CE265 - Wood

Wood is a complex natural polymer with some amazing properties. In countries blessed with trees, wood has long been the structural material of choice. So much so that ancient Greeks deforested their country with lasting environmental damage, and Britain enacted strict laws at the start of the industrial revolution to avoid the same fate. Today, wood is seen as a potentially sustainable structural and packaging material. Relative to most other materials, the energy embodied in its production and the pollution produced is quite low.

Wood is a cellular natural polymer composite, and as such does not fit into normal categories of materials. The primary chemical components of wood are cellulose, hemi-cellulose and lignin. Extractives are also important (they provide decay resistance and odour) but are not relevant to the mechanical properties.

Component	Softwood mass %	Hardwood mass %	Polymer structure	Derivative molecules	Function
Cellulose	42 ± 2	45 ± 2	Large, linear, oriented crystalline	Glucose	fibre
Hemi-celluloses	27±2	30±5	Smaller, semi-crystalline	Glacatose	Composite matrix
Lignin	28± 3	20±4			
Extractives					Decay resistance, etc.

Cellulose, with a mer of $C_6H_{10}O_5$ is present in long chains (about 5000 nm), has a degree of polymerization of from 2000 to 10000. It is produced in the cell wall from the glucose monomer of $C_6H_{12}O_6$. The polymer is somewhat more complex than synthetic polymers, and varies somewhat through the wood structure, but its general formula can be seen below.

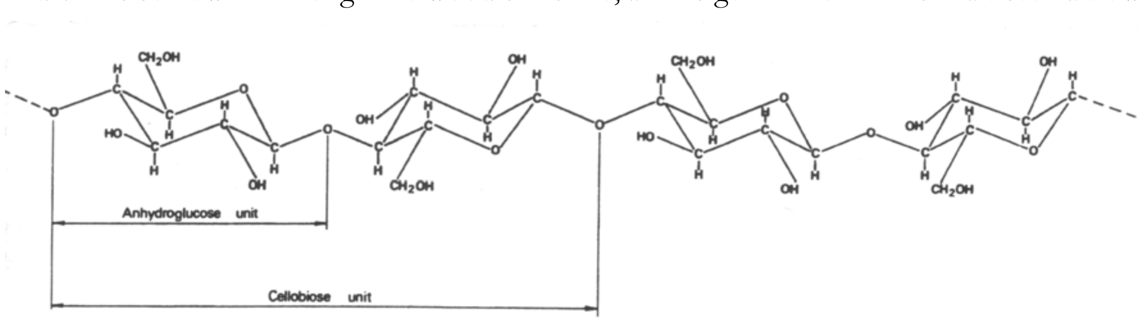


Figure 1: The cellulose mer

Hemi-cellulose and lignin act as the cementing material or matrix for the cellulose microfibrils. Lignin is a complex 3D molecule composed of phenyl groups. The hemicellulose are branched carbohydrates molecules of low weight (perhaps 200 units).

