Structure and Properties of Wood
Slide notes

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3. Joyce Kilmer, a famous American poet, once wrote these immortal lines, "I think that I shall never see a poem lovely as a tree.” No doubt he was only talking about the outside of trees.

4. The interior is also beautiful, and complex. It reveals the complete history of the tree: its age, the conditions of growth, its structure and even some of its properties.

5. Before we go inside the tree, let's look at the two basic classes of trees - the broadleaved or deciduous trees, that produce hardwoods, and the coniferous or evergreen trees, that produce softwoods. The terms “hardwoods” and “softwoods” are not always descriptive because some softwoods are harder than some hardwoods.

6. There are more than 100 species of broadleaved trees in Canada, but only a small percentage of these are used commercially. The leaves change colour and shed from the tree before winter.

7. There are fewer species of conifers - only about 30. These trees bear cones and most of them have needle-like leaves all year round. Douglas Fir is the largest conifer in Canada. Sometimes it grows over 90 metres high and four and one half metres in diameter. Softwoods comprise more than 80 percent of the total volume of standing timber in Canada, and account for most of Canada's commercial lumber and wood products.

8. To give an idea of production, a rail car of softwood lumber is manufactured each minute in Canada.

9. There are several easily visible layers in the tree. The first layer, the outer bark, provides protection for the tree. For some species, such as Poplar, it is very thin. For others, such as Douglas Fir, it can be very thick, sometime more than 10 centimetres.

10. Moving into the tree, the next layer is the inner bark which stores the nutrients and transports them down through the tree. Just inside this layer is a very thin, invisible layer, the cambium. It produces new growth in girth of the tree. It produces inner bark on the outside...

11. …and sapwood on the inside. The sapwood transports the sap from the roots to the leaves where it is turned into nutrients. Width of the sapwood may vary from a few centimetres in Douglas Fir and Spruces to more than 30 centimetres in Ponderosa Pine.

12. The heartwood is the inactive layer underneath the sapwood. It is often darker than the sapwood although there is not much difference in colour for many species.

13. The central core of the tree is the pith. It is formed by the stem, which pushes growth upward each year. It also starts new growth upward and downward, at twigs and roots.

14. Branches cause the knots inside trees. As the trees grow, the lower branches gradually die due to lack of sunlight and fall off. That stops knot formation at that level. Later, those knots become covered with clear, knot-free wood. It is used to produce clear grades of lumber.

15. There are many thin layers inside the inner bark. Each indicates a year of growth, commonly called an annual ring. The total number of layers at ground line tells the tree's age. Thickness of the layers varies with species, tree age and growth conditions. A thin layer, for example, could indicate a year of low rainfall.

16. Each layer usually has two distinct zones, a fast growth area on the inside, the earlywood, and a slower growth area, the latewood.

17. The wood consists of rows of tube-like cells, or fibres, bonded together along their outer surfaces with lignin, a glue-like substance. The earlywood cells are usually broader because they carry more water in the spring for the leaves and new shoots. The thicker-walled latewood cells are denser and stronger. Most cells are vertically oriented in the tree and provide mechanical support for the tree.

18. In softwoods, typical cells are 3 to 5 millimetres in length and four one hundredths of a millimetre in width. The cells in hardwoods are shorter, only about one millimetre long.

19. In hardwood trees, such as oak, the larger more pronounced cells are called vessels. They are used primarily to transport sap. Ray cells run radially across the tree in both hardwoods and softwoods, but are easier to see in hardwoods. They store and transport sap.

20. Each cell, in a magnified view, has two main zones, a thin primary wall that forms first, followed by a three-layer secondary wall that provides most of the strength. Cells are bonded to other cells with a binder called lignin.

21. The cell walls are framed with string-like microfibrils, which in turn are composed of millions of parallel close-packed cellulose molecules. The microfibrils are bound together in the cell wall by a hemicellulose and lignin matrix, similar to fibreglass construction.

22. The three layers in the secondary wall are identified by orientation of the microfibrils. The thick S2 layer is almost parallel with the major axis of the cell, providing strength in the longitudinal direction. The thinner S1 and S3 layers are almost perpendicular to the cell axis, acting mainly perpendicular to grain.

23. Each cell is a complete structural unit, acting like a tubular layered column with lateral support provided by neighbouring cells. Each Cell has considerably more strength and stiffness parallel to its axis than perpendicular. The anisotropy of wood will be addressed further.

24. Strength of wood molecules has been estimated to exceed 7000 N/mm^2. The microfibrils have a strength of about 480 and individual cells are estimated to have a strength of about 140 N/mm^2.

25. The chemical composition of the solid matter in wood consists of about two thirds cellulose and hemicellulose. The remainder is lignin and ash and extractives.

