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Wood and Wood Products

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4.1 INTRODUCTION

Wood is a hard and fibrous substance which forms a major part of the trunk and branches of a tree. It can also be defined as a natural polymeric material which practically does not age. Wood as a building material falls in two major classes—natural and man-made. With the advances in science and technology, wood in its natural form as timber, lumber, etc. is being rapidly replaced by composite wood materials in which natural wood is just a basic ingredient of a matrix or a laminate. The latter are found to be more useful and adaptable as they may be treated chemically, thermally or otherwise as per requirements. Some examples are plywood, fibreboards, chipboards, compressed wood, impregnated wood, etc.

Wood has many advantages due to which it is preferred over many other building materials. It is easily available (this won't be true after some years) and easy to transport and handle, has more thermal insulation, sound absorption and electrical resistance as compared to steel and concrete. It is the ideal material to be used in sea water. Wood is a good absorber of shocks and so is suitable for construction work in hilly areas which are more prone to earthquakes. Finally, since wood can be easily worked, repairs and alterations to wood work can also be done easily.

Owing to the above mentioned advantages, wood is very widely used in buildings as doors, windows, frames, temporary partition walls, etc. and in roof trusses and ceilings apart from formwork.

4.2 CLASSIFICATION OF TREES

Trees are classified as endogenous and exogenous according to the mode of growth.

Endogenous Trees

Trees grow endwards, e.g. palm, bamboo, etc.

Exogenous Trees

Trees grow outwards and are used for making structural elements. They are further subdivided as conifers and deciduous.

Conifers are evergreen trees having pointed needle like leaves, e.g. deodar, chir, fir, kail, pine and larch. They show distinct annual rings, have straight fibres and are soft with pine as an exception, light in colour, resinous and light weight.

Deciduous trees have flat board leaves, e.g. oak, teak, shishum, poplar and maple. The annual rings are indistinct with exception of poplar and bass wood, they yield hard wood and are non-resinous, dark in colour and heavy weight.

- Notes:** (i) Conifers, as compared to deciduous, are used predominantly for construction purposes for their long straight trunk and the better quality of wood.
 (ii) Characteristic differences between soft woods and hard woods are given in Table 4.1.

4.3 GROWTH OF TREES

In spring the roots of the tree suck sap as food from the soil which reaches the branches and the leaves. Sap contains moisture which gets evaporated. It absorbs carbon from air in presence of sunlight and becomes denser. In autumn, the sap descends and deposits in the form of a layer below the bark. This layer, referred to as the *cambium layer*, hardens and adds a layer of wood to the outside of tree every year in the form of concentric rings. These annual rings furnish valuable information regarding the age of the log, the rapidity and the uniformity of its growth.

Table 4.1 Difference between Soft-wood and Hard-wood

S.No.	Property	Soft wood	Hard wood
1.	Colour	Lighter	Darker
2.	Growth	Faster	Slower
3.	Weight	Lighter	Heavier
4.	Density	Low	High
5.	Annual rings	Distinct	Indistinct
6.	Heart wood and sap wood	Cannot be distinguished	Can be distinguished
7.	Strength	Strong along the grains	Strong along and across the grains
8.	Conversion	Easy	Difficult
9.	Resinous material	Exists in pores	Does not exist
10.	Examples	Chir, fir and others conifers	Teak, sal, sheesham, and other deciduous trees

Generally, the rings are widest at the centre and narrower nearer the bark. Also, the rings are widest at the bottom in young, thrifty trees and near the top in old ones. The cells formed in the

cambium layer are primarily cellulose and are commonly referred to as *fibres* because of their needle-like shape. They are cemented into groups by lignin, which gives the strength to wood. The comparative width of annual rings, the direction and the arrangement of the cells and fibres are the causes of the grains of the wood. Rapidly growing trees having wide annual rings produce coarse grained wood, while those of slower growth produce wood with narrow rings or fine grain. The wood is said to be *straight-grained* when the wood elements are straight and run parallel to the pith and *cross-grained* when the elements do not run parallel to the axis. Cross-grain has a pronounced weakening effect on the strength of beams when the slope of the grains is 1:15 or greater.

Timber should be felled as soon as it is matured. The best time is midsummer or midwinter, when the sap is at rest. If it is felled, when the sap is vigorous in movement, the timber decays. If the tree is cut young, it yields soft wood and if it stands too long, the decay starts.

4.4 CLASSIFICATION OF TIMBER (IS: 399)

The terms timber and wood are often used synonymously, but they have distinct meanings in the building industry. Wood is the hard, fibrous material that makes up the tree under the bark, whereas timber may be defined as a wood which retains its natural physical structure and chemical composition and is suitable for various engineering works. Following is the classification of timber as per IS: 399, except the classification of timber based on grading which is given in IS: 6534.

On the Basis of its Position

Standing Timber implies a living tree.

Rough Timber forms a part of the felled tree.

Converted Timber or Lumber are logs of timber sawn into planks, posts, etc.

On the Basis of Grading (IS: 6534)

All grading specifications are clearly distinguished between *structural* or *stress* grading, and *commercial* or *utility* grading based on Indian Standard classification.

Structural grading is also known as *stress* grading. However, there is a small distinction between the two. Structural grading refers to the principle by which the material is graded on the basis of visible defects which have known effects on the strength properties of the material. Stress grading refers to the principle by which the material is graded by consideration of maximum principle stresses to which it can be subjected.

Structural grading is further divided as:

1. Grading based on known effects of defects and estimating accumulative value.
2. Machine grading.

Commercial grading also known as *yard* grading or *utility* grading refers to the principle by which the material is graded by consideration of usefulness of the material and price factors. Commercial grading is further divided in the following classes:

Grade A: This classification is based on dimensions and general appearance. The dimensions of lengths, widths and thicknesses of converted materials are measured. This system is prevalent in Kerala and Mysore.

Grade B: This classification is based on the best ultimate use of the material. Such a system is mostly in Andhra Pradesh and some parts of Tamil Nadu. Here, each grade is further divided into A, B and C classes to indicate occurrence of defects. Only two lengths are recognized, long (L) which is 5m and above, and short(S) that is under 5m. Each log is stamped such as BAL (Beam, A-class, long), PBS (Plank, B-class, short), etc. Some times another letter is also added indicating the species, e.g. T for teak.

Grade C: This classification is based on qualitative evaluation of defects and rough estimate of out-turn of utilizable material. It is prevalent in Madhya Pradesh.

Grade D: This classification is based on evaluation of units of defects and fixing the permissible number of standard volume of area or the material in each grade. This system is prevalent in Bombay region and is increasingly adopted in Indian Standards and is recognized internationally.

On the Basis of Modulus of Elasticity

The species of timber recommended for constructional purpose are classified as

Group A: Modulus of elasticity in bending above 12.5 kN/mm^2

Group B: Modulus of elasticity in bending above 9.8 kN/mm^2 and below 12.5 kN/mm^2

Group C: Modulus of elasticity in bending above 5.6 kN/mm^2 and below 9.8 kN/mm^2

On the Basis of Availability

According to availability, timber can be of three grades, namely X, Y and Z.

X—Most common, 1415 m^3 or more per year

Y—Common, 355 m^3 to 1415 m^3 per year

Z—Less common, below 355 m^3 per year

This is based upon the figures supplied by the forest departments.

On the Basis of Durability

Test specimens of size $600 \times 50 \times 50 \text{ mm}$ are buried in the ground to half their lengths. The condition of the specimen at various intervals of time are noted and from these observations their average life is calculated. Timbers are classified based upon such observations as of:

High durability average life of 120 months and over.

Moderate durability average life of less than 120 months but of 60 months or more.

Low durability average life of less than 60 months.

On the Basis of Seasoning Characteristics

Timbers are classified depending upon their behaviour to cracking and splitting during normal air-seasoning practice under three categories.

Highly refractory (Class A) are slow and difficult to season-free from defects.

Moderately refractory (Class B) may be seasoned free from surface defects, etc. if some protection is given against rapid drying.

Non-refractory (Class C): These can be rapidly seasoned free from defects.

On the Basis of Treatability

This classification is based upon the resistance offered by the heartwood of a species to preservatives under a working pressure of 1.05 N/mm^2 as

- (a) Easily treatable.
- (b) Treatable but complete preservation not easily obtained.
- (c) Only partially treatable.
- (d) Refractory to treatment.
- (e) Very refractory to treatment, penetration of preservative being practically nil from the sides and ends.

4.5 STRUCTURE OF TIMBER

A tree can be divided into three portions, crown—composed of branches and leaves, trunk, and roots. The trunk accounts for about 80 per cent of the total bulk of wood.

Figure 4.1 shows the structure of well grown timber from trunk of the exogenous tree. The structure of timber visible to naked eye or at a small magnification is called *macro structure*, and that apparent only at great magnifications, the *micro structure*. Macro structure of the timber can be studied by cutting the trunk in three directions (Fig. 4.1 (a)). In the cross-sectional and radial ducts, the following main parts of a tree, e.g. bark, cambium, sap wood, heart wood and pith, become readily apparent (Fig. 4.1(b)). Each of the components has a specific function. The bark protects the wood against mechanical damage. Its inner layer, called bast conveys the nutrients from the crown downwards and stores them. The function of cambium is to grow wood cells on the inside and smaller bast cells on the outside. The sapwood assists in the life process of tree by storing up starch and conducting sap. The cells in the sap wood are active. The heart wood gives a strong and firm support to the tree. With the growth of tree, the cells in the inner older portion of trunk gradually become inactive and lifeless, but do not decay. This portion of the trunk is called heart wood. At the centre of the cross-section is the pith, a small area occupied by friable tissues consisting of thin walled, loosely connected cells called

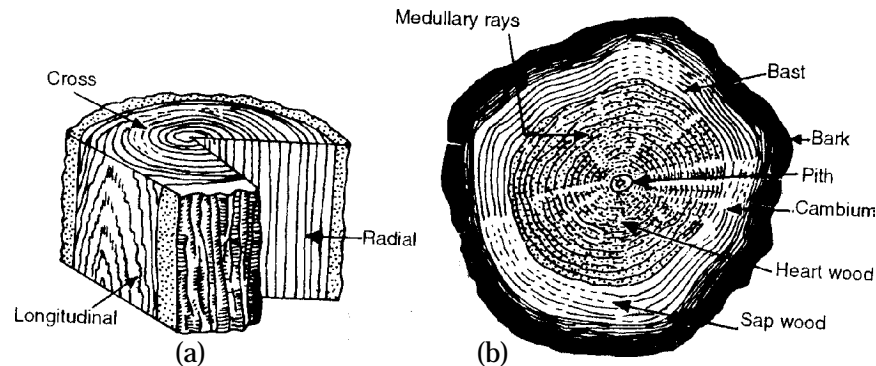


Fig. 4.1 Cross Section of a Tree

pith. In a felled tree, it easily crumbles and rots. In the cross-sectional direction, nutrients pass from bast to the heart through groups of cells running at right angles to the cambium layers and are referred to as medullary rays.

4.6 CHARACTERISTICS OF GOOD TIMBER

The principal characteristics of timber of concern are strength, durability and finished appearance.

1. Narrow annual rings, closer the rings greater is the strength.
2. Compact medullary rays.
3. Dark colour.
4. Uniform texture.
5. Sweet smell and a shining fresh cut surface.
6. When struck sonorous sound is produced.
7. Free from the defects in timber.
8. Heavy weight.
9. No woolliness at fresh cut surface.

4.7 SEASONING OF TIMBER

Timber cut from freshly felled trees is too wet for normal use and is dimensionally unsuitable. Seasoning is the process of reducing the moisture content (drying) of timber in order to prevent the timber from possible fermentation and making it suitable for use. It can also be defined as the process of drying the wood to a moisture content approximately equal to the average humidity of the surroundings, where it is to be permanently fixed. Very rapid seasoning after removal of bark should be avoided since it causes case hardening and thus increases resistance to penetration of preservatives. Some of the objects of seasoning wood are as follows:

1. Reduce the shrinkage and warping after placement in structure.
2. Increase strength, durability and workability.
3. Reduce its tendency to split and decay.
4. Make it suitable for painting.
5. Reduce its weight.

Methods of Seasoning

Timber can be seasoned naturally or artificially.

Natural or Air Seasoning: The log of wood is sawn into planks of convenient sizes and stacked under a covered shed in cross-wise direction in alternate layers (Fig. 4.2) so as to permit free circulation of air. The duration for drying depends upon the type of wood and the size of planks. The rate of drying is however very slow. Air seasoning reduces the moisture content of the wood to 12–15 per cent. It is used very extensively in drying ties and the large size structural timbers.

Artificial Seasoning: The prevalent methods of artificial seasoning are as follows:

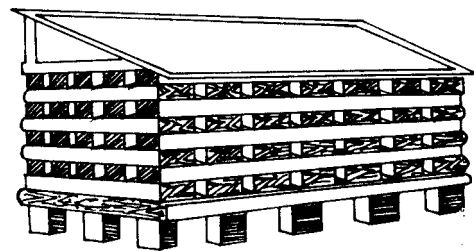


Fig. 4.2 Shed for Air Seasoning of Timber

Water Seasoning: The logs of wood are kept completely immersed in running stream of water, with their larger ends pointing upstream. Consequently the sap, sugar, and gum are leached out and are replaced by water. The logs are then kept out in air to dry. It is a quick process but the elastic properties and strength of the wood are reduced.

Boiling in water or exposing the wood to the action of steam spray is a very quick but expensive process of seasoning.

