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WOOD AND WOOD DERIVED MATERIALS

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ABSTRACT

Wood is a structural material outperforming all other materials combined in the total annual tonnage used worldwide. We point out the role of wood in the development of 'green' technologies. To provide a perspective, we discuss forests and woodlands in the past and their role in the growth of civilization. Wood structure is explained. The role of wood as a fuel is described. Manufacturing of paper from wood is discussed. We then discuss composites containing synthetic polymers and wood. Finally, we discuss wood as an art material.

Keywords: *wood, green materials, cellulosics, paper, polymer composites, art material*

1. INTRODUCTION

Wood, which always looks quite solid to the naked eye, actually possesses a very intricate and exquisite structure - developed by Nature primarily to fulfill the requirements of a growing tree. Wood is a wonder material. For millennia, civilizations have grown and died in parallel with their trees. Wood occupies an unusual position in science and technology; it is not only the subject of much interesting and important research from the biochemical and genetic level up, but it is an important structural material outperforming all other materials combined in the total tonnage used worldwide.

Apart from being an important structural material, wood today is also an important source of precursors for medical and chemical compounds used by human beings. Lippincott[1] clearly explained earlier the case for increased use of renewable resources (such as wood) rather than nonrenewable ones (petroleum): "Glucose, obtained by hydrolysis of cellulose, and its fermentation products (ethanol, acetone, butanol) could become basic feed stocks for synthetic materials of the future".

There is a growing urgency to develop and commercialize new bio-based "green" materials and innovative technologies that can produce bio-based structural materials competitive with current synthetic products - and at the same time have the benefits of reducing dependence on foreign oil, enhancing national security, improving the environment, and creating new opportunities for the economy as replacements for petroleum-based products. The present and future opportunities for biocomposite materials for transportation and building applications can be largely based on performance coupled with the will to use environmentally friendly materials. How well the structure satisfies the needs of a construction material as used by humans is a distinct issue. These, and many other aspects of wood, are topics which Materials Science and Engineering (MSE) should well include in instruction. This seems the reason behind volumes on wood published by the same Council that publishes this Journal [2-7].

MSE instruction currently focuses on three large branches: metals, ceramics, and polymers. Even though polymeric materials are studied, instructional literature primarily covers synthetic polymers and overlooks natural polymers such as wood. A study of wood that includes structure, properties, and processes provides a comprehensive and interdisciplinary approach, and could serve as a platform for building a strong awareness of materials and design considerations.

Wood education programs across the nation, at and below the secondary levels of education, have declined in enrollment in recent years[8]. To many, wood education means only carpentry or woodworking. A systematic approach to the subject, as a part of a basic MSE course, can reverse the material negative connotation and make wood education as attractive as it deserves. Wood serves as an important material for construction, furnishings, art and still other essential uses. We shall discuss these aspects as well as others in this article.

2. WOOD AND CIVILIZATION

A better understanding of what happened with forests and woodlands in the past might help us to preserve forests for the future.

The destruction of the world's forests is a major concern in our age. According to the United Nations, about 40 % of Central America's forests were destroyed between 1950 and 1980; during the same period Africa lost about 23 % of its forests. A whole range of environmental problems is associated with deforestation, including flooding, accelerated loss of soil, encroaching deserts and declining soil productivity. Sometimes we get the impression that these problems are unique to our time, but vast areas of the surface of the earth were stripped of their tree cover well before the modern period. According to Perlin[9], most of the Ancient Middle East lost its forests by the end of the third millennium, which was before our era. He argues that this removed one of the fundamentals under the ancient civilizations in the Middle East and as a consequence the center of trade and power in the Mediterranean shifted to areas that still had sufficient reserves of timber: Crete and the Greek world. The kingdoms and empires in the Middle East started to import wood for timber, fuel and the production of bronze from the island of Crete but, in the long run, this was not sustainable. In the early second millennium BCE, the Minoan civilization developed on Crete and its economy was based on the abundant availability of wood. Wood was used for fuel in the copper furnaces for the production of bronze, the major export of Crete at that time. The Minoan civilization flourished for about 600 years, but by 1450 BCE it collapsed almost entirely caused by the massive deforestation of the island. The Minoans had to turn to Greece for its timber and fuel supplies - and soon the center of gravity moved to the Greek world. In the millennium that followed, the Greek world developed into one of the major power centers of the Mediterranean. Two conditions were important for the growing influence of this region: the first was the long coastline of Asia Minor and Greece and the many islands scattered along these coasts; the second was the availability of timber. The first condition made communication by sea easy and the availability of timber made this communication possible because it allowed the construction of ships. Because of this, the forests of Asia Minor, the Greek peninsula, and of Macedonia were one of the main sources of the power and wealth of this region. The availability of wood transformed the different civilizations that developed in Greece and Asia Minor into formidable maritime and trading powers. It is not surprising that, when Rome conquered Macedonia in 167 BC, it *prohibited* the Macedonians from cutting timber. The Romans were aware of the role that wood had played in its rise as a great power. The prohibition was a precautionary measure to prevent Macedonia from developing into a maritime power that might rival Rome and of course to satisfy its own timber needs[10 - 12]. For the Romans, as for other civilizations before, wood played an important role in their economy. The importance of wood is reflected in Pliny's *Natural History*. He devoted books XII to XVI of his work entirely to trees and recognized the importance of forests for human existence:

…the trees and forests were supposed to be the supreme gift bestowed by her on man. These first provided him with food, their foliage carpeted his cave and their bark served him for aliment.

In Pliny's time, Italy was almost completely stripped of its forest cover. For this reason the Romans had to import most of the timber from all parts of their Empire; metallurgical industries, which depended heavily on charcoal, moved out of Italy. The centers of mining and metal smelting became the most deforested areas of the Roman Empire. Pliny must have realized that human industry and activities put forests at risk of destruction. But it was not just awe that inspired Pliny; the Romans realized that the forests were an important resource for their industries. Faced with wood shortages, Rome increasingly turned to northern Europe for their wood supplies. Unfortunately for them, they never succeeded in conquering the areas east of the Rhine and they had to turn elsewhere for timber, in particular to the Mediterranean. The Roman Empire's expansion into Syria had very harmful effects on the remaining cedar forests in the mountains. It was not until the Emperor Hadrian introduced protective measures and declared the cedar forests of Lebanon his Imperial Domain, that the destruction of the forests was slowed[13 - 16].

