enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements.
Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings. The actual time of formation of earlywood and latewood varies with environmental and growth conditions.
Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells).
Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth.
Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood
structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis.
The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers

to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (µm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, lowmolecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propylphenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths. Some softwoods (*Pinus, Picea, Larix,* and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma.

The structure of hardwoods is much more complex and diverse than that of softwoods with at least four major kinds of cells: fibers, vessels, longitudinal parenchyma, and ray parenchyma. Fibers are shaped something like tracheids of softwoods, but are much shorter (<1 mm) and tend to be rounded in cross section. Their function is primarily mechanical support. Vessel elements are specialized conducting tissue, unique to hardwoods, shorter than fibers, and connected end to end. They appear on the transverse face of the wood as pores. In some species, e.g., oak (*Quercus),* these large vessels become blocked with tyloses as the sapwood changes to heartwood. Tyloses may also form as a result of injury or drought. Longitudinal parenchyma are thin walled cells whose function is primarily storage of nutrients. Hardwood rays are made up of from 1 to 30 cell wide bands of parenchyma, storage tissue, running radially in the tree. In some species, such as the oaks and beeches, these are clearly visible to the eye, in others they are scarcely visible. Figure 4 is a three-dimensional representation of a hardwood, showing these types of cells on the transverse, radial, and longitudinal faces.

Eleventh Lecture

Composite materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties.
However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

Natural composites

Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is
also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one.
The bone in your body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen
(which is a protein). Collagen is also found in hair and finger nails. On its own it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body.

Early composites

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks.
Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel),cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

Making composites

Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

Modern examples

The first modern composite material was fibreglass. It is still widely used today for boat hulls,sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth.

On its own the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by sharing out the forces acting on them.

Some advanced composites are now made using carbon fibres instead of glass. These materials are lighter and stronger than fibreglass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs.

Carbon nanotubes have also been used successfully to make new composites. These are even lighter and stronger than composites made with ordinary carbon fibres but they are still extremely expensive. They do, however, offer possibilities for making lighter cars and aircraft (which will use less fuel than the heavier vehicles we have now).

The new Airbus A380, the world's largest passenger airliner, makes use of modern composites in its design. More than 20 % of the A380 is made of composite materials, mainly plastic reinforced with carbon fibres. The design is the first large-scale use of glass-fibre-reinforced aluminium, a new composite that is 25 % stronger than conventional airframe aluminium but 20 % lighter.

Why use composites?

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.