Kiln Seasoning is adopted for rapid seasoning of timber on large scale to any moisture content. The scantlings are arranged for free circulation of heated air with some moisture or superheated steam. The circulating air takes up moisture required from wood and seasons it. Two types of kilns, the progressive (Fig. 4.3 (a)) and the compartment (Fig. 4.3 (b)) are in use. For most

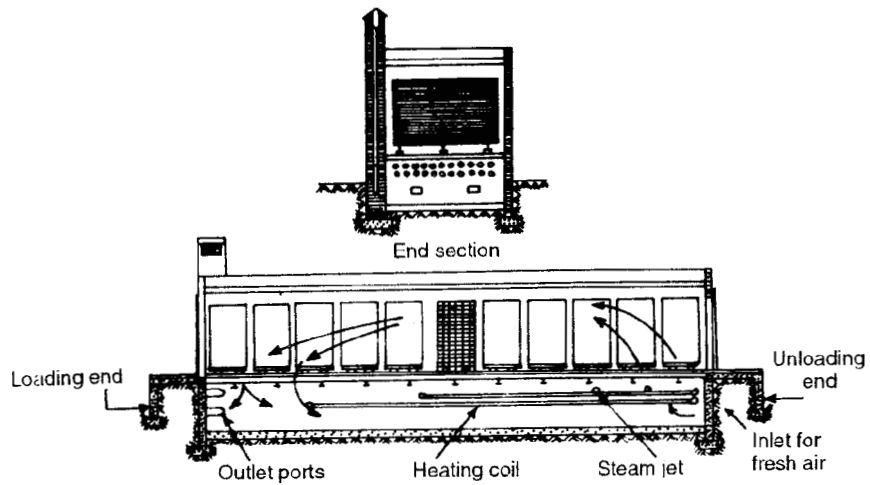


Fig. 4.3(a) Progressive Kiln

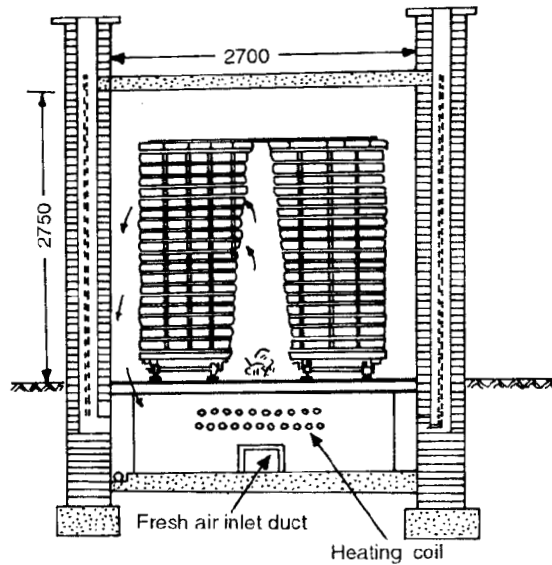


Fig. 4.3(b) Compartment Kiln

successful kiln-seasoning the timber should be brought to as high a temperature as it will stand without injury before drying is begun; otherwise the moisture in the hot outer fibers of the wood will tend to flow towards the cooler interior. With kiln drying there is a little loss in strength of timber, usually less than 10 per cent. Also, the wood is more thoroughly and evenly dried, thus reducing the hygroscopicity of the wood.

Chemical or Salt Seasoning: An aqueous solution of certain chemicals have lower vapour pressures than that of pure water. If the outer layers of timber are treated with such chemicals the vapour pressure will reduce and a vapour pressure gradient is setup. The interior of timber, containing no salts, retains its original vapour pressure and, therefore, tends to dry as rapidly as if there had been no treatment. The result is to flatten the moisture gradient curves, to reduce the slope of the curves, and consequently to reduce the internal stresses induced during drying. Since it is these stresses which are responsible for defects such as checks, etc. a chemically treated timber will exhibit fewer defects. Common salt or urea are generally used; the latter is preferred as the corrosive action of common salt is a drawback.

Electric Seasoning: The logs are placed in such a way that their two ends touch the electrodes. Current is passed through the setup, being a bad conductor, wood resists the flow of current, generating heat in the process, which results in its drying. The drawback is that the wood may split.

Mc. Neill's Process has no adverse effects; it is the best method although most expensive. The timber is stacked in a chamber with free air space (1/3rd of its capacity) and containing products of combustion of fuels in the fire place. The time required for complete seasoning is 15 to 60 days.

4.8 DEFECTS IN TIMBER

Defects can occur in timber at various stages, principally during the growing period and during the conversion and seasoning process. The defects in the wood as shown in Fig. 4.4 are due to irregularities in the character of grains. Defects affect the quality, reduce the quantity of useful wood, reduce the strength, spoil the appearance and favour its decay.

Defects due to Abnormal Growth

Following are some of the important defects commonly found in wood due to abnormal growth or rupture of tissues due to natural forces.

Checks is a longitudinal crack which is usually normal to the annual rings. These adversely affect the durability of timber because they readily admit moisture and air.

Shakes are longitudinal separations in the wood between the annual rings. These lengthwise separations reduce the allowable shear strength without much effect on compressive and tensile values. The separations make the wood undesirable when appearance is important. Both the shakes and checks if present near the neutral plane of a beam they may materially weaken its resistance to horizontal shear.

Heart Shake occurs due to shrinkage of heart wood, when tree is overmatured. Cracks start from pith and run towards sap wood. These are wider at centre and diminish outwards.

Cup Shake appears as curved split which partly or wholly separates annual rings from one another. It is caused due to excessive frost action on the sap present in the tree, especially when the tree is young.

Star Shake are radial splits or cracks wide at circumference and diminishing towards the centre of the tree. This defect may arise from severe frost and fierce heat of sun. Star shakes appear as the wood dries below the fibre saturation point. It is a serious fault leading to separated log when sawn.

Note: Shakes are most harmful to strength when they follow neutral plane of a beam or run diagonally across the tension side of it. In the first case, they weaken the resistance to horizontal shear, and in the second, they reduce the tensile strength.

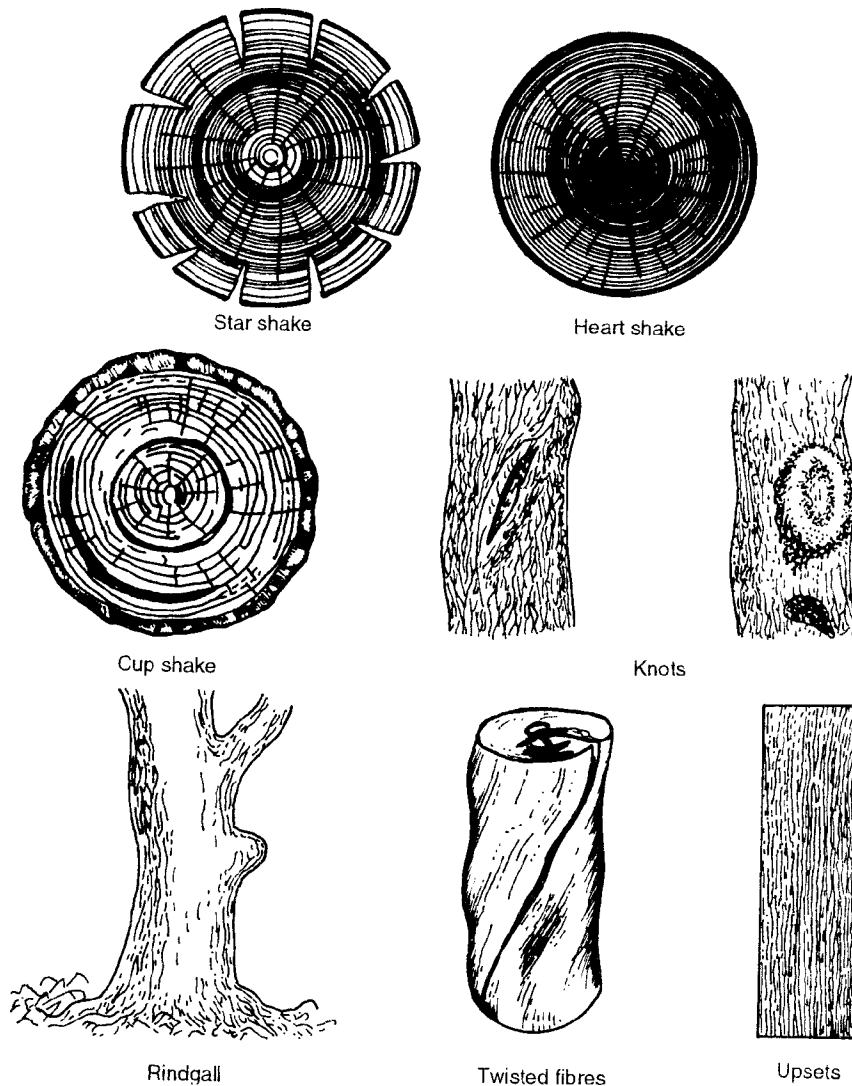


Fig. 4.4 Defects in Timber

Rindgall is characterised by swelling caused by the growth of layers of sapwood over wounds after the branch has been cut off in an irregular manner. The newly developed layers do not unite properly with the old rot, thereby leaving cavities, from where decay starts.

Knots are bases of twigs or branches buried by cambial activity of the mother branch. The root of the branch is embedded in the stem, with the formation of annual rings at right angles to those of the stem. The knots interrupt the basic grain direction of the wood, resulting in a reduction of its strength. In addition these affect the appearance of the wood. A *dead knot* can be separated from the body of the wood, whereas *live knot* cannot be. Knots reduce the strength of the timber and affect workability and cleavability as fibres get curved. Knots are classified on the basis of size, form, quality and occurrence.

Size Pin knot (under 12 mm), small knot (12–20 mm), medium knot (20–40 mm) and large knot (over 40 mm).

Form: Round knot and spike knot (a round knot exposed by sawing lengthwise).

Quality: Sound knot—as hard and solid as the surrounding wood, decayed knot—contains advanced decay and is softer than the surrounding wood, encased knot—the annual rings fail to grow into the fibres of the surrounding wood, tight knot—a knot so securely fastened that it holds its position in the finished product.

Occurrence: Single knot—when wood fibres deflect around one knot, cluster knot—when wood fibres deflect about two or more knots as a unit and, branch knot—two or more knots radiating from a common centre.

End Splits are caused by greater evaporation of sap at the end grains of log and can be reduced by painting the exposed end grains with a water proof paint or capping the exposed end with hoop iron bandage.

Twisted Fibres are caused by wind constantly turning the trunk of young tree in one direction.

Upsets are caused by the crushing of fibres running transversely during the growth of the tree due to strong winds and unskilled felling consequently resulting in discontinuity of fibres.

Foxiness is a sign of decay appearing in the form of yellow or red tinge or discolouration of overmatured trees.

Rupture is caused due to injury or impact.

Defects due to Conversion

Conversion is the term used to describe the process whereby the felled tree is converted into marketable sizes of timber. Conversion defects are basically due to unsound practice in milling or attempts to economise during conversion of timber. A *wane* occurs in timber which contains, on one or more faces, part of the bark or the rounded periphery of the trunk. This reduces the cross sectional area, with consequent reduction in strength in the parts affected. Excessive slope of grains may also be classed as a conversion defect when conversion has not been done parallel to the axis of the trunk.

Defects due to Seasoning

These defects are directly caused by the movement which occurs in timber due to changes in moisture content. Excessive or uneven drying, exposure to wind and rain, and poor stacking during seasoning can all produce distortions in timber. These defects result in loosening of fixings or disruption of decoration, or both. The common types of seasoning defects are:

checks—longitudinal separation of fibres not extending throughout the cross-section of wood; splitting—separation of fibres extending through a piece of timber from one face to another; warpage—consists of cupping, twisting and bowing.

4.9 DISEASES OF TIMBER

Dry Rot

It is decomposition of felled timber caused by the action of various fungi. The fungus reduces fibres to fine powder as shown in Fig. 4.5 and the timber loses its strength. This disease is highly infectious and causes tremendous destruction. It occurs when the timber is imperfectly seasoned and placed in a moist, warm and confined atmosphere having no free access of air. Fungus rapidly dies when exposed to air or sunlight. The best remedy is to cut away the affected part and paint the remaining part.

Note: Fungi that attack growing trees and continue to damage it in structures are known as white or brown rot, white trunk rot, etc.

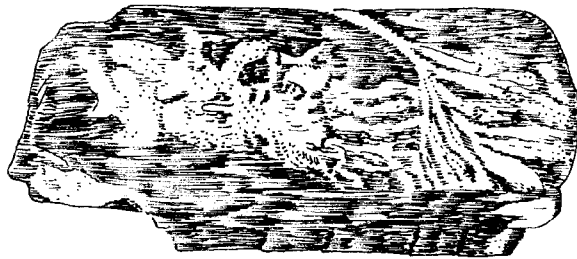


Fig. 4.5 Dry Rot

Wet Rot

When timber is subjected to alternate wet and dry conditions, decomposition of tissues takes place. This is not caused by fungal attack. In a living tree, it is set up by the access of water through wounds in the bark and causes the decomposition of sap and fibres of the tree. This may also occur when timber is seasoned by exposing it to moisture. To avoid wet rot, well seasoned timber is used with preservatives and paints.

4.10 DECAY OF TIMBER

Timber does not deteriorate by natural, physical or chemical changes or by pure ageing. It is, however, affected by destructive elements, such as weathering, chemical attack, fungi, insects or rodents. The most crucial amongst these are fungi, insects and rodents and are described as follows.

Decay due to Fungal and Bacterial Attack

Wood is essentially an organic substance, made up of a skeleton of cellulose impregnated with lignin. The organic substances are susceptible to attack by both bacteria and fungi. Bacteria are the smallest of living organism and do not cause any serious damage to timber, except for some discolourations. Fungi are a system of plant organism which live in and attack timber causing rot and decay.

The method by which bacteria decompose wood is probably similar in nature to a fungal attack. Fungi reproduce through minute particles called *spores*, millions of which are produced at the fruiting stage. These spores send out *mycelia*, which in turn destroy the wood tissue by secretions of solvent chemicals and enzymes. After a considerable proportion of the cell wall has been destroyed by mycelia, the wood becomes brittle and weak.

The basic requirements for the existence of fungi are moisture, suitable temperature and food supplies. The wood itself forms the food supply and optimum temperature conditions are in the range of 18°C to 30°C. Some fungi like *Merulius lacrymans* and *Poria incrassata* provide moisture by themselves and seem to thrive even in fairly dry wood leading to what is technically known as *dry rot*. The various symptoms of incipient decay are discolouration, abnormal mottled appearance, roughness of surface and presence of soft spots of intense discolouration.

Control of Fungi and Bacterial Attack: One of the prime requirements in the control of fungal attack is the dryness of timber. The timber should not be subjected to alternate wet and dry conditions. When this is unavoidable, a proper preservative treatment should be made. Felled trees should be air-dried as rapidly as possible and sawn timber should be kiln-seasoned properly in accordance with good air-seasoning practice. Thereafter, they should be protected from rain and other sources of moisture. It should be ensured that adequate ventilation is there around the timber to prevent fungal attack. Also, no timber used in a structure should contain sapwood which is more susceptible to fungal attack because of the food supplies stored in its parenchyma.

Damage due to Insects

Termites: Termites, or *white ants* as they are inappropriately called, are the most destructive of all insect agencies. They are small, social insects which form vast colonies and possess differentiated casts to carry on specialized functions in the social structure. They completely excavate the wood at the centre leaving the outer shell intact. They also attack furniture and wood work in houses and railway sleepers, etc.

Beetles are small insects and they cause rapid decay of timber by converting them into fine powder. Usually, the outer shell of timber remains intact and hence the timber looks sound from outside until it fails completely.

Powder post Beetles (Family Lyctidae) attack sapwood of hardwoods with large pores. The eggs are laid in the pores and the larva that comes out eats through the wood, leaving a very fine powder. Even seasoned timber containing sapwood is not immune to attack of these small beetles.

Long-horn Beetles (Cerambycidae) are 6 mm to 20 mm in size. They derive their name from long curved antennae. They normally do not attack seasoned wood and mainly thrive on timber in the forest yard. They can attack any type of wood, though they prefer sapwood. Their bore holes are elliptical in cross-section.