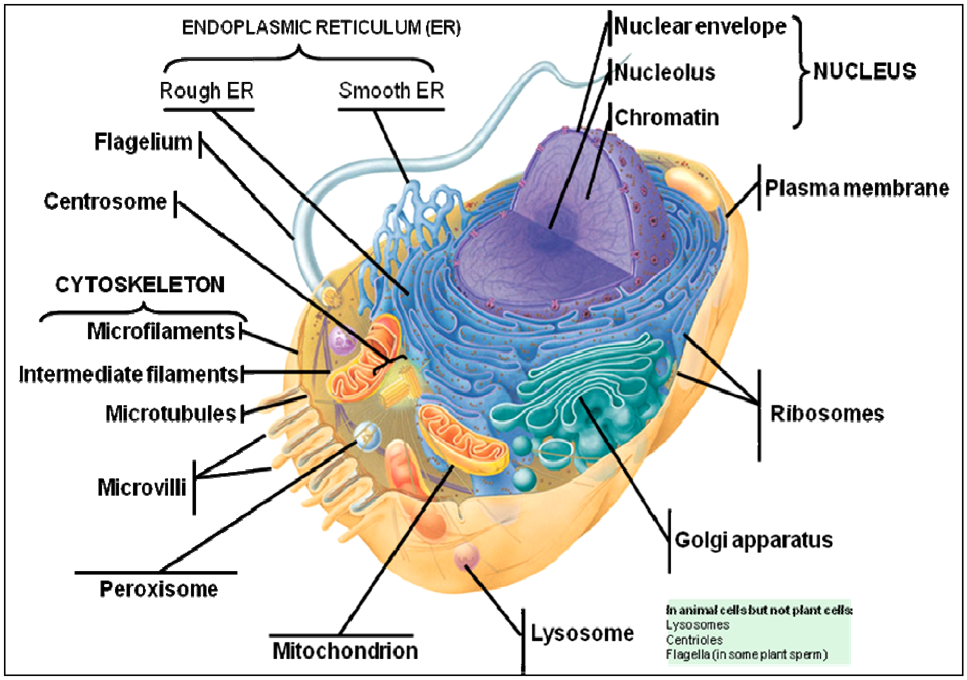
Now that we have explored the importance of wood and forests of Antiquity, we make a big jump forward in time to examine the importance of wood in the rise of the West. Without the abundant availability of wood, Europe would never have been able to undertake the exploration of world's oceans that led to the great geographic discoveries. This development had become very difficult in the Middle East since, as we mentioned earlier, the ancient forests there had largely disappeared during antiquity[17, 18]. In China, signs of wood shortages appeared in the 13th century. This was caused by a rapid growth of the population and the resulting demand on the timber supplies at that time. However, this did not prevent China from building ocean-going ships. The main reason China did not circumnavigate the Cape of Good Hope is of a more political nature than a matter of resource shortages or ecology[19, 20]. At the same time - on the other side of the Eurasian landmass - Europe woke up from its relative isolation of the Middle Ages. Trade and commerce started to expand and most of this trade was by sea. This was partly encouraged by its ecology; Europe did not have enough navigable rivers while transport by land was difficult because the massive woods, bad road conditions and extensive wetland areas which made it very difficult to transport goods over long distances over land. Luckily, Europe has a long coastline and for this reason most long distance navigation took place along the coasts. As a result, it was important for European powers to develop seaworthy vessels that could transport bulk goods over long distances and over rough seas. The first region where new vessels were developed was in the western Mediterranean, particularly in Venice. The city was very successful in building large numbers of high quality ships and for a considerable time, Venice was the most important maritime power in Europe. However, Venice paid a high price for its rapid expanding sea power. The first signs of timber shortages can be identified by the end of the 15th century; by 1590, Venice had to import complete ship hulls from Northern Europe. Soon Venice had to abandon its prominent position as a maritime power and the center of maritime activity shifted for the first time since antiquity away from the Mediterranean to the Atlantic and North Sea coasts[21]. This was the start of the rapid expansion of Europe overseas. The Spanish and Portuguese were the first, but others followed soon, especially the English and the Dutch. English pirates were raiding Spanish ships in the Caribbean and along the African coast. This brought Spain into conflict with England and other European powers. After years of preparation, Philip II ordered his Armada to attack and invade England in 1588. The invasion failed and the Armada was destroyed. The construction of the Armada in the 1580's left large parts of Spain devoid of trees and heralded the decline of Spanish supremacy at sea. The countries around the North Sea had access to abundant forests in Scandinavia, with a similar situation in the Baltic Sea region. However, in the south of England there were also some reserves of wood available. This availability of wood allowed England, France and Holland to build large fleets to take advantage of the opening up of the world seas. Because of this relative late development - during late Middle Ages and early Modern Period - of large-scale shipping and related industry around the North Sea basin, shortages of wood only appeared in the early Modern Period. In England the first signs of timber shortages were noticed during the wars against France in the 1620's. In the middle of the 18th century, Europe faced an acute shortage of wood, and, as a consequence, an energy crisis. The response to the energy shortage was the increasing use of an inferior fuel: coal. The change from wood to coal as major energy source had far reaching consequences. The knowledge of how to use coal spread slowly but surely; soon the production of iron rose because of the abundant availability of the new fuel in many localities, especially Northern England and the Midlands. These developments ended the supremacy of wood as a construction material and fuel; wood was replaced by steel as the chief construction material and by coal as the major energy source. The coal revolution in England made it the first country to leave the wood era, and enter the true Iron Age and the industrial period.