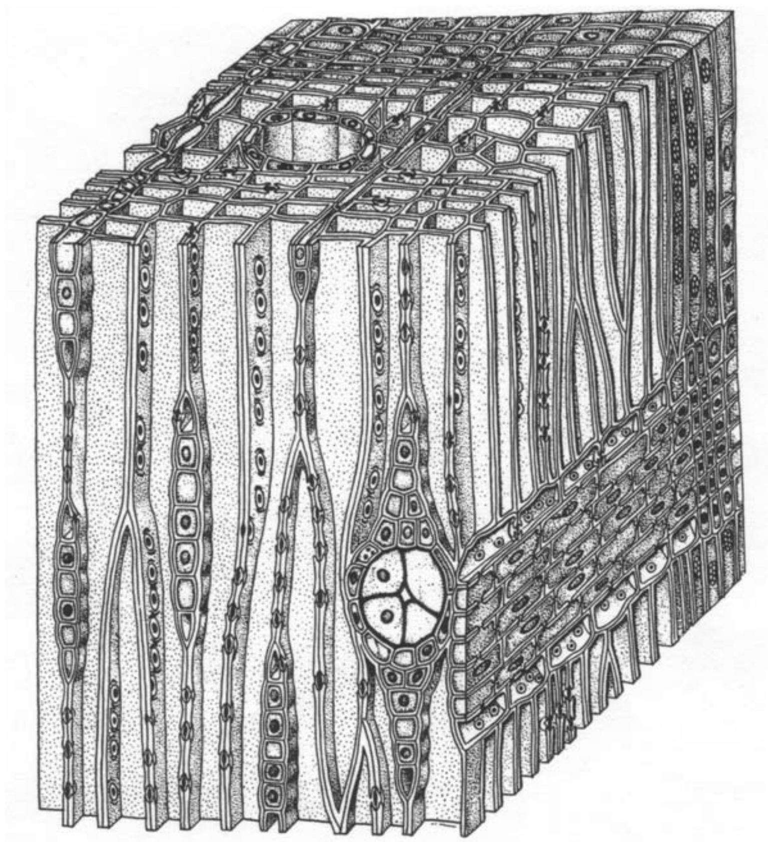


Figure 2: A View of Wood's Cellular Structure

This is a view of wood's cellular structure that can be seen with a powerful magnifying glass. The section is across one "ring", i.e., the slower growing dense summer wood is in the distance and the faster growing larger cells of spring wood in the foreground. The grain running perpendicular to the normal cell direction is a medullary ray.

