CHAPTER TWO

2.0 Literature Review

2.1 Nature and description of wood's structure

Wood is generally composed of cells parallel to each other along the trunk of a tree which is of primary interest to engineers as it is from the trunk that structural timber is manufactured. Wood cells possess cavities inside and are elongated and spindle-shaped. Figure 2.1 shows a cross-section of a trunk pointing out its main features in growing trees. Some basic information and perceptions of wood are prerequisites to understanding the behavior and the limitations of timber.

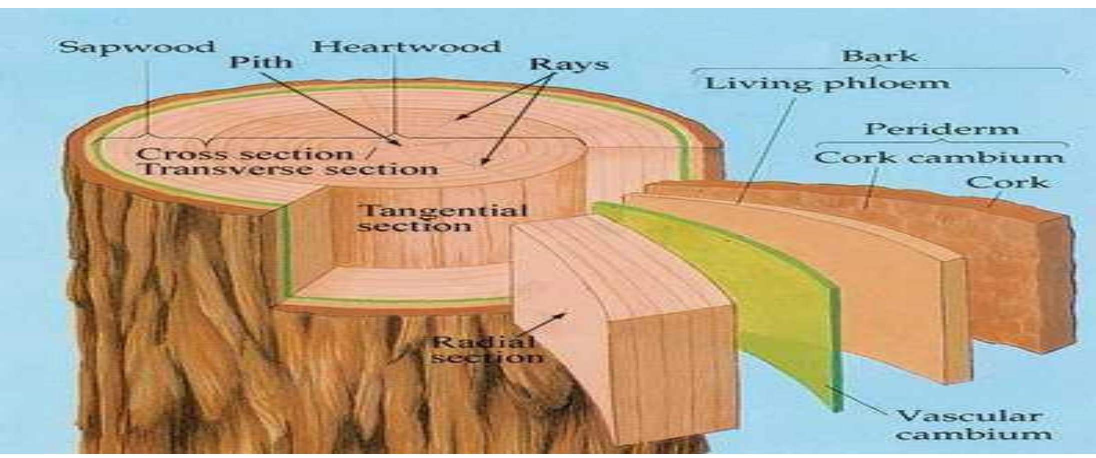


Figure 2.1: Cross-section of a trunk (Brostow et al., 2010)

In most trunks of trees, the first principal part to notice is the sapwood which is the outer, pale-coloured wood, lighter region close to the cambium that has three main functions in a tree: from the support to the conduction and the storage function. Furthermore, when the cells are dead, they convey water and minerals from the soil. Followed by the heartwood in the second instance which is the inner part of the wood that is mostly darker because of the resins and gums contained inside the cells but in contrast with the sapwood, the heartwood provides the main structural support for the trees. Meanwhile, it does not possess any living cells, water conducts or stores and is not essential in the growing process and the survival of the trees (Forest Products Laboratory, 1966). Another important part is the bark which shelters the interior of the trunk of the tree. The wood cells are produced by a layer of cells called the cambium that can only be seen using the microscope and inside all the tissues present at the center of the tree are referred to as xylem while those outside are the bark including the phloem that transport energy sources made by the plant and the cork layers. The ray and axial parenchyma cells, when initially produced by the cambium, are alive but they lose their cell contents and become hollow, microscopic tubes with lignified walls at the moment they become functioning, water-conducting cells, referred to as tracheids and vessels (Bamber, 1964).

2.1.1 Different types of wood

In a living tree from which h timber comes, the two main types of tree are softwood and hardwood which should not be mixed up with the hardness or softness of the wood itself but frequently, hardwood trees are denser than softwood ones though (Ragland, 2010).

Softwoods are woods from gymnosperm coniferous trees, evergreen with vertical cells called tracheid of about 3 mm long and roughly 30 μm wide sometimes referred to as non-pored wood such as Scots Pine which is the most world widely used softwood. Generally, softwoods provide longer trunks and grow faster in line with Ragland, (2010). These cells have an open channel and thin cell walls and are used for support and conduction while the storage cells are found in the radial direction. The water-conducting cells known as tracheid in softwood are taper in shape.