3. WOOD STRUCTURE

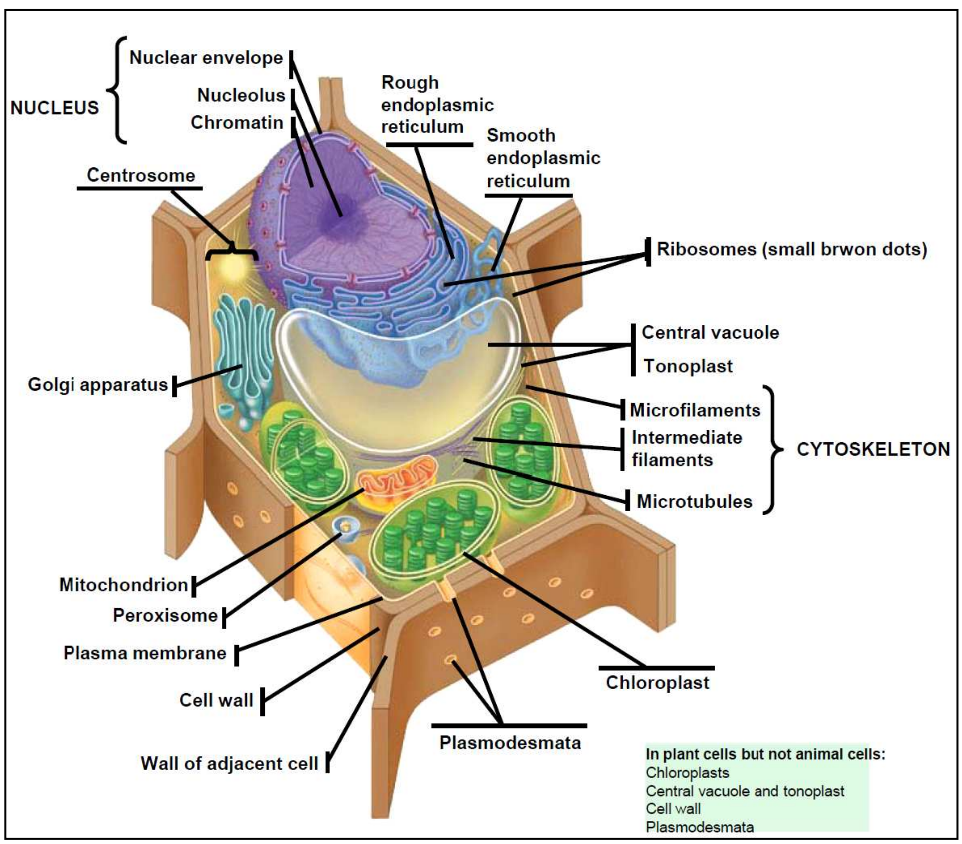
Wood is primarily composed of hollow, elongated, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. The basic unit of wood structure is the plant cell - the smallest unit of living matter capable of functioning independently. The cell has many functions, such as the manufacture of proteins, polysaccharides and mineral deposits. [A plant cell varies in diameter from 10 to 100 μm. The main difference between the plant and animal cell is that plant cells have a cell wall outside the plasma membrane, which is 0.1 to 100 μm thick (Figure 1). This makes the cells *rigid*, among other effects prohibiting the locomotion typical of animals. The cell wall supports the cell membrane; internal pressure in the cell can be as high as 1 MPa. The plasma membrane acts as a selective barrier enabling the cell to concentrate the nutrients it has gathered from its environment while retaining the products synthesized within the cell for its own use.

An extracellular matrix called the cell wall, which acts as a supportive framework, surrounds the plant cell. It is made of a network of cellulose microfibrils embedded in a matrix of lignin and hemicellulose, which are examples of polysaccharides (Figure 2). Cellulose is a polymer of some 8,000 to 10,000 monomers of anhydroglucose in the form of a flat 6-membered ring. The individual polymers are aligned in parallel and cellulose is up to 90 % crystalline. Cell secretions form the matrix, and cellulose and lignin comprise the bulk of a tree's biomass.

Wood has very high *anisotropy* because 90 to 95 % of all the cells are elongated and vertical (aligned parallel to the tree trunk). The remaining 5 to 10 % of cells are arranged in radial directions, with no cells at all aligned tangentially. Figure 3 shows a cut through a tree trunk.



A



B

Figure 1. Animal (**A**) and plant cell (**B**)[22].