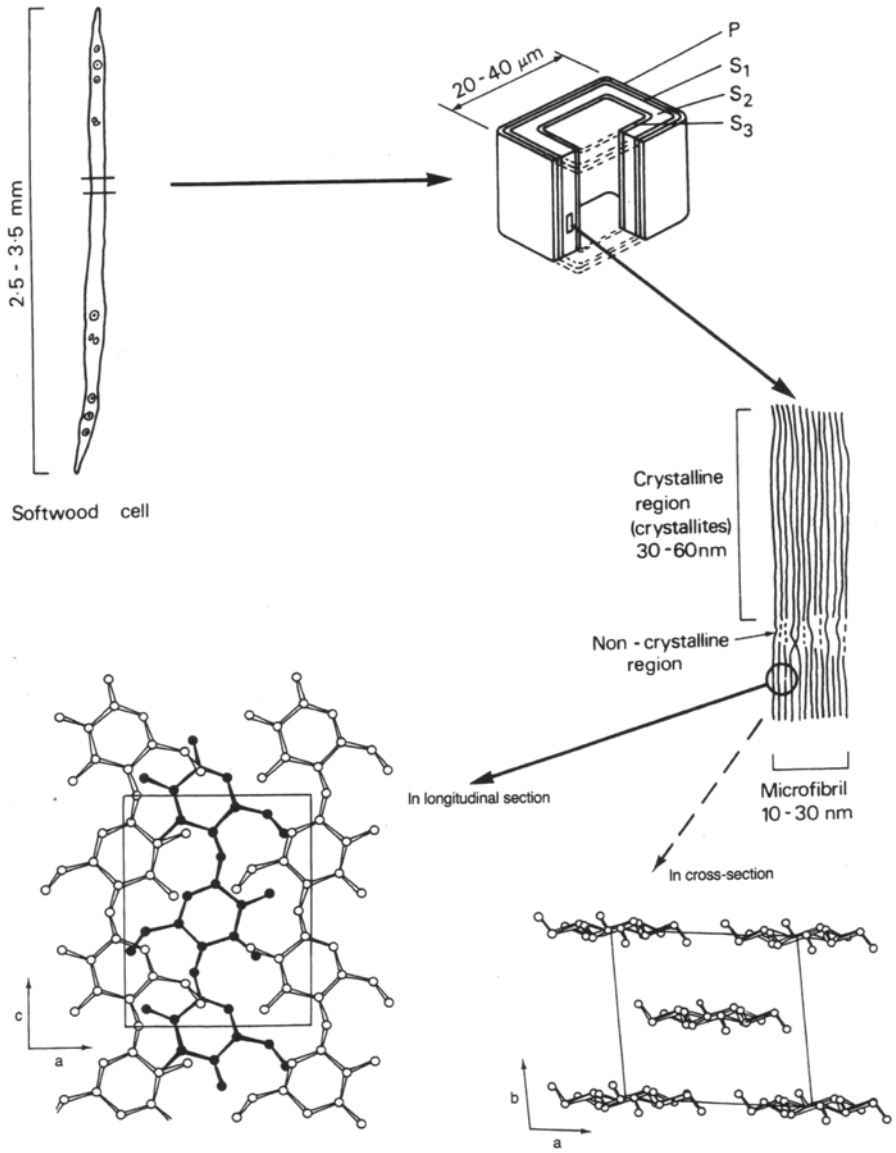


Figure 3: The microstructure of wood showing the various scales.
(Section a-b is shown in detail in Figure 1)

The cell itself is a long “fiber”, about 100 times its width (which is only 20 to 40 micrometers). The cell wall is made of microfibrils one of the most accepted models (we don’t really know) of which is shown below. The microfibrils are made of bundles of cellulose chains, mostly crystalline. These microfibrils are wound in a spiral or helix within the walls and the closer this helical angle (microfibril angle) is to the fibre axis, the stronger and stiffer is the fibre.

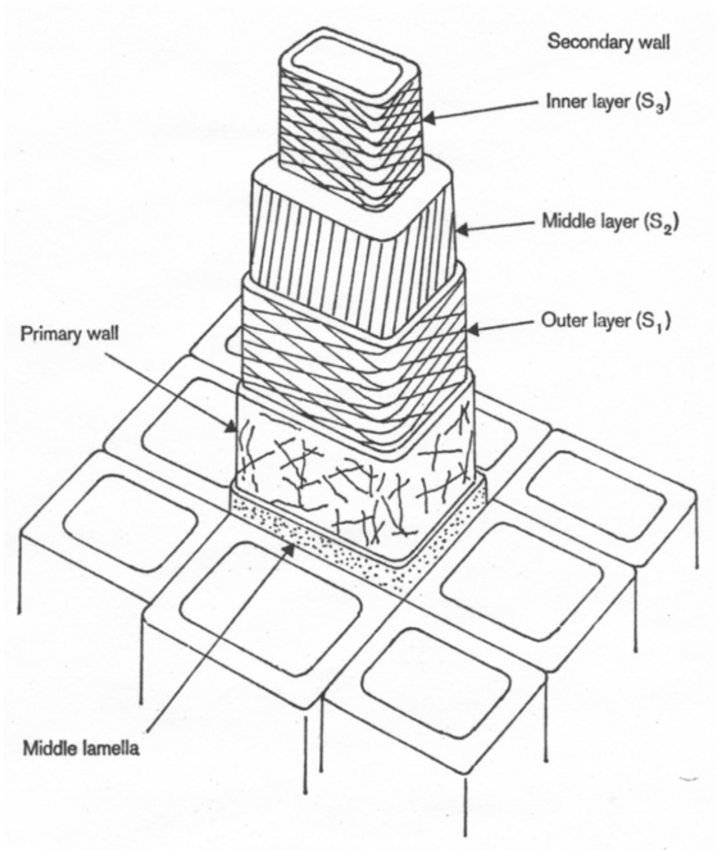


Figure 4: Wood Cell Structure

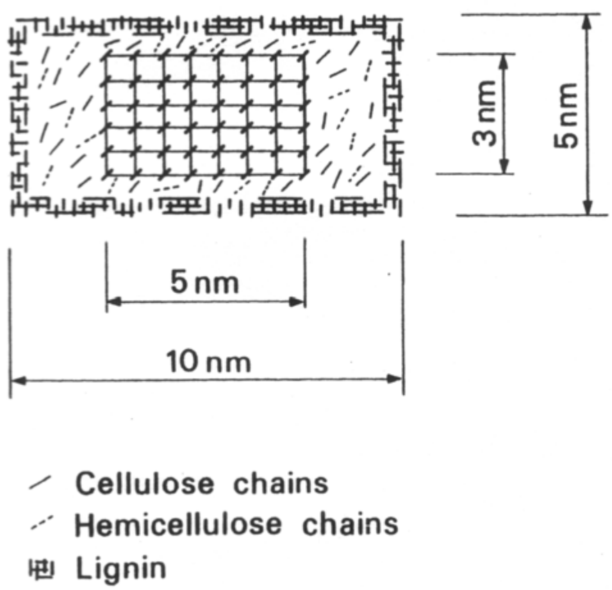


Figure 5: Microfibril Structure (the diameter is now thought to be closer to 2.5 nm)