Ambrosia Beetles or Pin hole Borers are very common and attack structural timber, furniture and other wood work in house. They are less than 6 mm in size and attack both sapwood and heartwood. The larva bores tunnels through the wood which are filled with the characteristic oval-shape pellets.

Furniture Beetles (Anobiidae) are very common and attack structural timber, furniture and other wood works in houses. They are smaller than 6 mm in size and attack both sapwood and heartwood. The larva bores tunnels through the wood which are filled with the characteristic oval-shaped pellets.

Death watch Beetles (Xestobium) are somewhat larger than the previous one and the tunnels made by these are also bigger and filled with bun-shaped pellets. They normally attack timber infested with fungi or otherwise decayed.

Carpenter ants are usually black in colour and vary in size within the same nest. Unlike termites, they do not eat wood but merely tunnel it out for habitation. Their food is largely nectar, honeydew, and other sweet substances. They normally attack slightly rotted or water-softened wood but may continue into wood which appears perfectly sound. Timbers are often riddled with galleries before the presence of ants is detected. The frass ejected from the workings is quite coarse and shredding.

Control of Insects is much simpler than eradicating fungi. The tunnels made by the insects help in the deep penetration of toxic elements that are used to destroy them. Large scale fumigation is carried out using powerful hydrocyanic acid gas, but this method is not recommended as this gas is highly poisonous and dangerous. The use of creosote is also not desirable because of its odour and undesirable colour. A good insecticide which does not damage the paint or varnish and vapourises easily is yet to be found. The vapours should also not be dangerous to human beings. It is found that no insecticide can fulfill all these requirements in one application and periodic applications are required to be effective. The best alternative is common turpentine mixed with a small quantity of orthodichlorobenzene. This vapour is very deadly to insects and is not poisonous to human beings and animals.

Damage due to Rodents

Although the domestic rodents do not destroy timber in the same sense as the organism so far considered, they are capable of penetrating both wood and concrete. The problem of rodents is more serious in food-handling establishments.

Control of Rodents: The guiding principle is to close all openings or passages and making doors and windows capable of closure in a rat-tight manner by fixing metal sheets over the lower parts of doors.

4.11 PRESERVATION OF TIMBER (IS: 401)

The durability of wood is decidedly variable property. If well-seasoned and kept in a dry place, if immersed in water, or if buried in ground, wood often lasts for centuries. When, however, unprotected wood can easily decay by swelling (when it gets wet), fungi, insects, fire, etc. The rapidly with which it decays depends on external conditions, the species of the wood, its preliminary conditioning, and its structure. One of the basic approaches to protect it is to create conditions unfavourable to fungi. Low humidity, heat and water insulation, etc. help to maintain the timber dry and thus make it insusceptible to damage by fungi. Water absorption, decay and other undesirable effects can be minimized by coating the surface of wood with polymer films or drying oils, oil base paints, varnishes and synthetic enamels. Preservative treatment of timber is not supposed to improve its basic properties like mechanical, electrical, or chemical properties. Some of the methods used to poison the food supply to fungus are as below.

Oil Type Preservatives (Type 1) applied over outside of exposed timber, give unpleasant smell and are not suitable when timber is to be painted. The types in use are creosote, carbolinium, solignum etc. with or without admixture with petroleum or suitable oils having a high boiling range.

Organic Solvent Preservatives (Type 2): (*Preservatives Insoluble in Water*) consists of toxic chemical compounds, e.g. pentachlorophenol, benzene-hexa-chloride, dichlorodiphenyl

trichloro-ethane (D.D.T) and copper naphthenate. These are dissolved in suitable organic solvents like naphtha, or in petroleum products such as kerosene, spirit, etc. The treated timber can be painted, waxed or polished.

Acetic Anhydride Treatment is used for protection of veneers, plywood and light lumbers against decay by acetylation. They are treated with acetic anhydride vapour, which minimises swelling and improves resistance to decay and attack by insects.

Water Soluble Preservatives (Type 3) are odourless organic or inorganic salts and are adopted for inside locations only. If applied over outside surfaces, the salts can be leached by rain-water. Examples of leachable (3A-water soluble) type of preservatives are zinc chloride, boric acid (borax), etc. Zinc chloride, sodium fluoride and sodium-penta-chloro-phenate are toxic to fungi. These are expensive and odourless (except for sodium-penta-chloro-phenate). Benzene-hexa-chloride is used as spray against borers. Boric acid is used against *Lyctus* borers and to protect plywood in tea chests.

Some of the other water soluble preservatives are fixed (3B-water soluble) type and are as follows.

Copper-chromate-arsenic composition is made of three chemicals.

Arsenic-pentaoxide	$\text{As}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$	1 part
Copper sulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	3 parts
Sodium or potassium dichromate	$(\text{Na or K})_2 \text{Cr}_2\text{CO}_7$	4 parts

The preservative is in the form of a powder and is used with water. Six parts of this powder is mixed with 100 parts by weight of water. The solution is applied in two coats. The timber is then allowed to dry for six weeks. This treatment renders the timber immune to the attacks of white ants and is known as *AsCu treatment*.

Acid-cupric-chromate composition

Chromic acid	1.7 parts
Copper sulphate	50 parts
Sodium dichromate	48.3 parts

Chromate-zinc chloride composition

Zinc chloride	1 part
Sodium or potassium dichromate	1 part

Copper-chrome-boric composition

Boric acid	1.5 parts
Copper sulphate	3 parts
Sodium or potassium dichromate	4 parts

Zinc-meta-arsenite composition

Arsenious trioxide	3 parts
Zinc oxide	2 parts
Acetic acid	Just to keep the above in solution under operating conditions

Zinc-chrome-boric composition

Boric acid	1 part
Zinc chloride	3 parts
Sodium dichromate	4 parts
Water	100 parts

Various Treatment Processes (IS: 401)

Surface Application is done either by spraying, dipping or by brushing the preservative for a short period on thoroughly debarked timber. For the oil type preservatives, the moisture content in timber should not be more than 14 per cent. With water soluble preservatives, a moisture content of 20 to 30 per cent is permissible. At least two coats should be applied. The second and subsequent coats should not be applied until the first one has dried or soaked into the wood. Where possible, the treatment is done hot. Surface treatment is used mostly for treating timber at site and for retreatment of cut surfaces.

Soaking Treatment consists in submerging debarked timber in the preservative solution for a sufficiently long period until the required absorption of the preservative is obtained. For dry vineers 15–30 minutes of soaking are enough.

Hot and Cold Process ensures sterilisation against fungi and insects. The timber is submerged in the preservative solution. Which is then heated to about 90° to 95°C and maintained at this temperature for a suitable period depending on the charge. It is then allowed to cool until the required absorption is obtained. During the heating period, the air in the timber expands and is partially expelled. While cooling, the residual air in the timber contracts and creates a partial vacuum which causes the preservative to be sucked into the timber. Generally two baths are used, the first containing water where the hot treatment is given and the second the cold bath containing the preservatives into which the timber is transferred immediately after heating. This overcomes the danger of precipitation of chemicals at high temperatures. This arrangement also helps to make the process continuous in case the quantity of timber is large.

Boucherie Process: Sapwood of almost all green timbers with the bark on and of bamboos in green condition, soon after felling, can be treated using any of the inorganic water soluble preservatives by this process. The log of wood attached to the hose pipe and connected to the reservoir containing preservative at an air pressure of 0.1–0.2 N/mm² on its surface is shown in Fig. 4.6. Due to hydrostatic pressure, the preservative displaces the sap in the wood. The treatment is stopped when the concentration of preservative at the lower end of the log is the same as that in the reservoir.

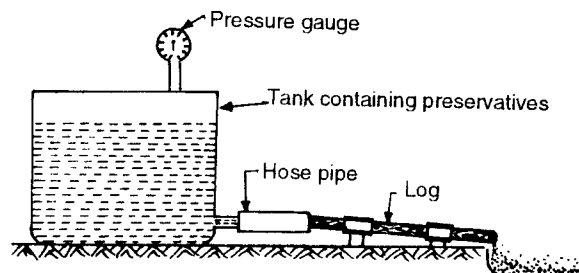


Fig. 4.6 Boucherie Process

Full Cell or Bethel Process is essentially a pressure process and is used when maximum absorption of the preservative is desired. The timber charge is introduced into the cylinder. The door is tightly closed and then a vacuum of at least 560 mm of mercury is created and maintained for half an hour to remove as much air as possible from the wood cells. At the end of the vacuum period, the preservative is introduced into the cylinder, with the vacuum pump working. When the cylinder has been filled with the preservative, the vacuum pump is stopped and the cylinder is subjected to an antiseptic pressure of 0.35 to 1.25 N/mm² depending on the species, size, refractory nature of timber, etc. to inject the preservative into the timber. The pressure is held until the desired absorption is obtained. The preservative is then withdrawn from the cylinder and finally a vacuum of 380 to 560 mm of mercury for about 15 minutes is once again applied to free the timber from dripping preservative. Specified retention of toxic chemicals in the timber during the treatment can be had by a proper selection of the concentration of the toxic material in the treating solution. Desired absorption of the preservative solution is controlled by the duration of pressure and vacuum period.

Empty Cell Processes are also known as *pressure processes* and are aimed at a maximum penetration of the preservative with a minimum net retention. The Lawry process and the Rueping process are commonly used.

Lawry Process: The cylinder is loaded with timber and closed, followed by filling with the preservative. An antiseptic pressure of 0.35 to 1.25 N/mm² depending on the timber species, size, etc. is applied until the required absorption is obtained. The pressure is released when a certain part of the preservative injected into the timber is expelled due to the expansion of the entrapped air in the cells. The cylinder is then drained off and finally, a vacuum is applied as described in full cell process.

Rueping Process: In this process, the cylinder is charged with timber and closed. An air pressure of 0.175 to 0.5 N/mm² is applied for a specified period depending upon the sapwood content of the timber and is maintained during the subsequent stage of filling up the cylinder with the preservative. When the cylinder is filled, an antiseptic pressure of 0.5 to 1.25 N/mm² depending on species, size, etc. is applied until the desired absorption is obtained. This is followed by a vacuum as described under full cell process. In this process, the preservative expelled on the release of the antiseptic pressure is considerable, yielding a low net absorption. This process is specially recommended for treating timber of mixed species and timbers containing sapwood and heartwood.

Diffusion Process: The diffusion process is a method of treatment of timber (poles and planks) and other plant material like bamboos, canes, palm leaves, veneers etc., in green condition. It lends itself best in the case of timbers which are not easy to impregnate under pressure in dry condition, and also, where there is danger of timber getting deteriorated during seasoning, particularly if air-seasoning is adopted. It may be employed in any of the following manners:

- (a) Momentary dipping in concentrated solution and then close stacking under cover. For refractory veneers over 1.6 mm, 15 minutes soaking and 1 to 2 hours stacking is necessary. It is essential that the glue used for subsequent bonding is compatible with the preservative.
- (b) Prolonged immersion in dilute solution and then close stacking under cover.
- (c) Application of a paste of the preservative over all the surfaces of the timber and then close stacking under cover. This is specially recommended for treatment of refractory species like fir generally used as railway sleepers.
- (d) Injecting the paste into timber through incisions interspread on the surfaces of timber.

4.12 FIRE RESISTANCE OF TIMBER

Timber is very inflammable. The fire hazard of timber structures is, however, often overemphasized. When wood burns, the first step is the vapourisation of moisture (118°C) and the next is the volatilisation of extraneous materials (110–165°C). At temperatures (165–220°C) well below the ignition point, destructive distillation or decomposition begins with scorching and evolution of inflammable gases which ignite and form the first flames around the heated wood. As the temperature builds up, the evolution of gases is more rapid and the surface of the timber begins to char. Finally, the point is reached at which the wood itself begins to glow and to ignite (220–390°C). Until this point is reached, the woody portion does not support its own combustion. Quick ignition of inflammable gases and glowing of charcoal occur at about 390–530°C.

Fire proofing makes timber resistant to fire to a degree that it is difficult to ignite and support its own combustion. The fire resistance of wood can be enhanced either by impregnating it with chemicals like phosphates of ammonia, mixture of ammonium phosphate and ammonium sulphate, borax and boric acid, sodium arsenate, sodium tetra-borate or by designing wood to provide slow burning construction.

Chemical Methods

These include the impregnation of timber with effective chemicals, or by coating the surface of timber with a layer of noncombustible paint.

Impregnating with Chemicals: As chemicals are water soluble, they are leached out due to rain when applied on exposed structures. Therefore, a second shallow impregnation with a fire-retardant, water-repellent sealer or paints like flamex and bitulac fire-retardant paint is applied which substantially retards leaching. Fire-retardant salts are impregnated by pressure process. Able's process for making wood fire resistant is as follows:

The surface of wood is painted by a weak solution of sodium silicate. Thereafter slaked lime solution of the consistency of a paste is applied followed by the application of concentrated solution of sodium silicate in two coats, the second being applied after 6 hours of the first coat. The composition of the solution is:

Sodium silicate	56 g
Water	50 g
Kaolin	75 g

Surface Coating Method: The most commonly used flame retardant coatings are cement grouts, clay-sulphate paste; paints such as silicate, chloride, phosphate paints and; emulsions like chloro paraffin. Some fire retardants (chemicals) form a film on the surface of wood and decompose under heat yielding non-inflammable gases that dilute the inflammable gases and consequently retard the ignition of the latter. Some of the other fire retardants have low melting point. These melt under heat and form a barrier to the supply of oxygen to the inside.

Structural Method

There is considerable difference between the burning of thin wooden members and that of large timbers. Timber of substantial dimension offers high resistance to fire. Heavy timber on

burning form a protective coating of charcoal, which being a heat insulator retards the penetration of heat to the interior. On the contrary, thin members quickly reach the ignition point and burn rapidly. Once the fire is started, flames rise upward in case of wood and hence, wood which is in vertical direction catches fire easily. That is why windows and doors burn more rapidly as compared to beams and floors.

4.13 TESTING OF TIMBER (IS: 1708)

The evaluation of basic properties of timber, such as strength, density effect of various treatments on strength, etc. and the establishment of design functions for structural timber has been done on the basis of tests carried out on small clear specimens of timber. A clear specimen is one which is free from defects, such as knots and shakes. The comparison of strength properties of different timber species is also done on the basis of the tests carried out on the clear specimen. In the actual design of timber structures the effect of different kinds of defects on clear specimen is assessed and after making necessary allowance for the defects, the resultant values are used.

In order to obtain a good average figure, which is truly representative of the species, it is necessary to take samples from green timber as well as from seasoned timber and also sapwood, heartwood and from different parts of the same tree. For standard evaluation of physical and mechanical properties of a species from a locality, at least ten trees are chosen at random from the locality and sampling of material for different test is done.