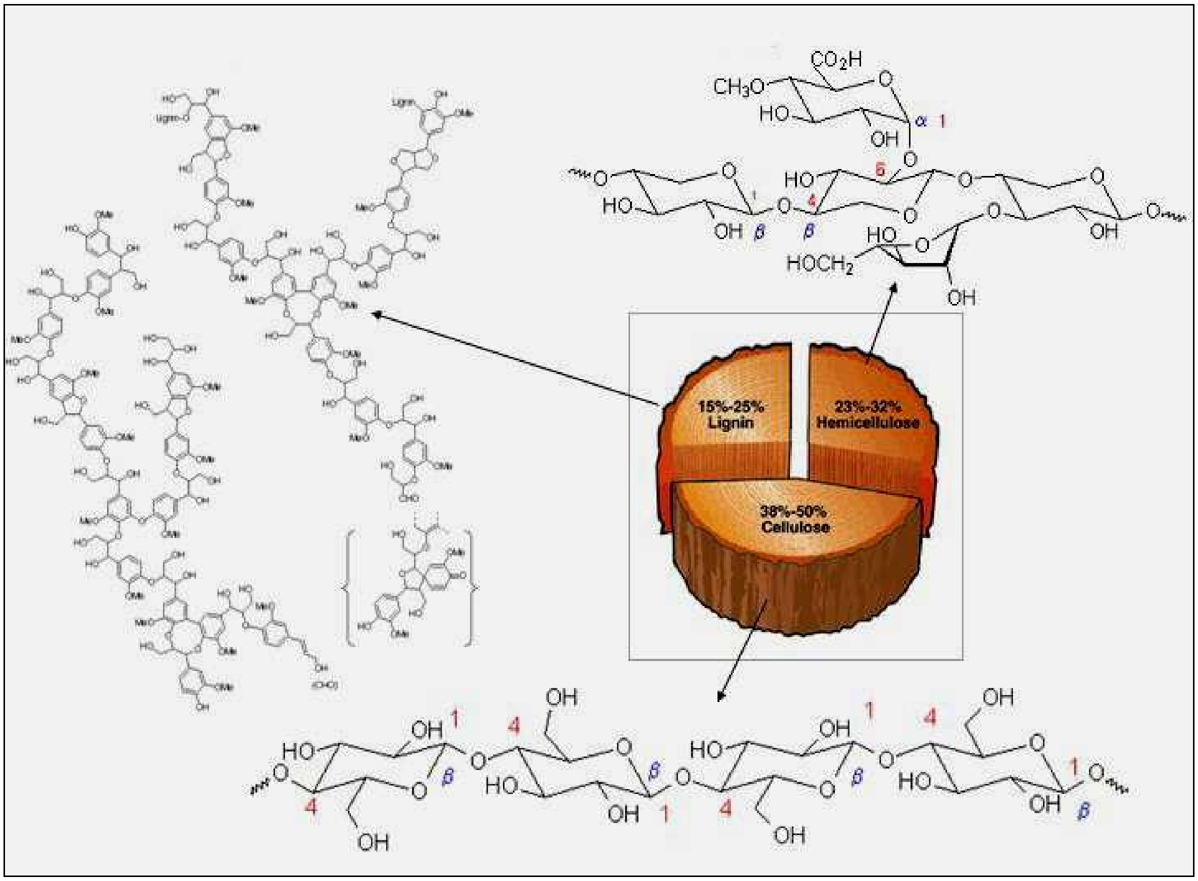
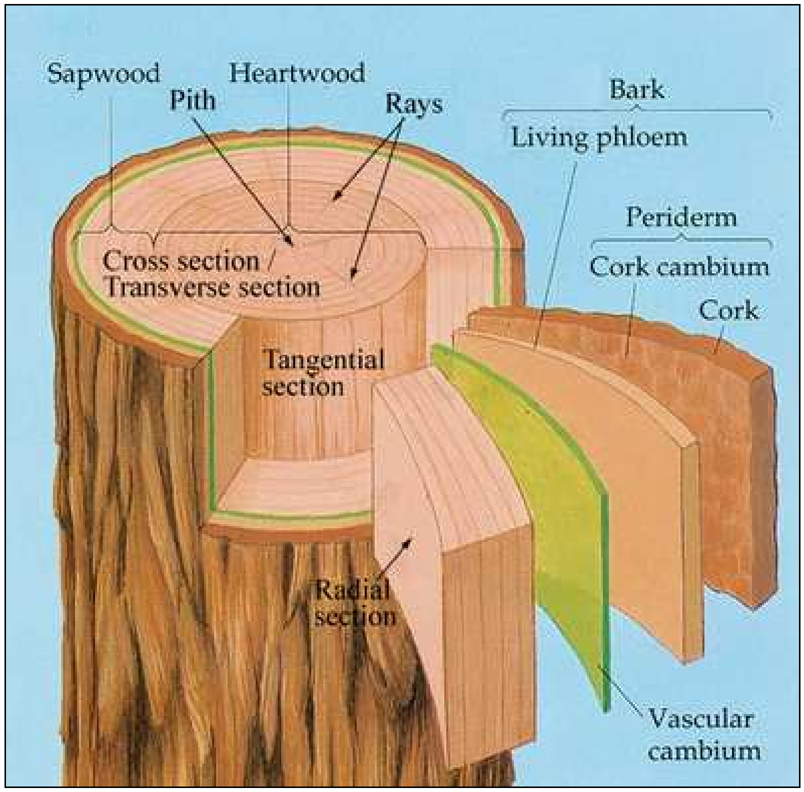


Figure 2. Chemical structures of wood constituents[23].

In the trunk there are three main sections: the *heartwood*, which is physiologically inactive; the *sapwood*, where all conduction and storage occurs; and the *bark*, which protects the interior of the tree trunk. All the tissue inside the cambium layer to the center of the tree is xylem or wood. All the tissue outside the cambium layer (including the phloem and cork layers) is the bark. Some botanists prefer to use the term phellem for the corky bark layer because it develops from a special meristematic layer outside the phloem called the phellogen. The wood of a tree trunk is mostly dead xylem tissue. The darker, central region is called heartwood. The cells in this region no longer conduct water. They appear darker because they often contain resins, gums and tannins. The lighter, younger region of wood closer to the cambium is called sapwood. Although they are dead, the cells in this region serve as minute pipelines to conduct water and minerals from the soil. Xylem cells are alive when they are initially produced by the meristematic cambium, but when they actually become functioning water-conducting cells (tracheids and vessels) they lose their cell contents and become hollow, microscopic tubes with lignified walls. The two main types of tree, *softwoods* and *hardwoods*, have distinct internal structures. *Coniferous* trees are softwoods, with vertical cells called tracheids 2 to 4 mm long and roughly 30 μm wide. These cells are used for support and conduction; they have an open channel and thin cell walls. The storage cells, parenchyma, are found in the radial direction. *Broad-leaved* trees are called hardwoods. The vertical cells in hardwoods are mainly fibers, 1 to 2 mm long and 15 μm wide. These are thick-walled with a very narrow central channel and are for support only. These cells are unsuitable for conduction, and so the tree needs vessels for this purpose. Vessels are either xylem, which