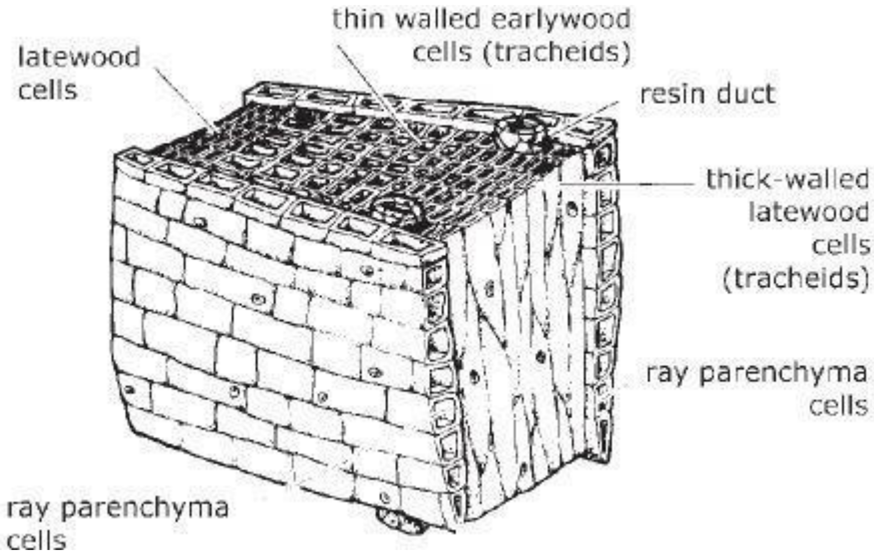


Figure 2.2: A section of Softwood (Primefacts, 2008)

Hardwoods are broad-leaved trees from dicot angiosperm or trees with enclosed seeds containing pores ranging in size and shape allowing water to travel from the roots to nourish the wood (Armstrong, 2017). They are made up of two distinct types of cells: the vessels that can usually be seen with the naked eye and the fiber cells that impart strength in the broad-leaved trees. They are reproduced by flowers with vertical cells of 1 to 2 mm long and 15 µm wide. These cells are thick-walled with a confining central channel, inappropriate for conduction, used only to support and so, the tree needs vessels for this purpose. Vessels are either open-ended xylem or phloem of 0.2 to 1.2 mm long, stacked vertically to form tubes of less than 0.5 mm in diameter (Primefacts, 2008). It is all produced by a fluid movement inside the capillary, reaching the tops of even very tall trees related to the surface tension. The vessels and the fibers in hardwood are tubular.

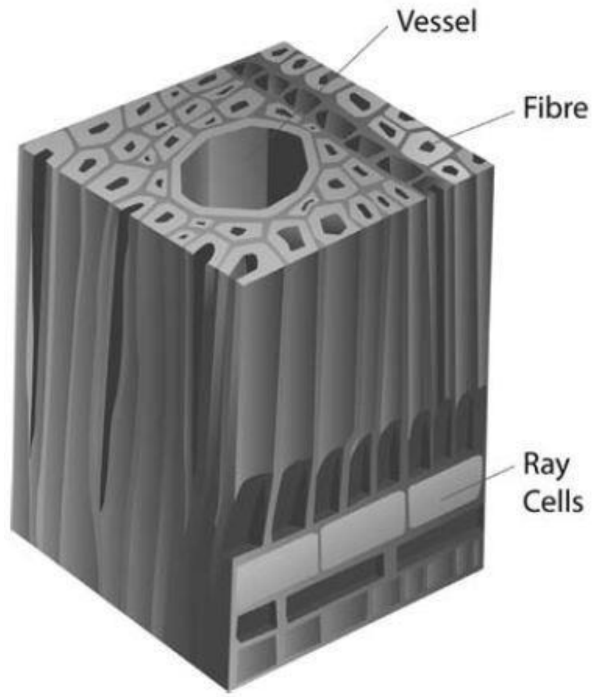


Figure 2.3: A close-up section of hardwood (Primefacts, 2008)

The strength property, shrinkage, and grain pattern properties of timber and other products are affected by the characteristics of the stalky cells and their arrangement. The microscopic cellular structure of wood including the ring in the cross-section of the stem or root of a temperate woody plant, produced by one year's growth and the ray that stores food in the stem, produces the characteristic grain patterns in different species of the trees. This grain pattern is also determined by the plane in which logs are cut at the sawmill. The ray cells unlike other cells are arranged horizontally, extending radially outwards and towards the bark. The annual rings appear like concentric bands with rays extending outward like each of the bars or wire rods connecting the center of a wheel to its outer edge (spokes) in transverse or cross-sections and can be counted to age-date the tree as shown in Figure 2.4 (Brostow et al., 2010).