Specific Gravity Test

Almost all the mechanical properties of seasoned timber vary with moisture content and it is therefore necessary that the moisture content of the timber and its specific gravity be determined at the time of tests, preferably immediately after the tests.

Test specimens 50 × 50 mm in cross-section and 150 mm in length or 20 × 20 mm in cross-section and 60 mm in length are used to determine the sp. gr. of the wood. When rectangular specimens are not obtained, a specimen of about 10 cc volume may be used.

The specimen is weighed and its dimensions are measured. Then, volume is calculated by multiplying all the three dimensions. The volume of irregular specimen is determined by mercury volumeter. The level of mercury in the volumeter is raised to the given mark on the capillary tube and reading is noted. The level is then brought down and specimen is inserted in the volumeter. After raising the level to the given mark, the reading is taken again. Care is taken that no air bubble is entrapped in the volumeter. The difference of the two readings is the volume of the specimen.

Specific gravity is calculated as under:

$$\text{Specific gravity at test} = \frac{W_1}{V_1}$$

$$\text{Adjusted specific gravity} = \frac{W_1}{V_1} \times \frac{100}{100 + m}$$

Where W_1 = weight of test specimen
 V_1 = volume of test specimen (mm³)
 m = percentage moisture content of the test specimen

Note: If initial condition of the specimen is green (that is, well above the fibre saturation point) adjusted specific gravity is known as standard specific gravity; and if the specimen is dry, the specific gravity is called dry specific gravity. The weight (kg/m^3) at a given moisture content (m) = specific gravity at given moisture content (m) \times 1000.

Volumetric Shrinkage Test

Volumetric shrinkage is determined on $50 \times 50 \times 150$ mm or $20 \times 20 \times 60$ mm specimen.

The specimen is weighed initially (usually green) and the volume determined. A suitable vessel, half filled with water, is kept on the pan of a weighing balance and weighed. The specimen is then completely dipped in water by means of a needle as shown in Fig. 4.7 and weighed again. The difference of the two readings is volume of the specimen.

The specimen is taken out of the water, wiped with dry cloth, end-coated by immersion in hot paraffin, allowed to air-season under room conditions and weighed periodically until moisture content of about 12 per cent is reached. The volume is determined again. The specimen is then kept in an oven at $103^\circ \pm 2^\circ\text{C}$ until an approximately constant weight is reached. After oven-drying, the specimen is again weighed and, while still warm, is immersed in hot paraffin-wax bath, care being taken to remove it quickly to ensure only a thin coating. The volume of the paraffin-coated specimen is determined by immersion as before.

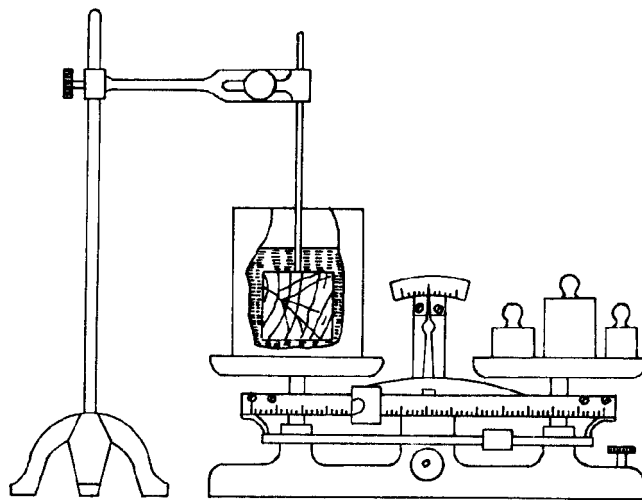


Fig. 4.7 Apparatus for Determination of Volumetric Shrinkage

Volumetric shrinkage from initial condition to required dry condition

$$= \frac{V_1 - V_r}{V_1} \times 100 \text{ per cent of volume in original condition}$$

$$\text{Moisture content, per cent} = \frac{W_r - W_0}{W_0} \times 100$$

$$\text{The oven dry specific gravity} = W_0 / V_0$$

where W_1 and V_1 = weight and volume at initial condition (usually green)

W_r and V_r = weight and volume at the initial required dry condition at r per cent moisture content (usually 12 per cent moisture content or oven dry condition)

W_0 and V_0 = weight and volume at the oven dry condition

Radial and Tangential Shrinkage and Fibre Saturation Point Test

Test specimens of $20 \times 20 \times 50$ mm sizes are cut truly radial or tangential as the case may be in lengthwise direction.

The specimen is weighed initially (usually green) and the length of the specimen is measured by means of a special screw gauge shown in Fig. 4.8. The specimens are allowed to air-season and periodically weighed and measured, until a uniform moisture content of nearly 12 per cent is reached. The specimens are then dried in an oven at $103^{\circ} \pm 2^{\circ}\text{C}$ until an approximately constant weight is attained. Finally, the specimen is weighed and measured.

The radial and tangential shrinkage are calculated from the following formulae:
 Shrinkage, s , tangential or radical from green to the required dry condition

$$= \frac{l_1 - l_r}{l_1} \times 100 \text{ per cent}$$

$$\text{Moisture content, } r, \text{ per cent} = \frac{W_r - W_0}{W_0} \times 100 \text{ per cent}$$

where W_1 and l_1 = weight and length in the initial condition (usually green)
 W_r and l_r = weight and length at r per cent moisture content
 W_0 = weight at oven dry condition

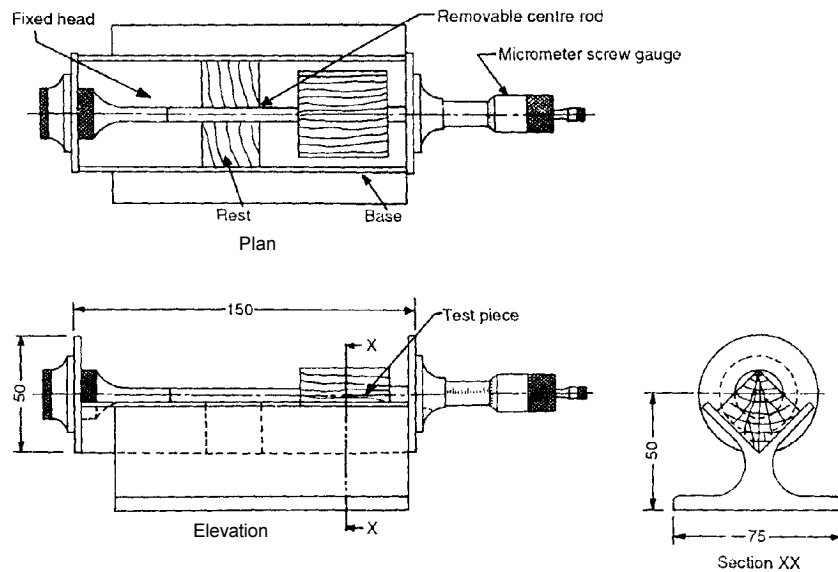


Fig. 4.8 Apparatus for Radial and Tangential Shrinkage

A graph is plotted with r as the ordinate and s as the abscissa. From this graph, the moisture content at which shrinkage commences appreciably is noted. This is known as Y_0 point. The average value of the Y_0 point in the radial and tangential cases is taken as fibre saturation point.

Static Bending Strength Test

One Point Loading Test: The specimen may be $50 \times 50 \times 750$ mm or $20 \times 20 \times 300$ mm. The test specimen is supported on the rig as shown in Fig. 4.9. The load is applied continuously at a constant rate of 2.5 mm per minute in case of $50 \times 50 \times 750$ mm and 1.0 mm per minute in case of $20 \times 20 \times 300$ mm.

Deflections of the neutral plane at the centre of the length are measured with respect to the points in the neutral plane above the supports. Deflections of the neutral axis are measured at the centre of the beam.

Deflection is measured at suitable load intervals such that about 8–10 readings are available up to limit of proportionality. Beyond the limit of proportionality up to maximum load or beyond maximum load the test is continued until a deflection of 150 mm for 750 mm and 60 mm for 300 mm specimens is reached or the specimen fails to support 1000 N for 50 × 50 × 750 mm or 200 N for 20 × 20 × 300 mm specimens, whichever is earlier.

The failure of the specimen is recorded according to its appearance and development as indicated in Fig. 4.10. The readings of deflections and the load recorded and a load-deflection curve is drawn. The various characteristics are determined by the following formulae and from the load-deflection curve. The area is measured by a calibrated planimeter.

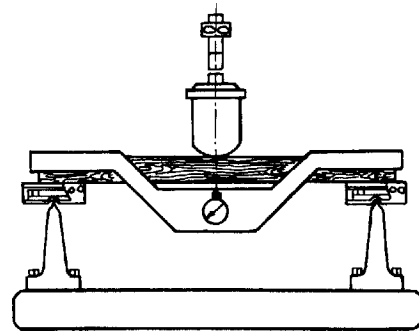


Fig. 4.9 Static Bending Test Equipment

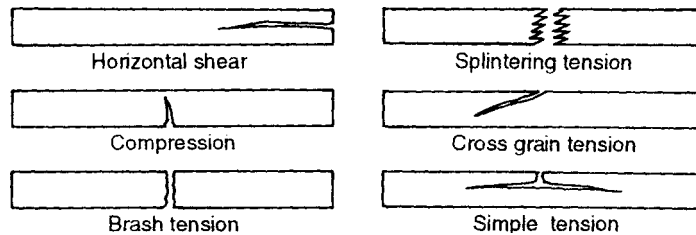


Fig. 4.10 Failure of Timber Specimen Under Static Bending Test

S. No.	Characteristic	Unit	Formula
1.	Fibre stress at limit of proportionality	N/mm ²	$\frac{3Pl}{2bh^2}$
2.	Equivalent fibre stress at maximum load (modulus of rupture)	N/mm ²	$\frac{3P'l}{2bh^2}$
3.	Modulus of elasticity	N/mm ²	$\frac{Pl^3}{4\Delta bh^3}$
4.	Horizontal shear stress on neutral plane at limit of proportionality	N/mm ²	$\frac{3P}{4bh}$
5.	Horizontal shear stress at maximum load	N/mm ²	$\frac{3P'}{4bh}$
6.	Work to limit of proportionality (elastic resilience)	N mm/mm ³	$\frac{CA}{lbh}$

7.	Work to maximum load	N mm/mm^3	$\frac{CA'}{lbh}$
8.	Total work	N mm/mm^3	$\frac{CA''}{lbh}$

where P = load at the limit of proportionality, the point in load-deflection curve at which the graph deviates from the straight line.

l, b and h = the length width and height of the test specimen respectively

P' = maximum load

Δ = deflection at the limit of proportionality

C = area constant

A = area of load-deflection curve up to limit of proportionality

A' = area up to maximum load

A'' = area up to the final reading when total work is required

Two-point Loading Test: The specimen may be $50 \times 50 \times 1000$ mm or $20 \times 20 \times 400$ mm. The distance between points of application of the load and the supports (Fig. 4.11) is 150 mm for 50×50 mm and 60 mm for 20×20 mm cross-sections. The load is applied at a constant rate of 3 mm per minute and 1.5 mm per minute in the two cases, respectively.

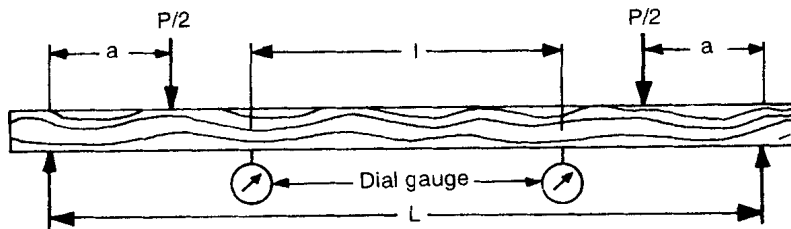


Fig. 4.11 Two Point Load Test

Deflection of neutral axis is measured at the mid span. The distance L between these two points (also called as gauge length) is kept 400 mm and 160 mm for the two specimens respectively. The deflection is measured at suitable load intervals such that 8-10 readings are available up to limit of proportionality and continued up to maximum load. The failure of the specimen is recorded according to its appearance and development as indicated in Fig. 4.10. A graph is plotted with load as ordinate and deflection as abscissa and the limit of proportionality, that is, the point at which the curve deviates from straight line is evaluated. The various characteristics are determined by the following formulae:

S. No.	Characteristic	Unit	Formula
1.	Fibre stress at limit of proportionality	N/mm^2	$\frac{3Pa}{bh^2}$
2.	Equivalent fibre stress at maximum load	N/mm^2	$\frac{3P'a}{bh^2}$

3.	Modulus of elasticity	N/mm ²	$\frac{3 Pa l^2}{4 bh^3 \Delta}$
4.	Horizontal shear stress on neutral plane at limit of proportionality	N/mm ²	At centre = 0 At ends = $\frac{3P}{4 bh}$
5.	Horizontal shear stress at maximum load	N/mm ²	At centre = 0 At ends = $\frac{3P}{4 bh}$
6.	Work to limit of proportionality (elastic resilience)	Nmm/mm ³	$\frac{P\Delta}{2 lbh}$

where l = distance between two fixed points for which deflection is recorded in mm (gauge length).

Impact Bending Strength Test

The specimen for impact bending test is same as that used for static bending strength test. The test is conducted on a suitable impact bending machine. The span is 700 mm in case of 50 × 50 × 750 mm and 280 mm in case of 20 × 20 × 300 mm specimens. The hammer is 25 kg and 1.5 kg for the two specimen sizes, respectively.

Static deflection x due to the weight of the hammer is measured at the centre of the specimen. For recording of deflection, a drum is provided which can be brought in contact with a stylus attached to hammer and can be rotated on a vertical axis. On the drum, a paper is fixed by means of sticking tape, under which a carbon paper is placed inverted for recording the impressions. First, a datum line is marked by placing the hammer to rest on the specimen and rotating the drum with stylus touching it. After that, the hammer is dropped from different heights and deflection recorded on the paper fixed on the drum. The first drop of hammer is from a height of 50 mm after which the height of the successive drops is increased by 25 mm until a height of 250 mm is reached, and thereafter increment in height is 50 mm until complete failure occurs or 150 mm or 60 mm deflection is reached for the two sizes, respectively. Deflections due to successive drops are recorded. For this purpose, at the drop of the hammer, the drum is rotated as the hammer rebounds.