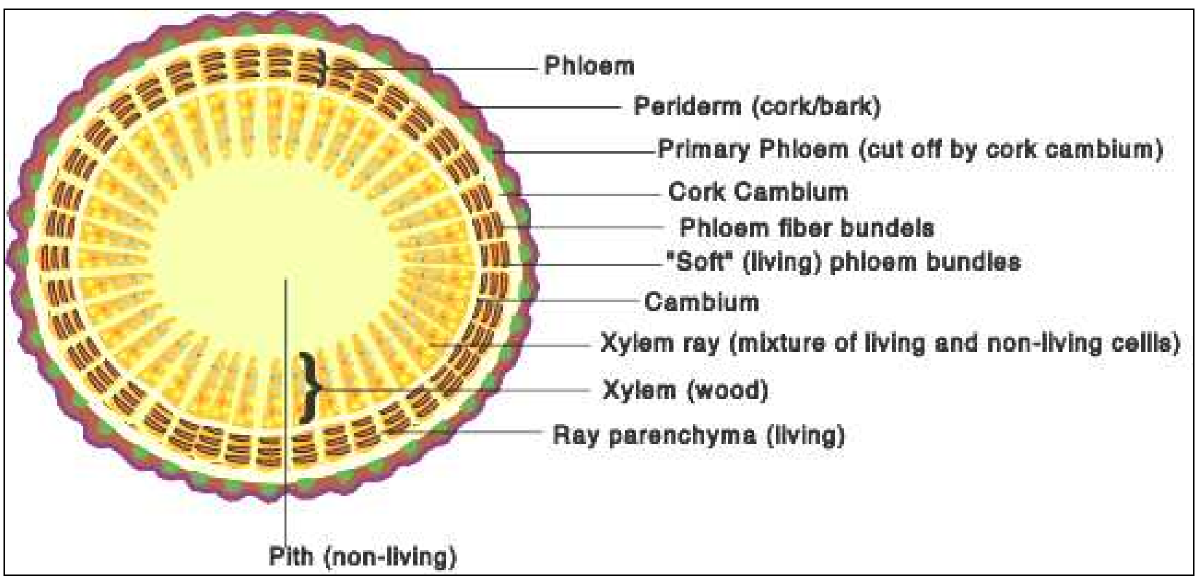


Figure 3. Structure of a tree trunk[23].

are dead cells that carry water and minerals, or phloem, which are live cells and transport energy sources made by the plant. Vessels are 0.2 to 1.2 mm long, open-ended, and are stacked vertically to form tubes of less than 0.5 mm in diameter. Hardwoods also have a small number of tracheid cells, and parenchyma cells are still present radially for storage. We have here a fluid movement inside of a capillary, reaching the tops of even very tall trees - related to surface tension.

When lumber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage, as well as the grain pattern of the wood. The microscopic cellular structure of wood, including annual rings and rays, produces the characteristic grain patterns in different species of trees. The grain pattern is also determined by the plane in which the logs are cut at the saw mill. In transverse or cross sections, the annual rings appear like concentric bands, with rays extending outward like the spokes of a wheel. The annual rings appear like concentric bands and can be counted to age-date the tree; see Figure 4.

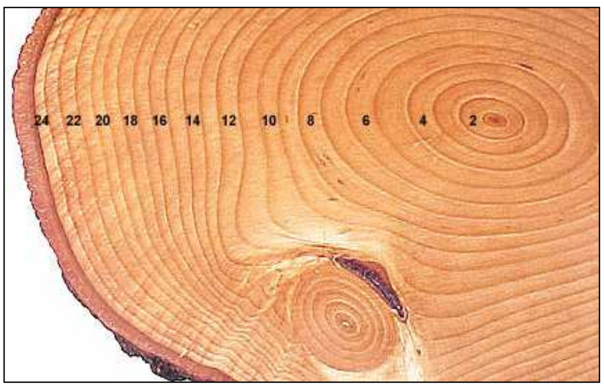


Figure 4. A tree cross section with 24 distinct annual rings; a smaller set of rings pertaining to a branch is visible also[24].

At the beginning of the growing season, in Spring, the cells grow to a large size due to the greater amount of moisture available. Throughout summer, the amount of moisture available decreases; the cells also decrease in size as a result. By Winter, cells can no longer grow, and cells at the edge of the sapwood region near the central heartwood dry out and die. This sequence is evident as annual growth rings. This process is used to date trees by *dendrochronology*. The central core of wood counts as the first year of growth since the pith is no longer present on Figure 4. Smaller series of concentric rings at the bottom of the photo is a lateral branch embedded in the main trunk. In Muir Woods National Monument (a park 12 miles or 19 km north of San Francisco) one can see a tree with the year 1215 marked – when Magna Carta Libertatum was signed by King John of England.

The structure of the tree trunk has now been discussed at both cellular and macroscopic scales. In terms of the complete structure, there is a further point of interest: the tree is pre-stressed. The center of tree trunk is in compression, and the outer layers are in tension (Figure 5). The stressing is achieved as the inner sapwood shrinks as it dries and becomes heartwood. As the heartwood has lower moisture content, it is better able to resist compression.

Wood cell walls can be subjected to transverse compression stresses. As a consequence, they can experience three different stress modes: bending, buckling, as well as compression. Two major fracture paths have been found in wood: cell fracture and cell separation. We do not discuss here models of mechanical behavior of wood based on the assumption of plastic yielding; since wood is polymeric in nature, its viscoelasticity has to be taken into account.

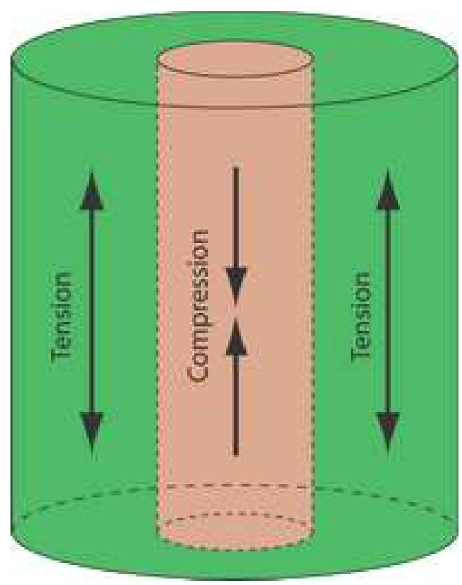


Figure 5. Tree trunk regions in compression and tension.

Furthermore, there is a transition between components on a nanometer scale. This gradual transition gives the constitutive polymers of wood the ability to maintain association under stress helping to create the material's remarkable strength, modulus, and toughness that is characteristic of many materials found in nature. This while there are differences between properties of wood depending on the species. This applies also to wood used as a fuel – as discussed in the following section.

4. WOOD AS A FUEL

Fire was civilization's first great energy invention, and wood was the main fuel for a long time.

Wood is a plentiful and accessible fuel. It is relatively clean and comes from a renewable resource — the forests. The combustion value of properly prepared wood compares favorably with other fuels. Coal, petroleum and natural gas supplies are limited, are not renewable and, therefore, are "expensive" fuels in terms of national resources. When we can get fuel wood from woodland through timber-stand improvement, the woodland also benefits. During power failures or national emergencies, wood can be an important source of heat. However, wood does have disadvantages that have contributed to a decline in its use. These include storage problems (wood creates greater bulk per unit of heat content); moreover, wood must be dry for best performance.