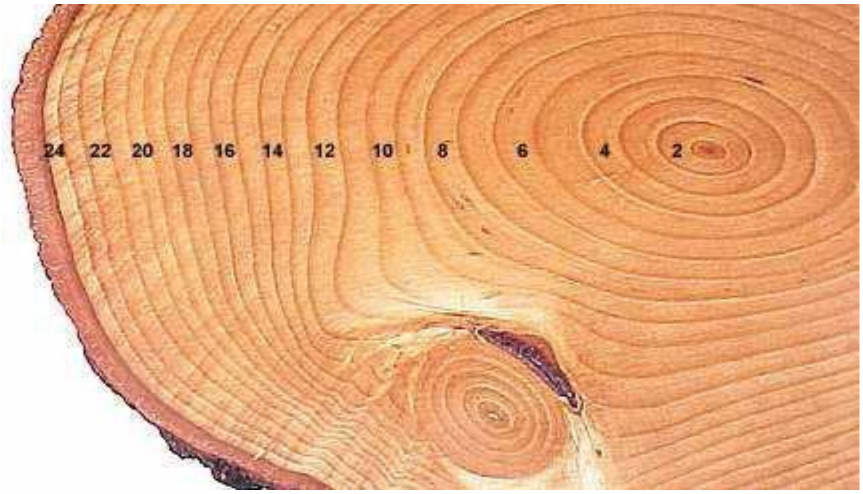


Figure 2.4: A tree cross-section with 24 distinct annual rings (Brostow et al., 2010)

2.1.2 Timber and its Appearance

Brostow et al. (2010), reported that timber is an organic construction material for most societies and describes sawn wood with a wide range of physical and mechanical properties for which it is important for the ones selected to have properties suitable for aspired use. The strength, appearance, durability, the moisture content (shrinkage rates) are the main properties affecting the choice of timber. But for certain applications, other properties such as density, hardness, fire performance, etc. are also important.

(Trada, 1999) affirmed that most timbers come in a variety of colors between and within species; timbers exposed to light and those that remain unprotected and exposed to weather will change color, especially for the latter once mold growth is developed. To broadly describe timber's appearance and some specific characteristics, the term grain may be used; it refers to the direction, size, and arrangement of the wood cells and should not be used alone instead for instance sloppy grain, wavy grain, spiral grain etc. (Forest and Wood Products Research and Development Corporation, 2004). Timbers also come in varieties of textures which can be coarse, fine, even, or uneven, etc., and based on the size and arrangement of wood cells, difference is made between the different types of texture. (National Association of Forest Industries, 2004). It can also divulge some other natural characteristics that can affect the strength properties and aesthetics like stains, splits gum veins, and knots which are the part of the branches embedded in the main stem of the tree and sloping grain.

2.1.3 Structural timber

Structural timber or timber machined for structural use has its constituents sawn from the tree trunk in a prismatic shape with a rectangular cross-section except for some exceptions in the shape. The size of the trees in the forest is the main factor that determines the maximum possible dimension of those constituents that are applied for load-carrying functions in structures. Many provisions in the production line to obtain the appropriate structural elements therefore exist; for instance, the longitudinal axis of a structural timber component should synchronize with the wood cells grain direction, (Kohler, 2007). As the outcome of the basic processing steps such as debarking, sawing, planning if necessary, finger-jointing only for some products, and gluing on the broader side, during the production of structural timber, its main characteristic is the anisotropic nature it has where the natural wood structure will be retained to a high degree (Angst et al., 2008).

concrete.

2.2 Timber as a Structural Material

Timber is characterized by anisotropic behavior, high strength-to-weight ratio, and excellent workability. Engineered wood products like LVL and glulam offer consistent mechanical properties and dimensional stability. Timber has been used as a structural material for thousands of years due to its natural abundance, ease of processing, and favorable mechanical properties. In modern structural engineering, timber has evolved from a traditional building material to an engineered product with consistent and predictable performance characteristics. With the growing emphasis on sustainability and carbon reduction in the built environment, timber is experiencing renewed interest as a primary or hybrid structural material. Timber is an orthotropic material, meaning it exhibits different mechanical properties along its three principal axes—longitudinal, radial, and tangential. Its longitudinal direction, which aligns with the grain, is the strongest and stiffest, making it particularly effective in resisting tensile and compressive forces along the grain.However, timber is relatively weak in tension and compression perpendicular to the grain and in shear, requiring careful detailing to avoid splitting and failure (Green & Evans, 2008). To overcome natural limitations of solid timber—such as knots, grain variability, and dimensional instability—engineered wood products (EWPs) have been developed. These are manufactured by bonding wood strands, veneers, or laminations under controlled conditions. Common EWPs include:

Glued Laminated Timber (Glulam): Made from layers of dimensional lumber bonded with durable adhesives. Offers high strength and can be curved into custom shapes.

