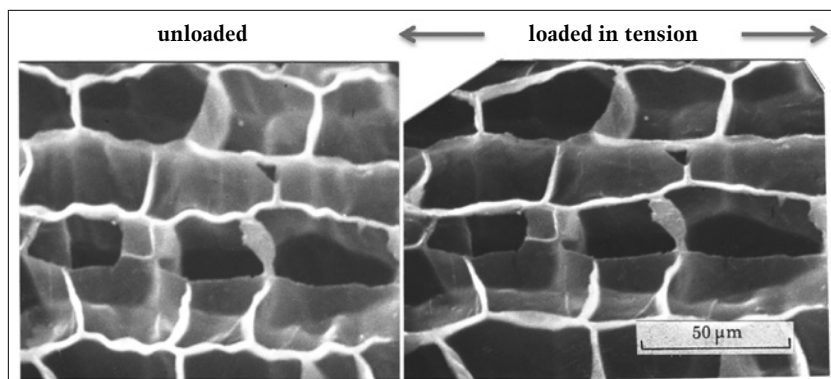
Micrographs showing (left) cork cells unloaded and (right) the progressive straightening of cell walls as cork is pulled along the prism axis (from Gibson et al., 1981).
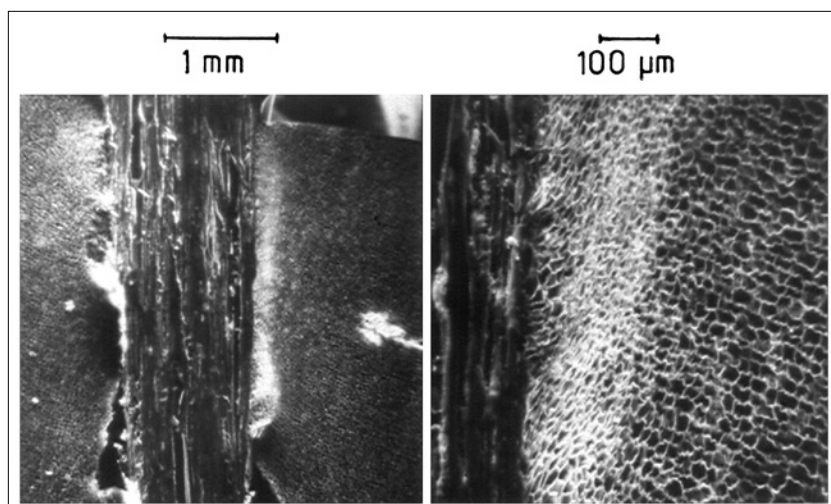
A pin pushed into cork results in a narrow band of crushed cells next to the pin (left) but little deformation of the cork beyond that (right) (from Gibson et al., 1981).

Cork is widely used for bulletin boards. When a pin is stuck into cork, the deformation is very localized around the pin. A narrow band of cork cells, occupying a thickness of only about a quarter of the diameter of the pin, collapses, crushing those cells nearly completely, to accommodate the diameter of the pin. The deformation in the cells beyond this highly deformed band is negligible in comparison. For this reason, the force needed to push the pin into a cork bulletin board is small. And cork recovers most of the deformation when it is unloaded, so that the hole nearly closes up after the pin is removed.

The cellular structure of cork is unique. It gives rise to a remarkable combination of properties that are exploited in everything from bottle stoppers and gaskets to the soles of shoes, flooring, and bulletin boards.

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Friction between a shoe and a cork floor has two origins. One is adhesion, in which atomic bonds form between the two contacting surfaces and work must be done to break them. Between a shoe and a tiled or stone floor, this is the only source of friction, and since it is a surface effect, it is completely destroyed by a film of water or soap, making the floor slippery. The other source of friction is due to energy losses associated with loading and unloading the floor (as a step is taken, for instance). In some materials, such as stone, these energy losses are small, but in cork, the energy losses are significant (it is said to have a high loss coefficient). Since the energy losses occur within the cork, and are not a surface effect, cork floors do not become slippery even when wet or soapy.