"Wood is the fuel that warms you twice, once when chopping and once when burning" - this is an old English expression. Unfortunately, wood seems to have the potential to generate heat for a third time, because the smoke from its burning is a major risk factor for respiratory infections and the fever that often accompanies them. It is believed that the burning of simple household biomass fuels-wood and fuel derived from trees, crops, animal dung or root plants-is responsible for some 1.4 million premature deaths annually[25]. When first hearing of the risks from wood smoke, we are skeptical because of our association of wood as a natural material. Chemically, wood is nearly all carbon, hydrogen and oxygen – as we have seen in Figure 2. Complete combustion gives off light, heat, and non-toxic gases: carbon dioxide and water vapor. However, in simple household stoves, combustion is far from complete. Then wood releases much of its carbon as products of incomplete combustion, toxic pollutants, volatile organic chemicals and carbon monoxide. Of course other organic raw materials including petroleum are by no means better in this respect.

Throughout the course of human history, wood has been the chief source of fuel; in many developing nations the vast majority of harvested wood is still used as fuel. About 1.5 billion people depend on wood or charcoal for 90 % of their energy needs for heating and cooking. Another billion people use wood for about half of their energy needs. It is estimated that 50 % of the wood harvested worldwide each year goes to fuel. In addition to being burned directly, wood can also be converted into *charcoal* by partial combustion in an oven or other enclosure that restricts air flow. Charcoal is almost pure carbon and burns at a much higher temperature than wood, so hot that it can be used for smelting ores into metals.

The fuel value of wood varies by the type of wood and depends on its density and moisture content. Combustion properties of several species of wood have been investigated[26]. Thus, *Quercus rubra* oak has the enthalpy of combustion $H^{comb} = -6.83 \cdot 10^3$ J/g, *Pinus monticola* pine has $H^{comb} = -9.95 \cdot 10^3$ J/g while Diospyrus spp. East Indian rosewood has $H^{comb} = -1.11 \cdot 10^4$ J/g. The respective densities are: 450 kg/m^3, 770 kg/m^3 and 1170 kg/m^3. However, inspection of all results in Ref. 26 shows that there is no simple proportionality between the enthalpy of combustion and density. In general, relationships between different kinds of properties of wood has not been convincingly formulated yet.

5. WOOD AND PAPER

World will never be paper free…

Wood pulp is a watery suspension of pulverized wood. In industrialized nations, approximately 50 % of the harvested wood goes into wood pulp, with the vast majority of pulp used in the manufacture of paper. Wood pulp is produced by two methods: mechanical and chemical. The mechanical process involves grinding the wood with water, making slurry. This process produces the greatest yield, but paper produced from such pulp is weak and yellows quickly. Newsprint, catalogs, and paper towels are manufactured using this process.

Chemical processes attack and dissolve the lignin in the wood. In one method, wood chips are dissolved in sodium hydroxide, while sulfites or sulfates are employed in other chemical processing methods. These methods will produce paper that is quite strong and resistant to yellowing. In addition to paper, wood pulp is used in the manufacture of cardboard and fiberboard, as well as rayon (artificial silk) and cellophane.

Written human communication has come a long way from its humble beginnings as pressed symbols on clay tablets. Although today the Internet promises worldwide computer link-up and instantaneous electronic exchanges, paper is still the major medium of written communication in modern society. The United States accounts for over one-third of the world's production and use of paper and cardboard. Each year about one billion trees are cut down to meet the demand for paper and paper products, with each American directly or indirectly using approximately 400 kg of paper.

Paper made from wood pulp can be traced back to China, early in the second century, where paper was made using a process not all that different from contemporary production. For about 500 years, papermaking remained the intellectual property of the Chinese. Knowledge of the process then slowly made its way to Japan, then to Central Asia, the Near East, and into Egypt. The Moors introduced the use of paper to Europe, and the first European paper was made in Spain around 1150. The introduction of movable type in the fifteenth century provided a major stimulus for the production of paper. In 1803, [British papermakers Henry and Sealy Fourdrinier developed the Fourdrinier screen, a continuous belt of wire cloth onto which pulp is deposited; see Figure 6.] The water drains through the screen, leaving a mat of fibers that comprise a sheet of paper.

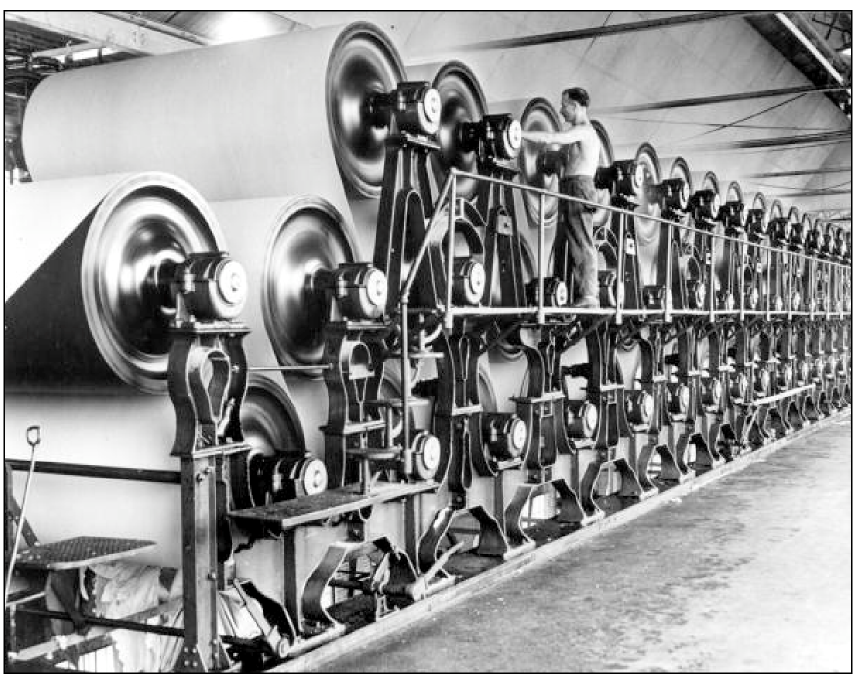


Figure 6. The Fourdrinier machine.