The cells in timber are somewhat rectangular, and the cell walls are composed of a mixture of materials. The microfibrils wrap helically around a core. This provides a significant amount of strength while ensuring toughness. The approximate thickness and angles of the layers are shown below.

Cell Wall Layer	Approx Thickness (% of total)	Angle to long. axis
P	3	Random
S_1	10 (< 0.1 μm)	50 – 70°
S_2	85 (0.6 μm)	10 – 30°
S_3	2	60 – 90°

Tensile stresses are primarily resisted by microfibrils in the S2 layer of the cell wall – the angle of the helix is critical to the strength. Eventually microfibrils unwind off the S2 layer and break – this creates a very large area of fracture surface thereby absorbing energy. Thus wood is very difficult to break in tension along cell wall axis, i.e. along the grain of the wood, but it is easy to split between the cell walls.

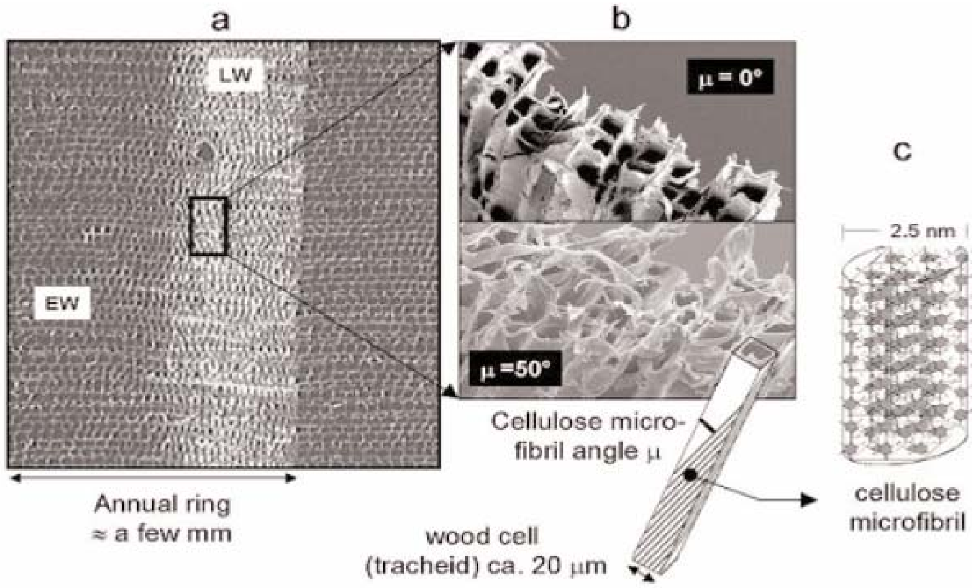
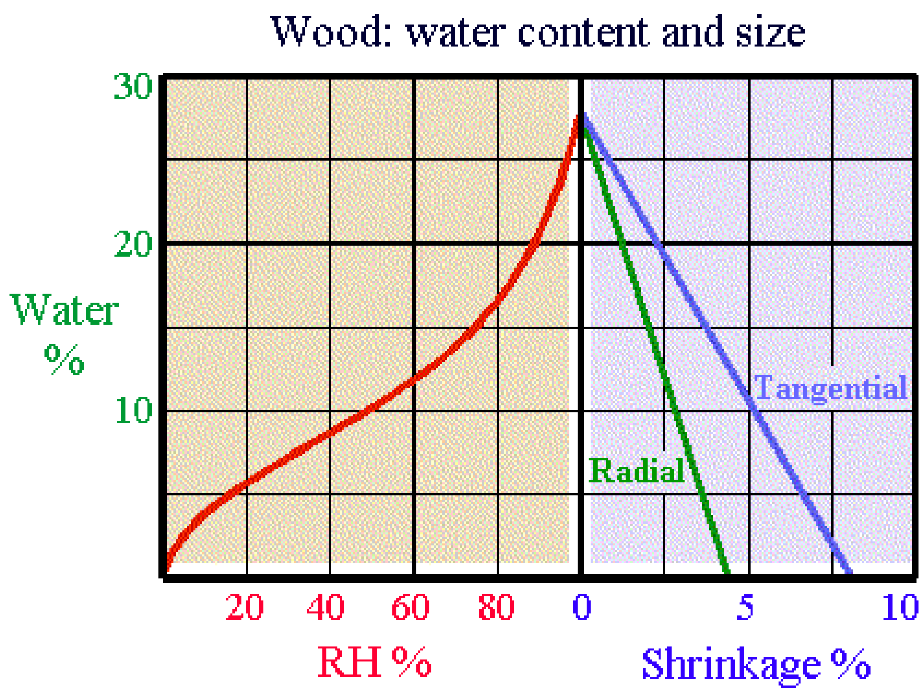