From the tracing on the drum, record the actual deflection at each drop (that is, the distance from the lowest point to the datum line). A graph is then plotted with the exact height of drop plus maximum deflection at that drop $H + (x + y)$ as the ordinate and $(y + x)^2$ as the abscissa. The point at which the curve deviates from a straight line is taken as limit of proportionality. The various characteristics should be determined by the following formulae:

<i>S. No.</i>	<i>Characteristic</i>	<i>Unit</i>	<i>Formula</i>
1.	Maximum height of drop	mm	H
2.	Height of drop at limit of proportionality	mm	H'
3.	Fibre stress at limit of proportionality	N/mm ²	$\frac{3 H' W I}{bh^2 \Delta}$

4.	Modulus of elasticity	N/mm ²	$\frac{H'Wl^3}{2bh^3\Delta^2}$
5.	Work to limit of poroportionality	N mm/mm ³	$\frac{H'W}{lbh}$

where H = maximum height of drop under the given weight
 H' = height of drop at the limit of proportionality read from the curve (inclusive of deflection $x + y$)
 W = weight of the hammer
 l = span of the test specimen
 b = breadth of the test specimen
 h = depth of the test specimen
 Δ = ($y + x$) at limit of proportionality from the curve

Compressive Strength Test

Parallel to Grain: The specimen may be 50 × 50 × 200 mm or 20 × 20 × 80 mm. The load is applied continuously during the test at a constant rate of 0.6 mm per minute for both the sizes.

For 200 mm specimen a load of 2.5 kN is initially applied to set the specimen. Deformation under compression is then measured over a central gauge length of 150 mm. Where possible, direct points are obtained on a graph sheet. The reading is continued well beyond the proportional limit. The final reading at the maximum load is recorded. For 80 mm specimen, final reading of the maximum load only is recorded.

Compression failures are recorded according to the appearance of the fractured surface as shown in Fig. 4.12. In case two or more kinds of failures develop, they are described in the order of their occurrence (for example, shearing followed by crushing). The load deformation curves are drawn. Load and deformation at limit of proportionality are then read accordingly. the various characteristics are determined by the following formulae:

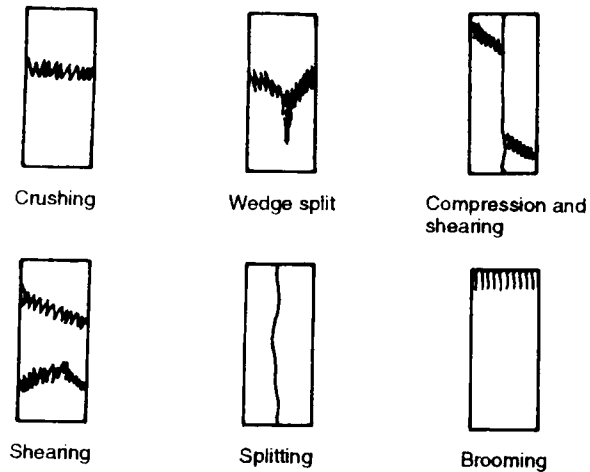


Fig. 4.12 Failure of Timber Specimen Under Compression Parallel to Grain

S.No.	Characteristic	Unit	Formula
1.	Compressive stress at limit of proportionality	N/mm ²	P/A
2.	Compressive stress at maximum load	N/mm ²	P/A
3.	Modulus of elasticity in compression parallel to grain	N/mm ²	$\frac{LP}{\Delta A}$

Perpendicular to Grain: The specimen may be $50 \times 50 \times 150$ mm or $20 \times 20 \times 100$ mm. It should be free from defects and faces should approach closely to the true radial and tangential direction.

The load is applied to the radial surface continuously at a constant rate of 0.6 mm per minute for both the sizes.

A small load not more than 500 N on 150 mm and 100 N on 100 mm specimen is initially applied to set the specimen and the deformation is measured to obtain 10 readings up to limit of proportionality and is continued up to a deformation of 2.5 mm. If maximum load is reached at some lesser value of compressive deformation, the same is recorded along with corresponding deformation. A curve between load and deformation is plotted. The load and deformation at limit of proportionality is then read. The load at 2.5 mm compression is also recorded. The various characteristics are determined by the following formulae:

<i>S. No.</i>	<i>Characteristic</i>	<i>Unit</i>	<i>Formula</i>
1.	Compressive stress at limit of proportionality	N/mm^2	P/A
2.	Compressive stress at compression of 2.5 mm	N/mm^2	P'/A
3.	Crushing strength at maximum load	N/mm^2	P_0/A
4.	Modulus of elasticity in compression perpendicular to grain	N/mm^2	$\frac{Ph}{A\Delta}$

where P = load at the limit of proportionality
 A = cross-sectional area
 P' = at 2.5 mm compression
 L = gauge length between compressometer points
 Δ = deformation at the limit of proportionality
 P_0 = maximum load if reached at a compression less than 2.5 mm
 h = height of the specimen

Hardness Under Static Indentation Test

The specimens are same as that used in compressive strength test perpendicular to grain. The test is carried out on a suitable testing machine equipped with a special device for penetration into the specimen of a steel bar with hemispherical end or a ball of diameter 11.28 mm to a depth of 5.64 mm that is the projected area of greatest circle is 100 mm^2 . The specimen is so placed on the machine that two penetrations are made on the radial face, two on the tangential face and one on each end in case of $50 \times 50 \times 150$ mm size and for $20 \times 20 \times 100$ mm size one penetration is made on tangential and one on radial face. The load is applied continuously at a constant rate of 6 mm per minute for both sizes.

The load required to penetrate the standard steel ball or hemispherical end of the steel bar (11.28 mm dia) to the specified depth of 5.64 mm is recorded for tangential, radial and end surfaces. Where two penetrations on one surface or one penetration on both ends have been made, the average value is taken. The average of radial and tangential hardness is denoted as side hardness.

Shear Strength Test (Parallel to Grain)

The specimen may be $50 \times 50 \times 60$ mm or $20 \times 20 \times 30$ mm. They should be notched on one end as shown in Fig. 4.13 to produce shear failure on 50×50 mm or 20×20 mm surface in the radial

or tangential plane. The test is carried on a suitable testing machine with the help of a shearing tool in rig. The direction of shearing should be parallel to the longitudinal direction. The load is applied continuously at a constant rate of 0.4 mm per minute. The maximum load required for shearing the area is recorded. The load divided by the area gives the maximum shearing stress in the concerned plane (radial or tangential) for both sizes.

Tensile Strength Test

Parallel to Grain: The test specimen for the two sizes are shown in Fig. 4.14 (a, b). The cross-section of the central portion of the specimen should be 7 × 7 mm or 5 × 5 mm for the specimen in Fig. 4.14 (a) and Fig. 4.14 (b), respectively. The specimen is held firmly in the grips and the suitable elongation measuring device is attached to the gauge length. The load is applied continuously at a constant rate of one millimeter per minute for both sizes. Elongation is measured at suitable load intervals such that 8–10 reading are available up to limit of proportionality. Reading is continued well beyond the proportional limit and final reading of load at failure is recorded.

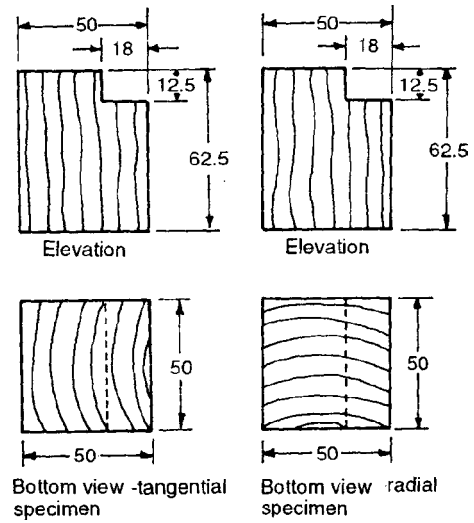


Fig. 4.13 Test Specimen for Shear Parallel to Grain

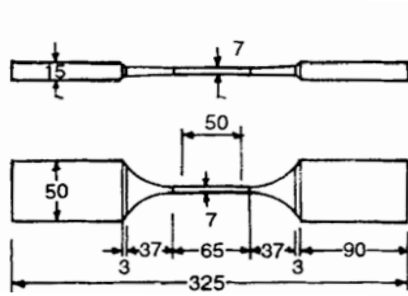


Fig. 4.14(a) Perpendicular to Grain

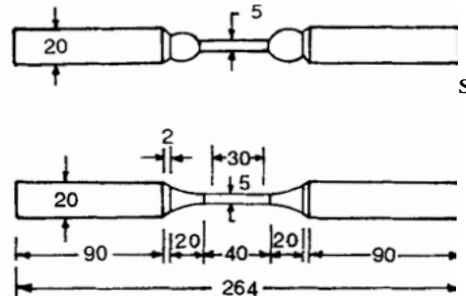


Fig. 4.14(b) Parallel to Grain

Load elongation curves are plotted. The load and elongation at proportional limit are then read. The various characteristics are determined by the following formulae:

S. No.	Characteristic	Unit	Formula
1.	Tensile stress at proportional limits	N/mm ²	$\frac{P}{A}$
2.	Tensile stress at maximum load	N/mm ²	$\frac{P'}{A}$
3.	Modulus of elasticity in tension parallel to grain	N/mm ²	$\frac{LP}{\Delta A}$

- where $P =$ load at the limit of proportionality
 $A =$ cross-sectional area
 $P =$ maximum load to cause the failure of the specimen
 $L =$ gauge length
 $\Delta =$ deformation at the limit of proportionality.

Perpendicular To Grain: The specimen for the two sizes are shown in Fig. 4.15 (a, b). The notches shown in Fig. 4.15 (a) and 4.15 (b) are so made as to produce a failure on 50×20 mm area (Fig. 4.15 (a)) or 20×10 mm area (Fig. 4.15 (b)) in the radial or tangential surface as desired. The test is conducted on a testing machine provided with suitable grips to hold the specimen. The load is applied continuously at a constant rate of 2.5 mm per minute until the maximum load is reached for both sizes.

The maximum load required for failure in the case of perpendicular to grain is recorded. The load divided by the area gives the maximum tensile stress perpendicular to grain in the concerned plane (radial or tangential).

Cleavage Strength Test (Parallel to Grain)

The test specimens for the two sizes are shown in Figs. 4.16(a) and 4.16(b). The notches shown in Figs. 4.16 (a) and 4.16 (b) should be such as to fail the specimen in radial or tangential surface as desired. The load is applied continuously at a constant rate of 2.5 mm per minute until the maximum load is reached for both sizes. The maximum load required for failure is recorded. The load divided by the width gives the maximum cleavage resistance N/mm in the concerned plane (radial or tangential).

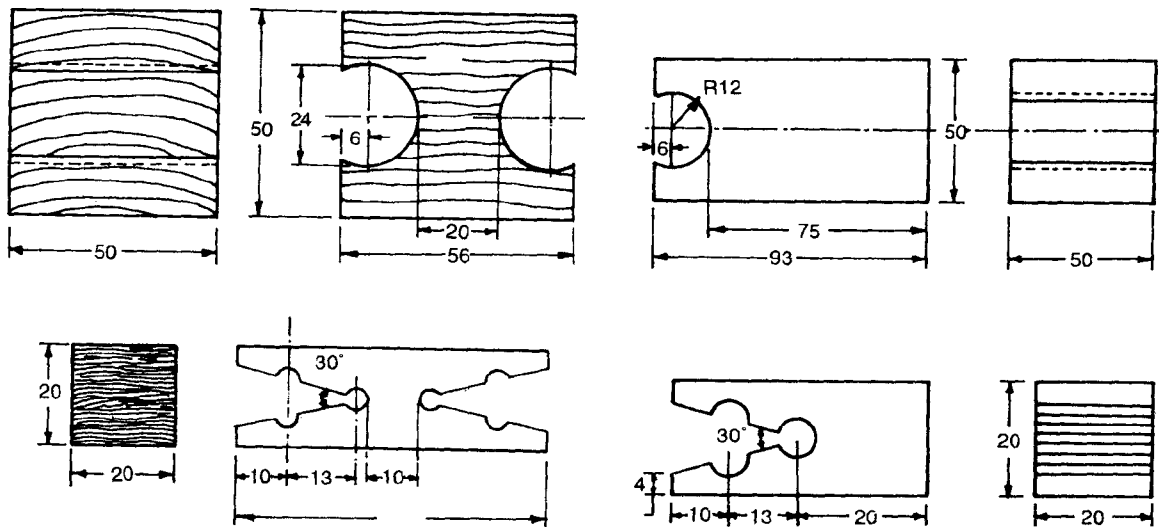


Fig. 4.15 Test Specimen for Tension Perpendicular to Grain

Fig. 4.16 Test Specimen for Cleavage

Brittleness Test

Izod Impact Test: The test specimen is 20×20 mm in cross-section and 125 mm in length. A saw notch 2 mm in width and 7 mm in depth is made on the radial face of the specimen at a distance of 50 mm from one end so as to produce maximum concentration of impact stress on the cross-section of 20×13 mm as shown in Fig. 4.17. The specimen is held vertical tightly clamped as a cantilever in a swinging pendulum machine such that 50 mm length of the specimen is under the clamp. The machine should have a calibrated dial so as to give direct reading of energy absorbed in breaking the specimen in a single blow. The specimen is so clamped that the blow is given in the radial face on the side of notch. The pendulum of the machine is so adjusted that on release from the initial position it may strike the specimen at the lowest point of swing (horizontally) at a distance of 10 mm from the upper end. The impact blow is given by releasing the pendulum and the reading on calibrated dial in N mm is recorded.

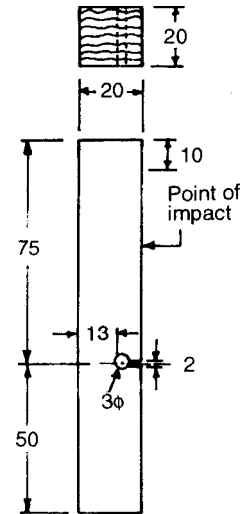


Fig. 4.17 Test Specimen for Brittleness (Izod Impact)

Charpy Impact Test: The specimen is 12.5×12.5 mm in cross-section and 125 mm in length with the notch at the centre on the radial face. The notch should be V type, 2.5 mm in depth and 5 mm in width as shown in Fig. 4.18 so as to produce maximum concentration of impact stress in a cross-section of 12.5×10 mm. The specimen is freely supported horizontally with the notch vertical on the base of a swinging pendulum machine up to 10 mm on both ends. The machine should have a calibrated dial so as to give direct reading of energy absorbed in breaking specimen on a single blow. The blow is given on the opposite side of the notch at the centre of specimen. The pendulum of the machine is so arranged that on release from the initial position may strike the specimen at the lowest point of blowing (horizontally). The impact blow is given by releasing the pendulum and the reading on calibrated dial in N mm is recorded.

