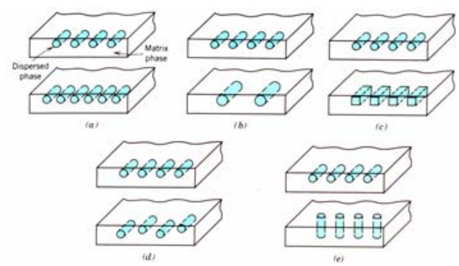
Chapter 12

Composite Materials

Composite material: a material system composed of a mixture or combination of two or more micro- or macro *constituents* that differ in *form* and *chemical composition* and are essentially *insoluble* in each other

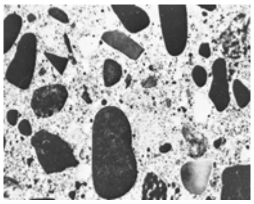


Classification Scheme

Composites

Particle-reinforced composites

Concrete: ceramic composite material composed of coarse granular material (aggregates) embedded in a hard matrix of a cement paste (binder)



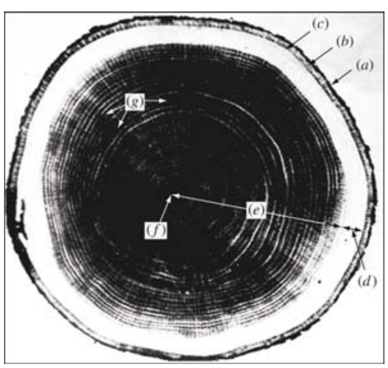
Cross section of hardened concrete

Cement: CaO, SiO_2, Al_2O_3, Fe_2O_3

Small amount of CaSO4 2H2O added to control the *setting* time

Wood

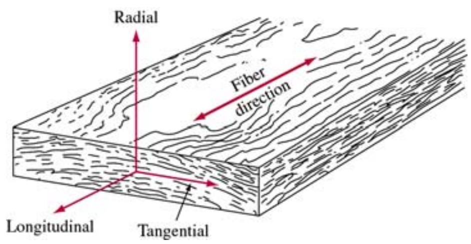
Macrostructure: strength of wood is highly anisotropic, tensile strength much higher in the direction parallel to the tree stem



Annual growth rings

A. Outer bark (dry, dead tissue, protection layer)
B. Inner bark (soft, carrier of moisture and food to leaves)
C. Cambium layer (formation of wood and bark cells)
D. Sapwood (contain cells for food storage and carry sap from the roots)
E. Heartwood (most strength)
F. Pith (soft tissue)
G. Wood rays (connect pith and bark)

Microstructure of the softwood



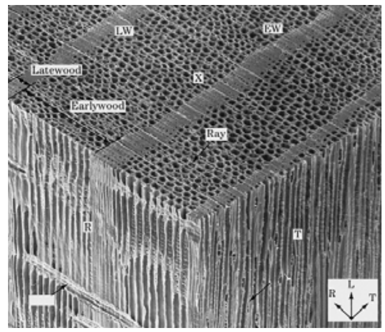
Symmetry considerations:

The axis parallel to the tree stem: **longitudinal axis**

The axis perpendicular to the tree stem: **radial axis**

The axis parallel to the annual rings: **tangential axis**

- Long, thin-walled tubular cells (**tracheids**) L=3-5mm, D = 20-80μm
- Large open space in the centre (**lumen**) : fluid conduction

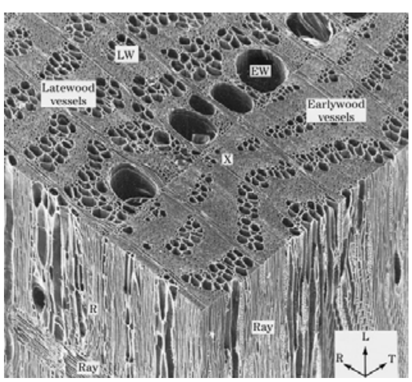


SEM of softwood (pine), x75

Adapter from Smith&Hashemi

Microstructure of the hardwood

Hardwoods: have large diameter vessels for the conduction of fluids



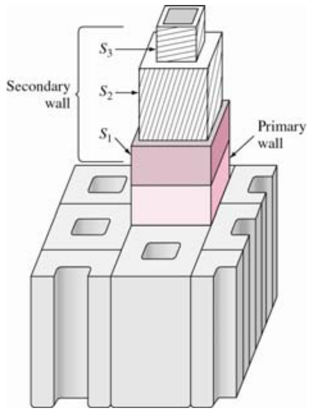
Scanning electron micrograph of ring-porous hardwood (American elm), x54

Adapter from Smith&Hashemi

- Long **fibers** L=0.7-3 mm, D = <20μm
- Fibers are closed packed together to leave an empty space for fluid transfer - *vessel elements (*aligned in the longitudinal direction of the tree)

⇐ Vessel elements are larger for EW; smaller for LW

Wood cell "molecular structure"



Primary wall: forms during cell division

Cell grows in *longitudinal and transverse* direction

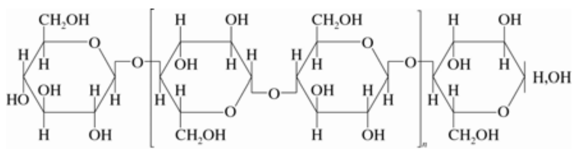
When growth is completed: *secondary wall* forms in concentric layers (S_1, S_2, and S_3) into the centre of the cell

Principle constituents:

Cellulose (45-50%) of wood solid material

Hemicellulose (20-25%)

Lignin (25-35%) complex 3D cross-linked polymer formed from phenolic units

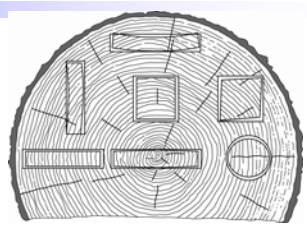


Mechanical Strength of Wood

Moisture content is important!

Green wood shrinkage eliminate moisture and causes distortion

(more shrinkage in *transverse* direction)



	Density, g/cm^3	Modulus of elasticity, GPa	Compression parallel to grains, MPa	Compression perpendicular to grains, MPa
Elm (green)	0.46	7.7	20.1	2.5
Elm (dry)	0.50	9.3	38.0	4.8
Pine (dry) softwood	0.34	7.0	16.8	1.5
S.Steel	7.9	193	760	

Young's Modulus for Composites for Isostrain and Isostress Conditions

Q: Calculate the tensile modulus of elasticity of a unidirectional carbon-fiber-reinforced-plastic composite material that contains 64 % by volume of carbon fibers and is stressed under isostrain conditions. The carbon fibers have a tensile modulus of elasticity of 54.0 $\times 10^6$ psi and the epoxy matrix a tensile modulus of elasticity of 0.530 $\times 10^6$ psi.