Laminated Veneer Lumber (LVL): Thin wood veneers glued in the same grain direction, resulting in high strength and stiffness.

Cross-Laminated Timber (CLT): Layers of timber oriented perpendicularly and bonded together, providing dimensional stability and strength in multiple directions.

Oriented Strand Board (OSB): Used primarily in sheathing, it consists of wood strands bonded in specific orientations.

These products allow timber to compete with steel and concrete in terms of structural performance, especially in mid- and high-rise construction (Mohammad et al., 2012).

2.3 Composite Action in Timber-Concrete Systems

Timber-concrete composites (TCCs) have been studied primarily in floor systems where concrete bears compression and timber resists tension. The composite action is often achieved using mechanical fasteners, notches, or adhesive bonding. Composite construction integrates two or more distinct materials to act together structurally, achieving enhanced performance by utilizing the strengths of each. In timber-concrete systems, the goal is to combine timber's tensile strength and lightweight characteristics with concrete's compressive strength, rigidity, and mass. These systems are primarily used in floor construction, where timber beams or slabs are topped with a layer of reinforced concrete. Timber-concrete composites (TCC) are a response to the growing demand for sustainable, efficient, and low-carbon construction systems. By leveraging the complementary behavior of wood and concrete, TCC systems offer improved strength, stiffness, and serviceability compared to traditional timber floors, while being lighter and more sustainable than conventional reinforced concrete slabs (Dias et al., 2007). Composite action refers to the degree of cooperation between two bonded materials to resist loads. In a TCC system, full composite action implies that no slip occurs at the interface between timber and concrete, resulting in maximum structural efficiency. However, due to material differences and practical constraints, partial composite action is usually achieved. The effectiveness of composite action depends on interface connection system, material compatibility, stiffness of connectors, shear transfer capability. According to Lukaszewska (2009), partial interaction affects both flexural stiffness (EI) and load distribution, making accurate modeling and testing essential for design.

2.3.1 Structural Behavior of Timber-Concrete Composites

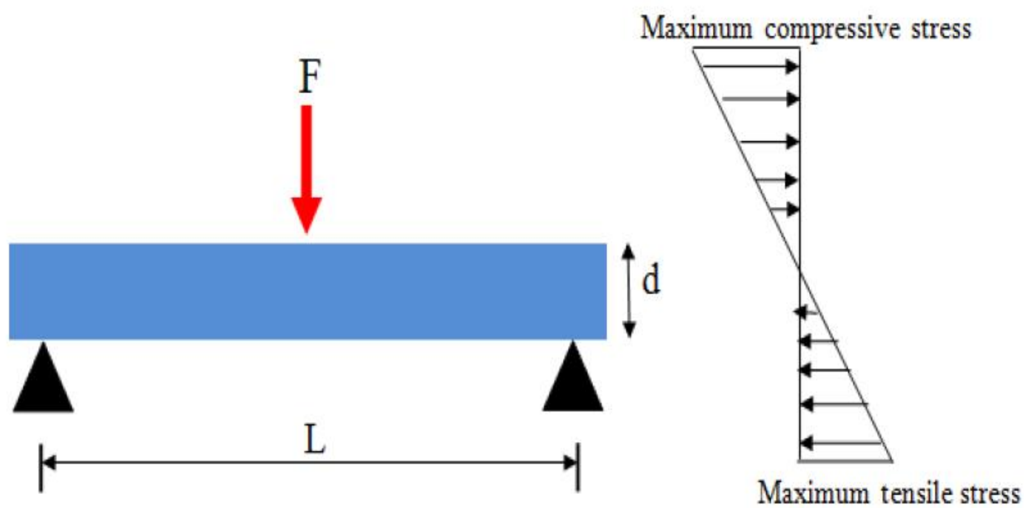
In bending, concrete (in compression) and timber (in tension) share the load based on their stiffness and the level of interaction at the interface. The effective bending stiffness of a TCC system lies between that of a non-composite (no-slip) and a fully composite (perfect bond) section. The γ-method, as introduced in Eurocode 5 (EN 1995-1-1), is a widely used design approach to quantify the degree of composite action by using a gamma factor (γ) to modify the stiffness of the system (Lukaszewska, 2009). Key structural benefits includes increased load-bearing capacity, reduced mid-span deflection, improved vibration performance, better sound insulation and fire resistance due to the mass of the concrete. Timber-concrete composite floors are increasingly used in residential and commercial buildings, retrofits of old timber structures (to increase capacity without full demolition), sustainable mid-rise and low-rise buildings and modular and prefabricated systems. Composite action in timber-concrete systems allows for the efficient use of both materials by combining their strengths. While full composite action is rarely achieved due to interface slip, partial interaction—properly designed—can result in structurally sound, cost-effective, and sustainable systems. These hybrid structures hold great promise for both new construction and renovation, particularly in low- to mid-rise applications where lightweight construction and environmental performance are priorities.