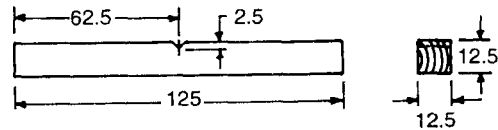


Fig. 4.18 Test Specimen for Brittleness (Charpy Test)

Torsional Strength Test

The dimensions of the cylindrical specimens are shown in Fig. 4.19. The central cylinder should be 220 mm in length for both sizes but the radii should be 25 mm and 12 mm, respectively. The end portion for holding the specimen should be 30 mm and 15 mm, respectively and 40 mm in length for both the sizes. The test is conducted on a torsion testing machine provided with suitable types of grips to hold the specimen during test firmly on one end and free to rotate at the other end. The specimen is mounted on the machine and the strain (angular twist) measuring device is attached to the specimen at the centre on a gauge length of 150 mm. The torque is applied gradually by turning wheel of the machine at a uniform rate so as to produce a torque of about 5000 N mm per minute. Angular twist is measured in radians or degrees on the

specified gauge length of 150 mm at regular intervals of torque such that 8 to 10 readings are available upto the limit of proportionality. Readings are continued well beyond the proportional limit and final reading of torque at failure are recorded. The torque-twist curve is drawn. The torque and angular twist at proportional reading limit is read from the curve. The various characteristics are determined by the following formulae:

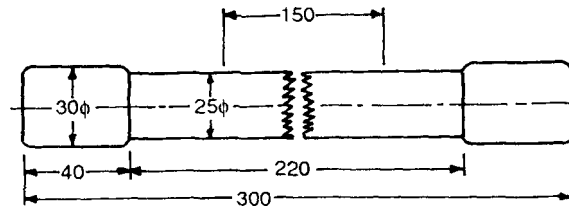


Fig. 4.19 Test Piece for Torsion

S. No.	Characteristic	Unit	Formula
1.	Torsion shear stress at proportional limit	N/mm ²	$\frac{2M}{\pi r^3}$
2.	Torsion shear stress at maximum torque	N/mm ²	$\frac{2M'}{\pi r^3}$
3.	Torsion modulus of rigidity	N/mm ²	$\frac{2ML}{\pi r^4}$

where M = torque at the limit of proportionality
 r = radius of the portion of the specimen under gauge
 M' = maximum torque
 L = gauge length
 π = the angular twist of one end relative to other end at a distance of L

Moisture Content Test

The moisture content of timber and products made of it can be determined by any of the following methods.

Oven-drying Method is most reliable, except where certain timber species containing volatile oils (like deodar) are involved. The method is, however, time consuming and requires cutting of the timber to be tested. Test specimens consisting of a cross-section, 15 to 20 mm long in the direction of the grain, free from all defects, are cut from each sample.

Immediately after each test specimen is cut and loose splinters and saw dust are removed by brushing or scraping, it is weighed. The weighed test specimens are completely oven-dried at $103 \pm 2^\circ\text{C}$ for 12–18 hours. The oven-dry mass of all the test specimens, is now determined directly after removing from the oven, or after cooling them in desiccators to near room

temperature. In case, cutting of specimen from the selected samples is not possible, the moisture content in the whole sample may be determined by collecting borings to a depth of half the thickness of each sample (obtained by means of an auger) in preweighed weighing bottles. The moisture content of each sample is determined by the following formula:

$$M = \frac{W_1 - W_0}{W_0} \times 100$$

The average of moisture content of all the samples from the lot tested is reported correct to the nearest whole number by the following formula for checking conformity of a lot to the requirements of the relevant specification:

$$\bar{M} = \frac{\sum_i^n M}{n}$$

where W_1 = initial mass of test specimen
 W_0 = oven-dry mass of test specimen
 \bar{M} = average moisture content (per cent)
 M = moisture content of individual samples (per cent)
 n = number of samples selected from the lot

Electrical Moisture Meter Method is a direct, quick, convenient and non-destructive means of determining moisture content of timber and its products. These are of special value in field inspections and for checking of finished timber products. Because of the rapid measurements, and no loss of material by this method, more extensive checking is possible than permitted by the oven-drying method. Resistance type meters with electrode pins of suitable lengths and with species correction and temperature correction charts for the species to be tested are used. The meter readings are taken at three sections along the length in the middle width of each face of every sample. Two sectors are measured at a distance of 450 mm from the ends and the third one at mid length of the sample. If the length of the sample is 1 m or less, readings are made at mid length only on each face. Electrode pins of adequate length are selected for the thickness of timber under test, that is, to probe up to a depth not less than one-fifth the thickness of timber but preferably up to half the thickness. Readings at the various depths into the section are first taken on a few samples to ascertain the presence of large moisture gradients or a wet core (moisture content 20 per cent or above) or a reverse moisture gradient (surface wetter than the core). Moisture gradients are considered to be large if the difference of readings at one-fifth and half the thickness of a sample exceeds four per cent absolute in timber up to 40 mm thick and seven per cent absolute in timber 40 to 65 mm thick. If presence of the condition detailed is confirmed, the meter readings cannot be taken as reliable estimates of the average moisture content in the whole section, but only of the maximum moisture content prevailing within the depth of insertion of pins in case of meters provided with naked pin electrodes, or of the spot moisture content prevailing at the depth of insertion in case of meters provided with insulated pin electrodes. If presence of the conditions detailed is negated, readings at one-fifth thickness are taken as representative of the average in the whole section.

The average moisture content of each sample is calculated as:

$$M = \frac{\sum_{i=1}^n m}{P} \times 100$$

where M = average moisture content of sample (per cent)
 m = corrected moisture meter reading in any sector of sample (per cent)
 P = number of sectors measure

The average of moisture content of all samples tested from a lot is calculated by the formula for checking conformity of a lot to the requirements of the relevant specification:

$$\bar{M} = \frac{\sum_{i=1}^P m}{n} \times 100$$

where \bar{M} = average moisture content (per cent)
 m = moisture contents of individual samples (per cent)
 n = number of samples selected from the lot

Distillation Method: This method is used for species like deodar containing volatile oil or extractives. It is also used for timber impregnated with volatile or non-volatile chemicals that are likely to interfere with the correct determination of moisture content by oven-drying or electrical moisture meter methods.

The apparatus for the test consists of distillation flask with indirect heating arrangement, cold water-cooled condenser of the cold finger type (Fig. 4.20), water trap, scales of accuracy 10 mg, and scalable weighing bottles.

About 50 g of each test sample is distilled till no more water collects in the water trap. Any water condensed elsewhere in the trap is washed down into the trap with the help of a solvent spray. Sufficient time is allowed for a clear separation of water and solvent (xylene or toluene) in the trap. Any bubbles inside the water collected in the trap are removed by tapping it. The moisture content of each sample is calculated by the following formula:

$$M = \frac{M_W}{M_1 - M_W} \times 100$$

where M = moisture content
 M_1 = mass of test specimen before distillation
 M_W = mass of water

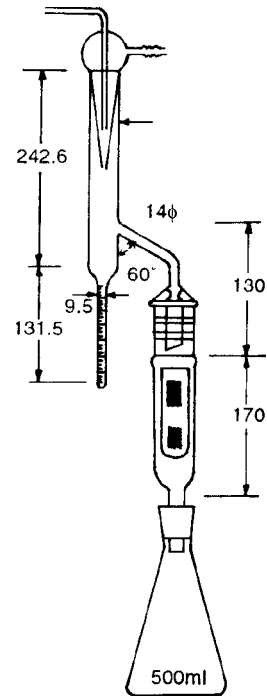


Fig. 4.20 Distillation Apparatus

4.14 SUITABILITY OF TIMBER FOR SPECIFIC USES

The characteristics and suitability of timbers are given in Table 4.2.

Table 4.2 Characteristics and Uses of Timber from Various Trees

<i>S. Purpose No.</i>	<i>Requirements</i>	<i>Nature of tree</i>
1. Agricultural implements	1. Hard and durable 2. Should take good polish	Bel, Arjun, Babul, Black wood
2. Houses	1. Sufficiently close grained 2. Takes good polish 3. Toughness and durability 4. Pleasing colour 5. Easy to work with	Sissoo, Teak, Ablus, Babul Haritaki, Jiyal, Kath bel, Mahua, Nirmali, Red wood, Walnut
3. Bridge	1. Strength, hardness 2. Resistance to salt water action 3. Durability in moist places and under water	Babul, Red cedar, Iron wood, Jarul, Nageshwar, Sal, Satin, Sissoo
4. Carts and wheels	1. Hardness and durability 2. Close grained	Jiyal, Arjun, Babul, Tamarind
5. Columns, beams door frames, etc.	1. Hardness and durability 2. Should take good polish 3. Flexibility 4. Light in weight 5. Easy to work 6. Lasts under water	Arjun, Gamhar, Bamboo, Coconut, Palm Mango, Pial, Palm
6. Furniture	1. Light, soft and durable 2. Should take good polish 3. Close grained 4. Easy to work with	Teak, Champa, Deodar, Rakta-ghandan, Walnut, Shishum
7. Fancy goods and toys	1. Easily workable 2. Strength and durability 3. Fairly hard and light weight 4. Scented	Simul, Sandal, Bamboo, Mahogany
8. Music instruments	1. Pleasing brick red colour 2. Soft and easy to work 3. Beautiful motteling	Toon, Walnut
9. Scientific instruments	1. Moderately hard and tough 2. Light 3. Easy to work with	Guava
10. Packing boxes	1. Soft and light in weight 2. Lasts under water 3. Cheap	Simul, Mango, Deodar
11. Pegs	1. Hardness and durability 2. Cheap	Arjun, Coconut, Palm, Kher
12. Piles	1. Strength, hardness and durability 2. Close grains 3. Durable in moist places and under water	Red cedar, Sissoo, Sal, Nageswar, Iron wood
13. Railway carriage	1. Close grains, hardness and durability 2. Should take good polish	Black wood, Teak, Iron wood, Red wood

(Contd)

Table 4.2 (Contd)

<i>S. Purpose No.</i>	<i>Requirements</i>	<i>Nature of tree</i>
14. Railway sleepers	1. Hardness, toughness and strength 2. Durability under moist conditions 3. Close grains	Sundari, Red cedar, Sal, Kath bel, Deodar
15. Scaffolding	1. Strength and durability 2. Flexible 3. Easy to work	Bamboo
16. Shuttering	1. Hardness and durability 2. Easy to work 3. Durability in moist conditions	Nageshwar, Gamhar, Haritaki
17. Ships, Boats	1. Hardness, toughness and strength 2. Durability under salty water	Jarul, Babul, Teak, Nageshwar, Bakul, Mahua, Khair
18. Well curbs	1. Lasts long under water 2. Softness and light weight 3. Easy to work	Red cedar, Palm, Banyan, Babul, Gamhar, Mango
19. Match Box	1. Moderately hard or soft	Kail, Simul

4.15 PROPERTIES OF WOOD

Physical Properties

Density and Specific weight: All the mechanical properties of clear wood are related to its density, which varies directly with the apparent specific gravity. The true specific gravity of wood is approximately equal for all species and averages 1.54, whereas the specific weight and apparent specific gravity vary with density of wood. The percentage of moisture in the wood has a very large effect upon the specific weight and hence true comparisons of this property can only be made on dry specimens.

Note: Since wood in the lower part of the trunk of a tree is more dense than that higher up, and since the densest wood at any given height is situated between the pith and middle ring of the cross section, a small variation in the strength of wood due to the position in the tree will be found.

Bulk density depends on the volume of pores and moisture content of the wood. For most wood species, the bulk density is less than density. Bulk density value is used to determine the quality factor which is the ratio of compressive strength to the bulk density. It is 0.6 for pine and 0.57 for oak.

Moisture movement: Water is found in three portions of wood: (1) it constitutes over 90 per cent of the protoplasm in the living cells; (2) it saturates the cell walls; (3) it fills, more or less completely, the pores of the life less cells. Timber is liable to shrink or swell with the movement of moisture. This movement is not the same in all the directions. Fig. 4.21 shows two pieces A and B cut from a log. In piece A, the layers producing the annual rings run roughly parallel to

the face of the timber, while in piece B, they run roughly at right angles to the face. Movement of the wood due to variations in moisture content is greatest in the plane of the annual rings. The movement a_1 will be greater than movement b . Also, as a_2 is nearer to the condition of b , it will move rather less than a_1 . It is clear, therefore, that if a piece of timber is to be used as a board or panel, it will move less if cut like B than like A. It should also be obvious that the slightly varying tendency to movements on the faces of piece may lead to stresses which will cause it to warp. Recommended moisture content for structural elements is 12–20 per cent for doors and 10–16 per cent for windows.

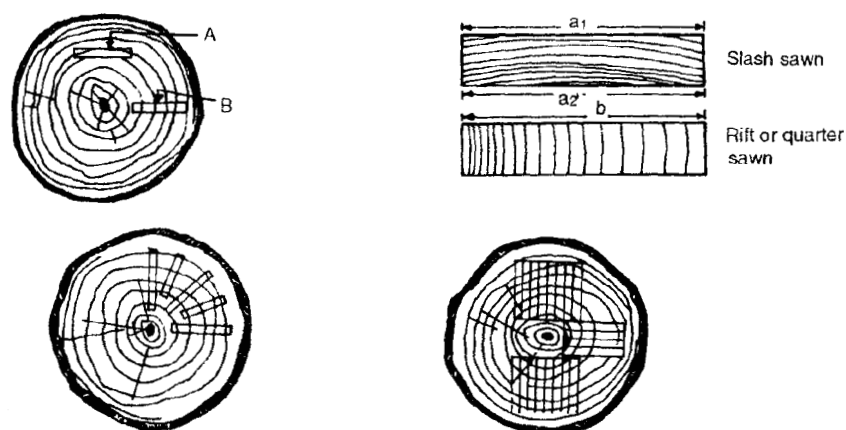


Fig. 4.21 Methods of Converting Timber

Shrinkage is the reduction in linear and volumetric dimensions in drying of wood. Evaporation of capillary water is not accompanied by shrinkage, the latter taking place only when hygroscopic moisture evaporates. Because of structural non-uniformity, wood shrinks or swells irregularly in various directions. Linear shrinkage along the fibres lies between 0.1 and 0.3 per cent, in radial direction between 3 and 6 per cent and in tangential direction between 7 and 12 per cent. In general, the radial shrinkage of wood is 60 percent of the tangential, and the longitudinal shrinkage is negligible. Therefore, the volumetric shrinkage is practically 1.6 times the tangential shrinkage.

Swelling is the capacity of wood to increase both its linear and volumetric dimensions when it absorbs water. Swelling of wood along the length of fibres ranges from 0.1 to 0.8 per cent, 3 to 5 per cent in the radial direction and 6 to 12 per cent in the tangential direction.

Heat Conductivity is quite low. The coefficient of heat conductivity along the fibres is 1.8 times greater than that across the fibres and averages 0.15 to 0.27 K cal/mh°C. As the bulk density of wood increases and its moisture content decreases, the amount of air entrapped inside cavities decreases, the effect being greater heat conductivity of wood.

Sound Conductivity: The velocity of sound in wood is 2 to 17 times greater than that in air and as such wood may be considered to have high sound conductivity.