At present, wood pulp is the major source of the world paper supply. However, *cotton and linen rags* were the sources for the necessary fibers in early forms of paper. Today fine quality stationery and paper for permanent records still contain a large percentage of rags. As demand grows and deforestation occurs at truly break-neck speed, it becomes imperative that we find alternatives to wood pulp. Just the Sunday edition of the *New York Times* alone consumes about 150 acres of forest!

From lumber and plywood to pulp and paper and from fibers and cellophane to fuel and cardboard, wood is an amazingly versatile material that has proven to be indispensable to humanity.

6. WOOD AND POLYMER COMPOSITES (WPCs)

With increases in population, consumption - and in environmental awareness - renewable materials including wood are growing in acceptance as replacement for materials derived from non-renewable sources. A method of reducing the amount of synthetic materials consumed is by using natural fillers. Filler materials are additives for thermoplastics or thermosets, which include glass, sand, clay and wood fibers that will either lower the cost or improve material performance. In North America, agrofiber-thermoplastic composites have developed into an annual market consisting of 300 million kilograms per year.

Wood fibers were initially used for reducing and disposing of large amounts of natural fiber waste materials and for cost reduction. However, they are now preferably used as reinforcing materials in polymers, and offer low cost and low density products[27]. Wood polymer composites have exhibited very high growth rates as their benefits as alternative decking materials become better known to builders and homeowners. The potential to reduce upkeep while maintaining a new, finished appearance for long periods of time has allowed this revolutionary class of building materials to sustain growth while commanding a price premium over conventionally treated wood. WPCs were initially used for decking and non-structural building applications (exterior window and door profiles). However, they have now been extensively developed for a wider range of applications, including buildings and constructions, automotives and gardening and outdoor products - although their strength limits are still questionable. The improvement of mechanical properties for structural engineering applications of the WPC products can be obtained if the wood fibers are properly blended with the polymers, carefully processed with suitable molding techniques, and modified by suitable additives.

Wood–polymer composites generally exhibit low moisture absorption and high resistance to decay, insect, and UV ray damage. Over the years, wood has been treated with a variety of chemicals to change its physical characteristics. Since 1930's a number of new wood treatments were introduced: acetylation of the hydroxyl groups, ethylene oxide addition to the hydroxyl groups, and the phenol formaldehyde treatments.

The wood surface can be modified to tailor the properties of the materials for special applications. The resulting properties of these materials, from lightness and enhanced mechanical properties to greater sustainability, has meant a growing number of applications in such areas as building, construction and automotive engineering.

7. WOOD IN ART: MATERIAL AND OBJECT

Wood-carving as an art has had a long history – as the 1911 edition of *Encyclopedia Britannica* tells us[28]. The ready availability of wood as a material and the simplicity of the tools required to manipulate it make it an ideal material for such art. At times, carving wood can become quite difficult due to the uniform direction of the grain of the wood; for the carver, going against the grain can chip or crack the wood.

Also, as wood is subject to decay; many ancient pieces have perished. Though, due to Egypt's dry climate, many pieces from ancient times have been recovered from that area. Wood panels, statues and furniture have been recovered from the tombs of various royal figures dating back as early as 4000 BCE. Most of the pieces found here were not merely art, but had religious significance (Figure 6).

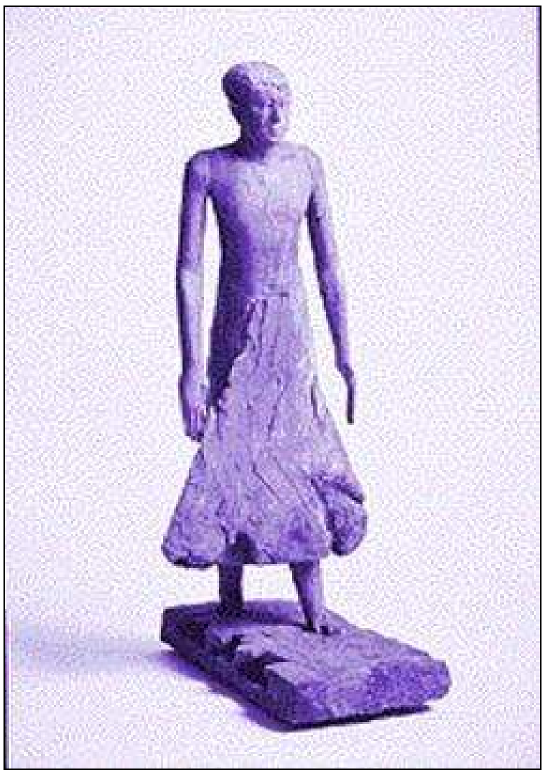


Figure 6. An ancient Egyptian wood carving[29].

In Rome and Greece, many artifacts did not survive until today, but historical texts point to the carving of gods and goddesses for decoration and worship. Between the first and eleventh century after Christ, many artifacts were created as a result of Christianity, whether they be religious icons or decoration inside the churches. One example of this is the main door of Santa Sabina, a fifth-century basilica in Rome. It is decorated with wood panels depicting scenes from the Old and New Testaments (Figure 7).

This religious style of carving also persisted through the gothic era, though it adopted the

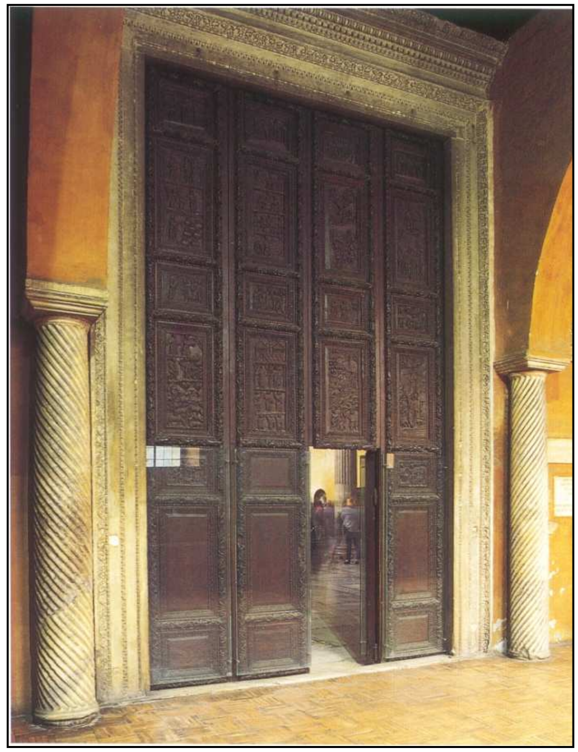


Figure 7. The wooden door at Santa Sabina and one of its panels depicting the miracles of Jesus Christ[30].

artistic styles of the time. The Scandinavian countries offer more examples of wood in art; they too carved decorations in churches as well as ornate doorways and other architecture (Figure 8).