26. Most woods contain extractives, such as resin. In this pine lumber some extractives are toxic to fungi, providing natural durability. For example, tannin in Oak and thujaplicin in Western Red Cedar make these two species relatively durable.

27. Moisture content is the weight of water contained in the wood, expressed as a percentage of the weight of oven-dry wood . The weight of water equals the weight of wet wood minus the weight of oven dry wood. This moisture content in living trees comes from sap, which consists of water and dissolved mineral salts. Moisture content in living trees can vary from 200 per cent in the sapwood of some trees to 30 percent in the heartwood of others.

28. When the cell walls are completely saturated, and there is no free water in the cell cavity, the wood is at its fibre-saturation point. This occurs when the moisture content is between 25 and 32 per cent, depending on species.

29. Above the fibre-saturation point, the cell walls are saturated and there is additional water in the cell cavity. This condition exists in living trees and in freshly cut logs or sawn lumber. Volume of wood does not change above the fibre-saturation point.

30. Below the fibre-saturation point, moisture starts to leave the cell walls, resulting in shrinkage proportional to the water removed. As the cells dry out they become stronger and stiffer.

31. That is why there are two sets of sizes for lumber -- green sizes and dry sizes. Lumber finished green is dressed oversize so that when it dries it will shrink to the same size as lumber dressed dry.

32. Wood is a hygroscopic material. It evaporates or absorbs moisture until its moisture content is in equilibrium with the surrounding air. This is called the equilibrium moisture content of wood. It is a function of temperature and relative humidity.

33. Shrinkage is not equal in all directions. For example, the greatest shrinkage occurs tangential to growth rings, reaching 7% if the wood is dried to 0% moisture content. In practice this never occurs because most lumber in housing stabilizes at an equilibrium moisture content between 10 and 15 per cent. This results in about 3 percent shrinkage. Millwork, however, will go below 10 percent moisture content in most homes.

34. Radial shrinkage is also substantial. About two thirds of tangential shrinkage, or 2 percent for most framing lumber uses. This usual 2 to 3 percent range of shrinkage in radial and tangential directions is used to arrive at differences between green and dry sizes for lumber.

35. Longitudinal shrinkage is insignificant in most cases, only about 10 percent of radial shrinkage.

36. These differences in shrinkage affect the way lumber reacts during drying, depending on how it was cut out of the log. Skilled sawyers at the sawmill turn large logs during sawing to produce lumber least susceptible to warping, thus minimizing effects of differential shrinkage.

37. Moisture content of lumber needs to be controlled after manufacture. For example, codes state that framing lumber must have a moisture content of 19 percent or less. Usually this is achieved by natural air drying, on site or in a storage yard.

38. But sometimes the products are kiln dried to speed up the process. This results in quicker availability of products, and improved quality control.

39. Rate of drying should be controlled to minimize shrinkage problems. Checking is usually the first indication of drying lumber too fast. Lumber should also be piled properly with spacers between layers, to promote uniform moisture evaporation. This minimizes drying defects such as bow, twist, crook and cup. Generally, as moisture content decreases, strength increases because of stiffening of the cell walls and an increase in compactness of the wood.

40. For design purposes, no adjustment need be made in allowable stress if the average equilibrium moisture content of wood over a year is l5 percent or less, that is considered to be a dry service condition.

41. In terms of density, the wood substance is actually heavier than water, with a specific gravity of about 1.5 regardless of species.

42. Nonetheless, wood usually floats. That's because wood cells are hollow. If the cavities become filled, the wood becomes water logged and sinks. But that takes a long time, usually years.

43. Most seasoned commercial softwoods in Canada, and even most hardwoods, are less than two thirds the weight of water for comparable volumes. Variations in size of cell cavities, and thickness of cell walls, cause some wood species to have more wood substance than others and therefore higher specific gravities.

44. Because specific gravity indicates the amount of solid matter, it is an excellent indicator of strength. The denser the wood, the stronger it is. All strength properties are not affected equally but that is not important to the designer because listed stresses already take that into consideration.

45. It was shown earlier that wood is anisotropic, meaning it has different properties in different directions. For example, wood is much stronger parallel to grain than perpendicular to grain.

46. The high parallel to grain strength is due to the predominantly vertical orientation of the wood cells and the microfibrils in the cell walls. Standing trees have developed this internal structure to resist external forces such as wind. Exposed trees have a rapid taper in the trunk to increase resistance to wind.

47. Wood is very strong in compression parallel to grain because the wood cells act as tiny columns or tubes bonded together, giving and receiving support from neighbouring cells.

48. Strength in compression perpendicular to grain is difficult to measure. Compressive strength increases with deformation, reaching a maximum when the wood is compressed to about one third of its original thickness.

49. Strength at angle to grain is somewhere between values for parallel and perpendicular to grain. Formulas and charts are used to determine strength values for angle to grain loading.