Resistance to Action of Acids and Alkalis: Wood is not affected by weak alkali solution but decays in an acid medium ($\text{pH} < 4$).

Mechanical Properties

Engineers, architects and carpenters must be well versed with the mechanical properties of timber. In order that the engineer may properly design columns and beams for various parts of wooden structures, he must be thoroughly conversant with the strength and stiffness of the available classes of timber. He must also know how various defects and conditions influence these properties. The architect must not only appreciate the beauty of various species, the relative ease with which each may be worked, the tendency to shrink, warp, and check; but he must likewise be prepared to proportion joints and rafters to carry the imposed loads without excessive deflection. The wheelwright must understand how the toughness and strength of his axles, spokes, and shafts are influenced by species, rate of growth, density, and defects. The carpenter and the craftsman must also have knowledge of the mechanical properties of wood in order that they may work it to best advantage. The mechanical properties of timber that need elaboration are as follows.

Stress-strain Relationship

Wood has three principal axes—longitudinal, radial and tangential— along which properties are fairly constant. Since wood is a nonisotropic material, it has three values of modulus of elasticity varying by as much as 150 to 1, three shear moduli varying by 20 to 1, and six Poisson's ratios varying by 40 to 1. There is no sharply defined elastic limit in wood but there is a proportional limit. However, the stress-strain diagram in any direction is fairly straight over a considerable range before it gradually curves off. It is a ductile material.

The relative stress-strain curves for direct tension, direct compression and bending stress intensities parallel to the grain in Fig. 4.22 show that in both, direct compression and bending, the proportional limit is in the vicinity of 65 to 75 per cent of the ultimate strength. For all practical purposes, there is no proportional limit in direct tension.

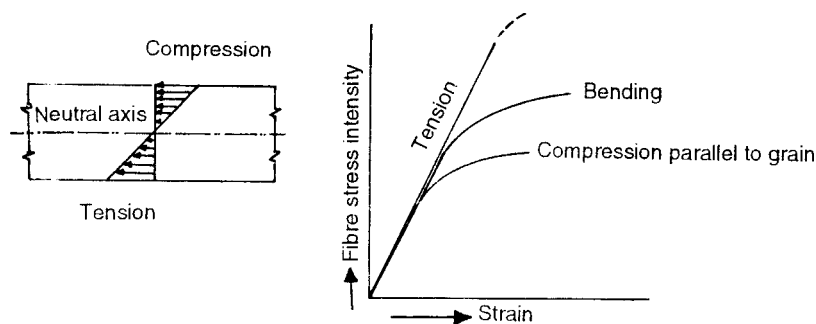


Fig. 4.22 Stress Strain Curves Parallel to the Grain

Modulus of elasticity of the grain is practically the same in direct tension, direct compression and bending, if shear deformation in bending is eliminated. Because modulus of rigidity of wood is low (approximately 1/15 to 1/20 the modulus of elasticity), the apparent bending modulus of elasticity varies somewhat with the type of loading and span, but in no case it is less than 90 to 95 per cent of the true bending modulus of elasticity. The mechanical properties of timber that need elaboration are as follows.

Compressive strength: When subjected to compressive force acting parallel to the axis of growth, wood is found to be one of the strongest structural material. Columns and posts are,

therefore, often fashioned of it. However, compressive strength perpendicular to fibres of wood is much lower than that parallel to fibres of wood. Compressive strength parallel to fibres, at 15 per cent moisture content, varies from 30.0 to 77.5 N/mm². Furthermore, a knowledge of the compressive strength is of value in estimating strength in bending since experiments have demonstrated that the yield point of wooden beams is determined by the compressive strength of the wood.

When wood is subjected to compression parallel to the grain, it may fail through collapsing of the cell walls or through lateral bending of the cells and fibres. In wet wood and in the hardwoods, which are composed of thick-walled fibres and vessels, incipient failure is due to bending of the individual fibres. In cross-grained pieces, the failure is likely to take place through shear parallel to the grain.

The strength of timber compressed across the grain is brought into play whenever a concentrated load is imposed on a beam. Since the compressive strength across the grain is only a small fraction of the compressive strength parallel to the grain, proper allowance for this discrepancy must be provided with a footing to distribute the pressure.

Tensile Strength: When a properly shaped wooden stick is subjected to tensile forces acting parallel to the grain it is found to have greater strength that can be developed under any other kind of stresses. Indeed, the tensile strength of wood parallel to the grain is so great that much difficulty is encountered in designing end connections so that the tensile strength of a piece can be developed. Therefore, wood tension members are rarely used. Tensile strength parallel to the fibres is of the order 80.0 to 190.0 N/mm². However, wooden parts restrained at their ends suffer from shearing stresses and crushing which wood resists poorly, and cannot be extensively used in structure working under tension. Moreover, since the tensile strength parallel to the grain is two to four times the compressive strength, the latter governs the strength of beams. The tensile strength parallel to the grain is influenced to some extent by the nature of the wood elements and their arrangement, but principally by the straightness of the grain and the thickness of the walls of the longitudinal elements. When failure occurs, these elements are ruptured transversely. Knots greatly reduce the tensile strength parallel to the grain. The tensile strength is less affected by moisture than are other mechanical properties.

Across the grain, the tensile strength of wood is low. It is a property closely related to cleavability, and it often determines the strength of a beam which has cross-grain or spiral-grain in its tension fibres. Failure in tension across the grain occurs through separation of the cells and fibres in longitudinal planes. Knots, shakes, etc. reduce the tensile strength of wood across the grain.

Bending Strength: Wood well withstands static bending, owing to which it is widely employed for elements of buildings, e.g. beams, slabs, rafters, trusses, etc. The initial failure of long beams of uniform width is indicated by a wrinkling of the overstressed compression fibres, much like the failures which occur in compression prisms. Final failure of such beams is generally in tension. It is accompanied more or less by snapping as the individual fibres begin to break when the maximum load is reached. Very dry specimens sometimes fail very suddenly in tension before any wrinkling of the compression fibres is noticeable. However, green test pieces fail silently in compression without rupturing of the tensile fibres. Short deep beams fail by horizontal shear suddenly, and this is more common in well seasoned timber of structural sizes than in green timbers or in small beams. Very often shear failures result from defects.

Long narrow beams must be restrained laterally and supported in such manner that the wide sides are vertical. If the first condition is not fulfilled, the member will fail from column action in the compression fibres. Unless the second condition is met, strength of the beam may be very seriously reduced through the inclination of the neutral axis. These requirements are satisfied by diagonal bracing known as *bridging*. The bending strength of some of the timbers is given in Table 4.3.

Table 4.3 Bending Strength of Timbers

S. No.	Trade name	Unit weight N/m^3 at 12% moisture content	Bending strength (N/mm^2) Location		Durability
			Inside	Outside	
1.	Babul	8350	18.2	15.4	Low
2.	Chir	5750	8.4	7.0	Low
3.	Deodar	5600	10.2	8.8	High
4.	Fir	4650	7.8	6.6	Low
5.	Jaman	8500	15.2	12.6	Moderate
6.	Mango	6550	12.4	10.2	Low
7.	Oak	8650	14.8	12.4	Moderate
8.	Sal	8000	16.8	14.0	High
9.	Teak	6250	14.0	11.6	High
10.	Neam	8360			–
11.	Rosewood	7550			High
12.	Shishum	7850			Moderate
13.	Cail	5150			Low

Shearing Strength: Wood has low shearing strength of 6.5–14.5 N/mm^2 along the fibres. Resistance of wood to cutting across the fibres is 3 to 4 times greater than that along the fibres, but pure shear generally does not take place since the fibres are also subjected to crushing and bending.

Stiffness: Stiffness in a timber structure is often of as much importance as strength, but it is much more frequently neglected in designing. Floors must be sufficiently stiff so that they will not deflect appreciably under working loads as else they give one the feeling of insecurity. Likewise, the deflection of rafters should be limited, if it is desirable, to avoid the disagreeable appearance of a sagged roof. In general, denser woods are more stiff. A green timber is less stiff than when seasoned. The structural sizes of timber are about as stiff as the clear small sticks.

Toughness: A wood which has a large capacity to resist shock or blows is called tough. In order to be tough a wood must have both strength and flexibility. Hardwood as a class excels in toughness. Long leaf pine is the only one of the conifers possessing much toughness. In general, green wood is tougher than seasoned wood. Toughness is best measured by the energy of the blow required to rupture a beam in transverse impact.

Cleavability is the measure of the ease with which wood may split. Most hardwoods split more easily along radial planes than along tangential surfaces. Since splitting is accomplished by wedging apart the longitudinal elements, it is closely related to tension, across the grain. Woods which must be fastened by nails and screws should have a high resistance to splitting. Among the conifers, with an exception of longleaf pine, the difference in cleavage strength in the two directions is not great.

Hardness is defined and measured as resistance to indentation and resistance to scratching. Both are important properties in woods used for finishing and for furniture. These properties, together with the ability to wear without splintering, determine the wearing resistance of wood for floors and pavements. Aside from the indentation tests no satisfactory type of test has been devised to measure these properties.

Effect of Moisture on Mechanical Properties of Wood

Variations in the moisture content of the cell walls are accompanied by large changes in the strength and stiffness of wood. After years of seasoning, large timbers may lose enough water to effect an increase in tensile and compressive strength and in stiffness, but defects arising from shrinkage stresses often decrease the resistance to horizontal shear stresses. In kiln-seasoning, the normal increase in strength due to loss of moisture is often nullified by case-hardening, a condition which prevents complete drying of the piece and produces internal stresses.

The mechanical properties of wood are not materially affected by a reduction of the moisture content until the point of fibre-saturation is reached. Further drying causes a large, proportionate increase in strength and stiffness.

Effect of Temperature on Strength of Wood

The effects of temperature on wood are dependent upon the moisture content. Dry wood expands slightly when heated, while wet wood shrinks owing to evaporation of moisture. When the temperature of wood is raised above room temperature it becomes weaker in most strength properties. Very high temperatures, such as those used in vulcanizing, slightly weaken dry wood. Freezing somewhat increases both the strength and stiffness of wood. If wood is kept moist during the heating process, it is rendered very pliable and is weakened.

4.16 WOOD PRODUCTS

Many wood based products have been developed to economise on the use of timber. These wood products are manufactured under controlled conditions in factories. As such, these have desired shape and dimensions, appearance, strength and durability. Some of these are described below.

Veneers (IS: 14315)

The primary process in the manufacture of wood based products is veneering which produces thin sheets of wood known as *veneers*. The thickness of veneers varies from 0.4 to 0.6 mm. In no case it should exceed 1 mm. The most suitable wood for this purpose is walnut. However other species like teak, sissoo, rose wood, etc. are also used. The logs to be used for this purpose are kept in wet storage to avoid end splitting and are softened by heating with hot water or steam and the bark is removed. The log is then cut to veneers. Depending on the cutting process, the veneers are classified as rotary veneers (Fig. 4.23) and sliced veneers (Fig. 4.24). These are used in the manufacture of plywood and other laminated boards.

Classification

Veneers are classified into two types or surfaces namely, Type A and Type B. The quality requirements in the terms of permissible defects for the two types of surfaces are given in Table 4.4. The maximum numbers of categories of defects permitted are restricted and are given in Table 4.5.

Dimensional Tolerances

Following tolerance are permitted on the dimensions.

Dimension	Tolerance
Length	+6 mm
Width	+3 mm
Squareness	0.2 %
Edge straightness	0.2 %

Table 4.4 Quality Requirements of Veneers

S. No.	Defect Categories	Type of Surfaces	
		A	B
(i)	Discolouration	Nil	5 percent
(ii)	Dote*	50 mm/m ²	150 mm/m ²
(iii)	Insect hole	Scattered up to 12 holes/m ²	Scattered up to 24 holes/m ²
(iv)	Joints	One joint for every multiple of 200 mm provided, no individual piece is less than 100 mm in width	No restriction
(v)	Knots (dead)	2 No. up to 12 mm dia/m ²	4 No. up to 20 mm dia/m ²
(vi)	Pin knots (dead)	2 No./m ²	6 No. m ²
(vii)	Pin knots (live)	No restriction	No restriction
(viii)	Knots (tight)	6 No. upto 25 mm dia/m ²	No restriction
(ix)	Patches	4 patches/m ² provided. They are all tight patches and do not mar the appearance	Any number provided they are all tight patches and do not mar the appearance
(x)	Splits	2 splits, each not more than 1 mm wide and length not more than 100 mm	3 splits, each not more than 4 mm wide and length not more than 150 mm
(xi)	Swirl	Unlimited, provided they do not mar the appearance	No restriction

*It is an early stage of decay characterized by local discolouration of wood most frequently in the form of streaks along the grain but sometimes as spots.

Table 4.5 Permissible Categories of Defects

Types of Surfaces	Maximum Number of Categories of Permissible defects per square metre
A	3
B	5

Plywood

A wood panel glued under pressure from an odd number (usually 3 to 13) of layers/piles of veneers is known as plywood (Fig. 4.25). The outer most veneer sheets in a plywood panel are called/faces. The interior ply/plies which have their grain directions parallel to that of the faces are termed as *core/centre*. Other piles which have grain directions perpendicular to that in the face are termed as *cross bands*.

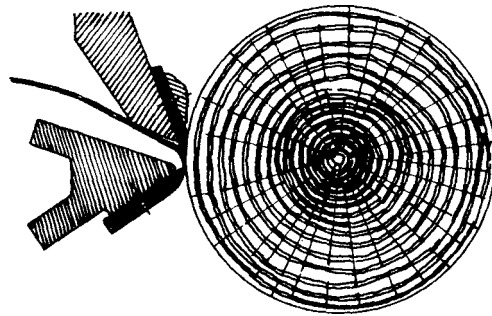
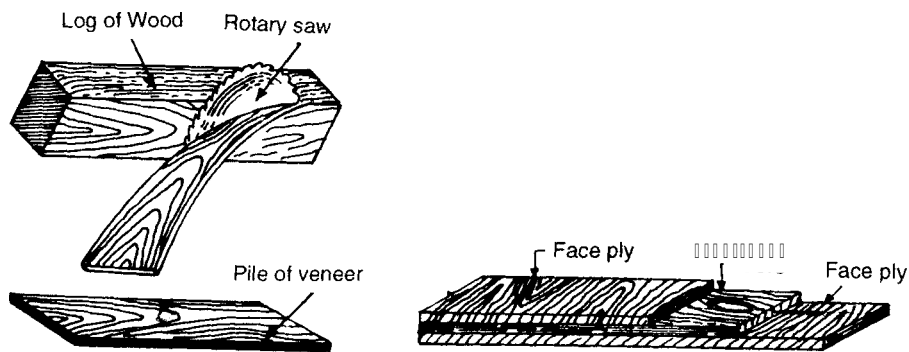


Fig. 4.23 Rotary Cutting



Fia. 4.24 Sliced Veneer

Fig. 4.25 Plywood

Plywood may be classified upon direction of grains in the plies and on the type of adhesive used. Normally the alternate plies are oriented at 30° or 60° in *star* plywood. The faces are arranged with the grain at 45° to that of the centres in *diagonal* plywood. When the plies are bonded together with water-soluble glues such as casein glue, *interior grade* plywood is obtained and when bonded with phenol formaldehyde adhesive it is identified as *exterior grade* plywood which is completely water proof.