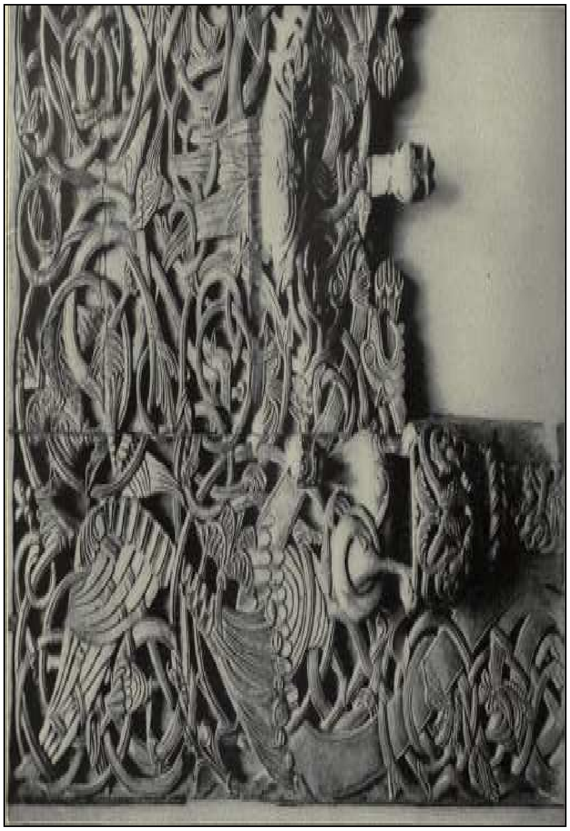


Figure 8. A doorway found in Norway[28].

In more recent times, wood-working and carving has taken a much more recreational turn. With modern machinery, carving has become quite accessible to the average person. Hand tools and compact lathes have made it possible to practice wood-working as a hobby out of the garage. At this level, pieces range from professional pieces of art to amateur knick-knacks for use around the house.

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REFERENCES

1. W. T. Lippincott, *J. Chem. Ed.*, **53**, 203 (1976).
2. F.F. Wangaard, editor, *Wood: Its Structure and Properties*, University Materials Council, University Park, PA (1979, 1980, 1981); R.F. Blomquist, A.W. Christiansen, R.H. Gillespie and G.E. Myers, editors, *Adhesive Bonding of Wood and other Structural Materials*, University Materials Council, University Park, PA (1980, 1981, 1982, 1983); A.D . Freas, R.C. Moody and L.A. Soltis, editors, *Wood: Engineering Design Concepts*, University Materials Council, University Park, PA (1984, 1985, 1986).
3. M. E. Criswell, *J. Mater. Ed*., **8**, 399 (1986).
4. M. J. Schmenk, *J. Mater. Ed*., **13**, 273 (1991).
5. T. M. Gorman, *J. Mater. Ed*., **13**, 473 (1991).
6. D. Mukherjee, *J. Mater. Ed*., **15**, 51 (1993).
7. T. M. Gorman, *J. Mater. Ed*., **13**, 335 (1998).
8. J.M. Mative, *Strengthen Wood Education through a Comprehensive Approach, Tech Directions* **64**, 24 (2005).
9. J. Perlin, *A Forest Journey,* W.W. Norton and Company Inc., New York (1989).
10. Pliny, *Natural History*, edited by E.H. Warmington, Cambridge, MA (1968).
11. *Archestratos of Gela: Greek Culture and Cuisine in the Fourth Century BCE,* edited by S. D. Olson and A. Sens, (2000).
12. F. G. Kenyon, *Books and Readers in Ancient Greece and Rome* (1951).
13. P. H. Blyth, *Greek, Roman and Byzantine Studies*, **33**, 127 (1992).
14. M. Liberati and F. Bourbon, *Ancient Rome: History of a Civilization that Ruled the World*, (1996).

15. E. Bonechi, *All of Ancient Rome: Then and Now*, (1992).
16. Dio, *The Roman History: The Reign of Augustus*, translated by Ian Scott-Kilvert, Penguin Classics, (1987).
17. H. B. Baker, *Plants and Civilization,* 3rd edn., Wadsworth, Belmont, CA (1978).
18. C. DeDuve, *Vital Dust: The Origin and Evolution of Life on Earth*, Harper Collins, New York, (1995)
19. C. B. Heiser, *Seed to Civilization*, 3rd edn., Cambridge MA, Harvard University Press (1990).
20. C. Ponting, *A Green History of the World*, London, (1991).
21. D. Zohary and M. Hopf, *Domestication of Plants in the Old World*, 2nd edn., Oxford University Press, Clarendon (1994).
22. N. Campbell and J. Reece, *PowerPoint Lecture for Biology*, Seventh Edition, Pearson Education, Inc. publishing as Benjamin Cummings (2005)
23. D.P.C. Fung, Y. Tsuchiya and K. Sumi, *Wood Sci*. **5**, 38 (1972).
24. W. P. Armstrong, *Microscopic Structure & Grain of Wood*; available at: *http://waynesword.palomar.edu/trjuly99.htm;* accessed July 26, 2010.
25. K.R. Smith, *Human Health and Forests: A Global Overview of Issues, Practice, and Policy*, Earthscan, London, Ch. 5 (2008).
26. W. Brostow, K.P. Menard and N. Menard, *Chem. & Chem. Tech*. **3**, 173 (2009).
27. W. Brostow, T. Datashvili, V. Gupta and H. Miller, *Recycled HDPE and wood composites*, in preparation.
28. *Wood Carving, The Encyclopaedia Britannica*, 11th ed., 1911.
29. *http://www.houstonpress.com/photoGallery/index/222011/1*; December 23, 1999.
30. *http://campus.belmont.edu/honors/ECArchTwo/ECArchTwo.html.*