50. Wood is also strong in tension parallel to grain. Knots reduce the strength, but this is already considered in setting design strength properties.

51. Wood is relatively weak in tension perpendicular to grain. However, it is rarely required to take much load in that direction except for secondary stresses in some curved members.

52. For example, tension or compression perpendicular to grain can be induced by radial stress in curved members.

53. Wood is very strong in bending. Shallow beams have relatively greater resistance to bending in comparison to proportionately deeper beams. Therefore, depth effect is considered in setting design properties.

54. Longitudinal or horizontal shear is often a controlling factor in beam design. It is caused by bending loads, creating maximum longitudinal shear stresses parallel to grain at the neutral axis.

55. Wood is very resistant to fatigue caused by cyclic loading in bridges or structures subject to high wind loads or vibrating machinery.

56. Strength of wood is little affected by temperatures and for normal construction applications is considered to be the same, from the arctic to the equator. At low temperatures, strength increases slightly. Up to 37° celcius, strength is hardly affected, even with occasional exposures up to 51°. Above that, stresses should be reduced. In actual practice, however, these extremes would seldom occur.

57. Codes and design standards sometimes require strength values to be adjusted for preservative treating processes, especially when the wood is incised. Also, when wood is treated with fire-retardant chemicals, the design values must be reduced.

58. Thermal expansion of wood is usually insignificant, especially along the grain. For very long spans, such as in bridges and wood stave pipes, expansion should be calculated taking the offsetting effect of moisture shrinkage into account.

59. Wood is a natural insulator against heat and cold because of the tiny air pockets within its cellular structure. Wood is also a good acoustical material. Wood converts sound energy into heat energy by frictional and viscous resistance in the wood cells.

60. This also reduces vibrations, improving the performance of wood panelling as a reflective surface.

61. Certain precautions against decay should be taken when using wood. Decay is caused by low forms of plant life known as fungi, which feed upon the wood. This decay can spread from spores which are seed-like bodies produced by the fungi.

62. Growth of fungi is dependent on adequate moisture content, air, favourable temperature and food. Remove anyone of these factors and decay will not occur.

63. Moisture is usually the easiest factor to control in buildings. Below the fibre-saturation point, decay is greatly retarded. Below 20 percent, growth of fungi is inhibited. Good construction practices will minimize moisture problems.

64. Exclusion of air also prevents decay. Piling under structures will last for centuries if the water or soil remains higher than the pile, thus excluding air. Deeply buried wood decays very slowly, if at all. Some wood buried in clay in British Columbia is estimated be l00,000 years old, and it is still sound.

65. Decay organisms can thrive in a wide range of temperatures, but develop best at about 27° celcius. At low temperatures they become dormant, but resume activity as temperature rises. Some decay organisms, such as white speck, are active only in living trees. When the tree is cut, the decayed area stops expanding.

66. In kiln drying, high temperatures kill the fungi, but the wood can be re-infected if exposed to favourable decay conditions.

67. When decay conditions cannot be avoided, decay can be prevented by treating the wood with preservatives in pressure treating cylinders. This treatment makes the wood toxic to fungi and eliminates food as one of the main factors of fungal growth.

68. Sapwood lacks decay resistance, but heartwood of some species has some decay resistance because natural preservatives were deposited in the cells during heartwood formation.

69. Sub-terranean termites, carpenter ants and wood-boring beetles can attack wood structures. In Canada, damage from subterranean termites occurs only in southern B.C. and southwestern Ontario. Good construction techniques minimize the chances of problems. Also, preservatives effective against decay are generally effective against all insects.

70. Wood-boring organisms, known as marine borers, can cause severe damage to untreated piling and timbers in salt or brackish waters. There are two distinct types of borers -- mollusks, such as Teredo and Bankia, and crustaceans, such as Limnoria. Effective protection can be provided by pressure treating the wood with high absorptions of preservative.

71. Fire is another hazard against which wood must be protected. Some structural assemblies with untreated wood members have achieved 2-hour fire-resistance ratings under standard fire tests. Although wood burns, surface burning characteristics can de reduced by impregnating the wood with fire retardant chemicals.

72. Weathering often enhances the appearance of wood. Unprotected wood, however, can deteriorate physically from extreme exposure to sun, rain, wind and frost. Preservatives and exterior grade paints and coatings can retard the weathering of wood.

73. Some wood species, such as Douglas Fir and Yellow Cedar, are resistant to chemical action and are widely used as structural materials in the chemical industry. In general, wood resists most chemicals and organic materials very well, especially acids.

74. With a basic understanding of wood, and its structure and properties, designers are better equipped to use wood products properly, and in many applications, to make buildings as lovely as a tree - well, almost anyway.