2.4 Flexural Strength

In the flexural test, the theoretical maximum tensile stress reached in the bottom fiber of a test beam or slab is known as the modulus of rupture, which is also flexural strength, bending strength, or fracture strength. When concrete is subjected to bending, the transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until it fractures or yields. The value of flexural strength would be the same as tensile strength if the materials are homogenous. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress represented with the symbol sigma. For determining the flexural strength or modulus of rupture, the following two systems of loading of the specimen may be adopted (Gupta & Gupta, 2004):

Central Point Loading

In this system of loading, the load is applied at the mid or central point of the test specimen which gives a triangular bending moment distribution. The maximum stress fiber stress will be below the point of loading where the bending moment is maximum. Thus, the maximum stress occurs at one section of the specimen, not necessarily the weakest section of the specimen. Figure 2.19 shows the arrangement of the apparatus in a one-point test to determine the flexural



strength of a rectangular beam.

Figure 2.1: Flexural test (Central loading). Source: (Gupta and Gupta, 2004)

For a rectangular sample under a load in a two-point bending setup (Figure 2.1), the flexural strength is calculated with equation (2.1)

(2.1)

Where

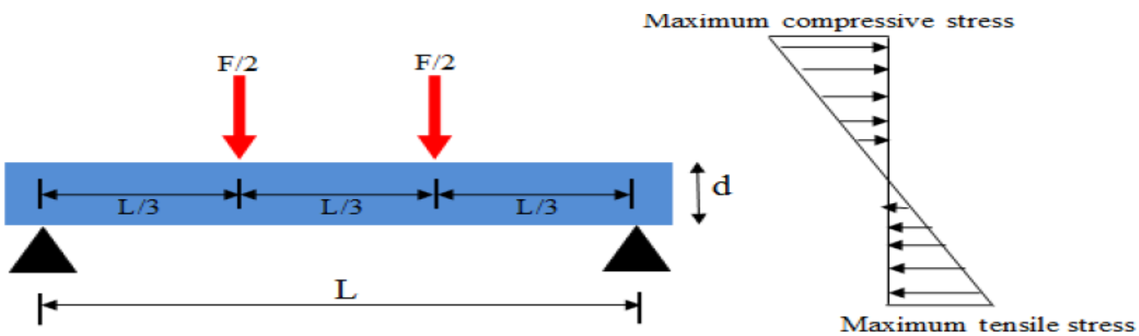
F is the load (force) at the fracture point (N) L is the length of the support span (mm)

b is width (mm)

d is thickness (mm)

Two Points Loading

This system of loading produces a constant bending moment between the load points so that one-third of the span is subjected to the maximum stress and thus in this region cracking is likely



to take place. Nowadays, this system of loading is taken as the standard method of loading. The system of two points loading is shown in Figure 2.2 For a rectangular sample under a load in a four-point bending setup (Figure 2.20) where the loading span is one-third of the support span, the flexural strength is calculated with equation (2.2)

Figure 2.2: Flexural test (Two points loading). Source: (Gupta and Gupta, 2004)

(2.2)

Where:

F is the load (force) at the fracture point (N) L is the length of the support span (mm)

b is width (mm), d is thickness (m)