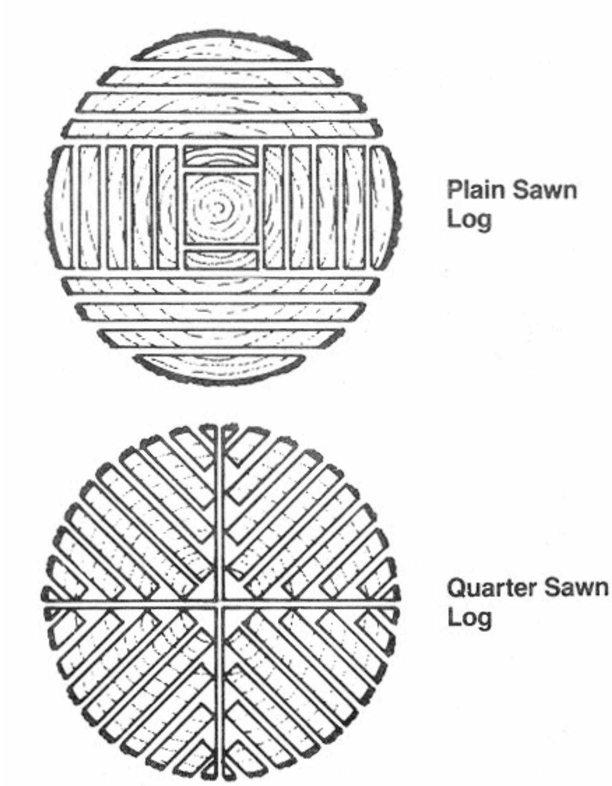
Figure 6: Hierarchical structure of spruce wood. (a) is a cross-section through the stem showing earlywood (EW) and latewood (LW) within an annual ring (from [9]). Latewood is denser than earlywood because the cell walls are thicker. The breadth of the annual rings varies widely depending on climatic conditions during each particular year. (b) shows scanning electron microscopic pictures of fracture surfaces of spruce wood with two different microfibril angles (from [10]). One of the wood cells (tracheids) is drawn schematically showing the definition of the microfibril angle between the spiralling cellulose fibrils and the tracheid axis. (c) is a sketch of the (crystalline part) of a cellulose microfibril in spruce (from [11]).

Figure 6: Photos of the different wood structural scales

Water easily penetrates the lignin and hemicellulose between the microfibrils, weakens the hydrogen bonding within the amorphous network but does not significantly enter the tightly packed microfibrils themselves. This is why wood swells on exposure to moisture. The S2 layer again plays a dominant role, and the angle influences the amount of swell.



The moisture content versus RH and shrinkage versus MC of a typical wood



Boards that are quarter sawn have more uniform grain, and hence do not tend to cup and bow in service.