Classification

Based on Grades: Plywood for general purposes should be of the following two grades, depending upon the bond strength developed by the adhesive used for bonding the veneers:

- (a) Boiling water resistant or BWR Grade, and
- (b) Moisture resistant or MR Grade.

Based on Appearance: Plywood for general purposes should be classified into three types, namely, AA, AB and BB based on the quality of the two surfaces, namely, A and B in terms of general permissible defects. The type of plywood should, therefore, be designated by the kind of surfaces of the panels. The better quality surface should be called 'face', and the opposite side should be called 'back'. If the face and the back are of the same quality, they are not distinguished. The type of plywood would denote first the quality of face followed by the quality of back. For

example, Type AA should have both surfaces of quality A, Type AB should have face of quality A and the back of quality B and Type BB should have both the surfaces of quality B.

The thickness of plywood boards for general and structural purposes should be as given in Table 4.6.

Table 4.6 Thickness of Plywood Boards (IS: 303 and 10701)

<i>Board</i>	<i>Thickness (mm)</i>	
	<i>General Purpose</i>	<i>Structural Purpose</i>
3 ply	3, 4, 5, 6	4
5 ply	5, 6, 8, 9	6, 9
7 ply	9, 12, 15, 16	12, 16
9 ply	12, 15, 16, 19	16, 19
11 ply	19, 22, 25	19, 25
Above 11 ply	On order	

Tolerances

The following tolerances on the nominal sizes of finished boards should be permissible:

<i>Dimension</i>	<i>Tolerance</i>	
	<i>General Purpose</i>	<i>Structural Purpose</i>
(a) Length	+6 mm	+6 mm
	-0 mm	-0 mm
(b) Width	+3 mm	+3 mm
	-0 mm	-0 mm
(c) Thickness		
1. less than 6 mm	±10%	±10%
2. 6 to 9 mm	} ±5 %	±7 %
3. above 9 mm		±5 %
(d) Squareness	± 0.2%	0
(e) Edge straightness	±0.2%	0

Structural plywood panels are available in following sizes.

2400 × 1200 mm, 2100 × 1200 mm, 1800 × 1200 mm, 2400 × 900 mm, 2100 × 900 mm, 1800 × 900 mm.

Advantages

1. It has good strength both along as well as across the grains.
2. The wood shrinks or swells more across the grains. Since plywood has cross-grained construction, the tendency to shrink or swell is reduced.
3. It has better splitting resistance due to the grains in adjacent veneers in cross direction as such nailing can be done very safely even near the edges.
4. Plywood can be curved into desired shapes.

Uses: These are extensively used for partitions, ceilings, doors, concrete form work, plywood boards, lamin boards (built-up boards with core strips up to 7 mm wide and 7 mm thick) and block boards (built-up boards) etc.

Fibre Boards (IS: 1658)

These boards built up of felting from wood or vegetable (wood wastes, waste paper, agricultural wastes, etc.) are classified by the process of their moulding. If the boards are moulded by wet process, the main bond is by the felting of woody fibres and not by added glue. For the boards moulded by dry process, the bond between the predried fibres is improved by adding 4–8% of synthetic resin. For better performance wood preservatives and other admixtures are often added to the pulp. *Insulating boards* are not compressed during manufacture. Fibre boards are manufactured in various densities like soft, medium and hard. The soft boards are used for walls and ceilings. Medium boards find their application in panelling, partition walls, doors and windows. *Hard boards* have one surface smooth and the other one textured. These have higher densities, better mechanical properties, and improved moisture and termite resistances. The strength and weather properties of hard boards can be improved by oil tempering and such boards are known as *tempered hard boards*. Some of the trade names of hard boards are Masonite, Celotex, Essex boards, etc.

Classification Hard boards are classified as medium, standard or normal and tempered hard boards depending upon the density. The requirements of hard boards are given in Tables 4.7, 4.8 and 4.9.

Table 4.7 Requirements of Hardboards

Type of Board	Average density ($10^3 \times \text{Kg/m}^3$)	Thickness (mm)	Bending strength (Modulus of rupture) average (MPa)	Maximum water absorption by mass after 24 hrs immersion (%)	
Medium hardboard	Min. 0.35 Max. 0.80	8	6	40	
		10	6		
		12	6		
Standard hardboard	More than 0.80	3	30	40	
		4			
		5			
		6			30
		7			
Tempered hardboard	1.2	3	50	20	
		4			
		5			
		6			
		9			

Table 4.8 Thickness of Hardboards

Type	Nominal thickness (mm)	Tolerance (mm)	
Medium hardboard	6	± 0.5	
	8	± 0.7	
	10	± 0.7	
	12	± 0.9	
Standard hardboard	3	± 0.4	
	4		
	5		
	6		± 0.5
	9		± 0.7

Table 4.9 Width and Length of Hardboards

Type	Width (m)	Maximum tolerance on Width (mm)	Length (m)	Maximum tolerance on length (mm)
Medium hardboard	1.2		1.2, 1.8, 2.4	
Standard hardboard	1, 2	± 3	3.0, 3.6, 4.8	± 5
Tempered hardboard	1.2		and 5.5	

Uses: They are widely used for wall and ceiling cladding, partitions, doors, perforated acoustic tiles, railway carriages, bus bodies, etc.

Particle Boards or Chip Boards (IS: 3129, 12406, 3478)

They are manufactured from particles of wood or other ligno cellulose materials which are agglomerated, formed and pressed together by the use of an organic binder together in the presence of heat, pressure or moisture. They are manufactured from small timber pieces and wood wastes. The latter is first converted into small chips. The moisture content of chips is reduced to a certain percentage and then some gluing material, usually phenol formaldehyde, is sprayed. The chips are then spread to form a mat and then pressed in a hydraulic press in presence of heat and moisture. Particle boards avoid wastage of timber as in its making the entire volume of the fallen tree can be utilized. The trees used for making particle boards are eucalyptus, subabool, and rubber wood, and waste of saw mill. These boards provide dimensional stability, smooth uniform surface, and no difficulty in nailing.

Classification

Depending on density these are classified as given in Table 4.10.

Uses: These are widely used in buildings, partitions, ceilings, floor slabs, doors, furniture, etc.

Block Boards (IS: 1659)

The core of block boards is made up of strips of wood each not exceeding 25 mm in width, forming a slab, glued between at least two surface veneers (Fig. 4.26). Veneers used for cross bands and faces are either rotary cut or sliced and should be reasonably smooth. Cross band thickness varies between 1–3 mm and face veneers between 0.5 to 1.5 mm in thicknesses. These are available in thicknesses of 12, 15, 19, 25, 30, 35, 40 and 50 mm. The directions of the grains of the core blocks run at right angles to that of the adjacent outer veneers.

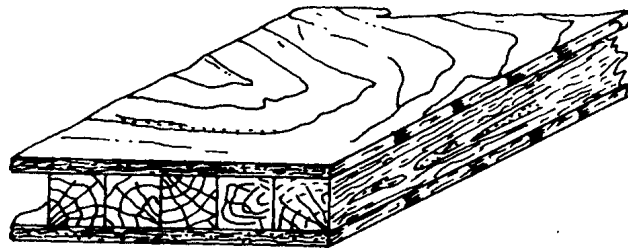


Fig. 4.26 Block Board

The directions of the grains of the core blocks run at right angles to that of the adjacent outer veneers.

Block Boards are available in sizes 2400 × 1200, 2100 × 1200, 1200 × 900, 1800 × 1200, 1800 × 900 mm. Following tolerances are permitted.

Table 4.10 Types and Properties of Wooden Particle Boards

Type	IS:3129 Low Density	IS: 12406 Medium Density					IS: 3478 High Density			
		FPS	FPT		XPS	XPT	Type 1		Type 2	
			FPT1	FPT2			Grade A	Grade B	Grade A	Grade B
Maximum Moisture Content(%)	16	15					3-7	5-16	5-10	5-16
Minimum Modulus of Rupture (N/mm ²)	1.5	11	12.5	11	2	1				
Density (Kg/m ³)	< 400	500-900					1200	900	1200	900
Minimum Tensile Strength (N/mm ²)		0.8	0.4	0.3	1.2	0.4	35	30	25	20
Water Absorption (24 hr)%		50	20	80	80	80	10	25	15	25
Sizes (mm)										
Length	3650, 3000, 2700 2400, 1800, 1500 1000, 900, 600, 450 and 300	4850, 3650, 3000, 2750, 2400 2100, 1800, 1500, 1200, 1000 and 900					1800, 1500, 1200, 1000, 900, 600, 450			
Width	1800, 1500, 1200, 1000, 900, 600 450 and 300	1850, 1800, 1500, 1200, 900 and 650					1500, 1200, 1000, 900, 450			
Thickness	12, 16, 19, 22, 25 27, 30, 35, 40, 45, 50	6, 9, 12, 15, 18, 19, 22, 25, 27 30, 35, 40					4, 6, 9, 12, 16, 20, 25, 30, 35, 40, 50			
Tolerances (mm)										
Length	± 8						± 8			
Width	± 8	± 8					± 8			
Thickness	± 1 (for above 25 mm) ± 0.8 (up to and including 25 mm)	± 2.5					± 2.5			
		± 5					± 5			

Note: Flat Pressed Single Layer (FPS)
Flat Pressed Three Layer Multilayer and Graded (FPT)
Extrusion Pressed Solid (XPS)
Extrusion Pressed Tabular (XPT)

- 4.1.1 Length** + 6 mm
- 0mm
- 4.1.2 Width** + 3 mm
- 0 mm
- 4.1.3 Thickness**
Less than 6 mm ± 10 percent
6 mm and above ± 5 percent
- 4.2 Edge Straightness**—2 mm per 1000 mm
- 4.3 Squareness**—2 mm per 1000 mm

The grades and types of block boards are represented as:

ICOM	Interior grade commercial type
IDEC	Interior grade decorative type
XCOM	Exterior grade commercial type
XDEC	Exterior grade decorative type

These are further subgraded as Grade I and Grade 2. Grade I is *exterior grade* used for bus bodies, railways coaches, prefabricated houses, etc. and Grade 2 is *interior grade* used for furniture, partition, panelling, ceiling, etc.

Uses: These are extensively used for construction of railways carriages, bodies of buses, marine and river crafts, partitions, furniture, etc.

Batten Boards and Lamin Boards: Batten boards have core made up of 80 mm wide wood pieces as shown in Fig. 4.27, forming a slab glued between at least two surface veneers.

Whereas, Lamin boards have a core of strips, each not exceeding 7 mm in thickness as shown in Fig. 4.28, glued together to form a slab which in turn is glued between two or more outer veneers. The directions of the grains of the core block run at right angles to that of the adjacent outer veneers.

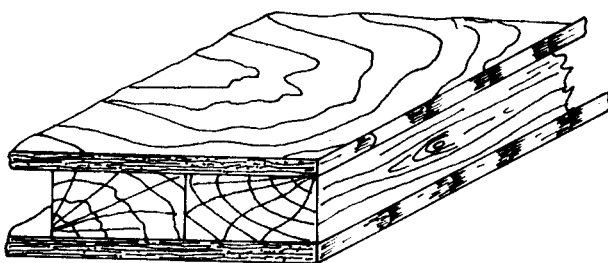


Fig. 4.27 Batten Board

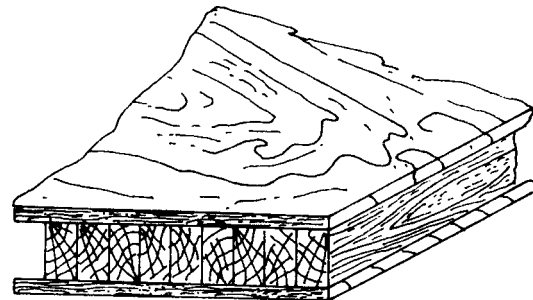


Fig. 4.28 Lamin Board

4.17 APPLICATIONS OF WOOD AND WOOD-PRODUCTS

In modern building practice, wood is extensively used for walls and floors of buildings, carpentry and graded plank items, as well as prefabricated standard wooden cottages. A great quantity of wood is consumed in building and installation work for making piles, poles, various load-bearing components formworks, scaffolds, etc.

Wood materials and items used in building practice include round timber (log); sawn timber and planks; floor materials—flooring boards, end-grain blocks and fibre board; carpentry items— doors, windows, partitions, panels and gates; roof materials—shavings, tiles and shingles, members of roof trusses; wooden structures—beams, columns, slabs, and items of prefabricated houses.

Glued wood components—e.g., beams, trusses, arches, frames and roofs of buildings and installations— are very effective in chemically aggressive media because their service life is 1.5 times greater than that of steel or reinforced concrete. However, the use of wood should be economically justified and the possibility of replacing it with prefabricated concrete, asbestos-cement, gypsum, plastics and other items should be carefully considered.

The use of fibreboard, ply-boards in building practice provides a substantial saving both in capital investments and running costs. The economy is provided, in the first place, by a more complete utilization of raw materials for the manufacture of building materials and items.

The use of boards made of pressed wood shavings in dwelling house construction has a great economical effect. Currently, wood waste is utilized to manufacture polymer and cement based fibreboard and wood shavings board. This also allows manufacturing materials of better physical, mechanical and decorative properties than wood.

EXERCISES

1. Draw the cross-section of a matured tree. What is the best season for felling a tree?
2. What suggestions do you propose for improvement in construction to avoid decay of timber, and what measures are to be taken, when it has occurred?
3. (a) State the principal causes of decay of timber.
(b) How is seasoning done on a large scale?
(c) Discuss the methods of preserving timbers.
4. (a) What are dry and wet rots? How are they caused and prevented?
(b) What is seasoning of timbers and why is it done?
(c) State the qualities you will consider in selecting timber for construction purposes?
5. (a) What is the effect of paint on unseasoned timber?
(b) What are the requirements of good preservatives? What are the main types?
(c) Describe various defects in timber?
6. Explain the following defects of timber.

(a) Shakes	(b) Rindgall
(c) Upsets	(d) Knots
7. (a) What is the difference between soft wood and hard wood?
(b) State the characteristics of good timber.
(c) Describe briefly the methods of timber preservation.
(d) What are the diseases of timbers?
8. Write short notes on the following:

(a) Defects in timber	(b) Ply wood
(c) Seasoning of timber	(e) Hard board
(d) Preservation of timber	(f) Veneers