9

Wood

This chapter mainly states the structure and the physics characteristics of wood. Furthermore it also introduces the corruption and the insect pest caused and the preventive measures to them. This chapter also tells something about artificial plate and its usage.

In the ancient history of Chinese architectural history, the wood used to be combined with materials of construction and those of decoration. The architectures built of them amazes the whole world for the outstandingly perfect usage of wood. Take the world famous Beijing Qi'nian Palace for example, which was made up of completely wood. Nowadays wood is mainly used for interior decoration and ornament.

Wood is used as architectural and decoration material for its several advantages as follows: its specific strength is intense, and it is light-weight and high-strength; it has great elasticity and tenacity that it can bear certain grade of bow and shock wave; its thermal conductivity is low but thermal isolation is good; Being conserved properly, it can be very durable; it is also easy to process, and it can be made into products in various shapes; the wood is beautiful-grained, mild-toned, elegant-styled and well-effected in decoration; the combination of its elasticity, heat isolation and warm tone makes us comfortable; moreover it has high insulating ability without poison.

And for sure the wood also has following disadvantages: it is not even in structure, and it is of anisotropy; its quality and usage are affected by the numerous natural disadvantages; it expands with wetness and shrinks with dryness, so it is liable to crack or warp when being used incorrectly; if not properly conserved, it may be corrupted or mildew and rot or even eaten by worms; in addition its fireproof is poor and is liable to burn.

9.1 Classifications and Structures of Wood

9.1.1 Classifications

In architecture the wood are made of trees, which are many in species. But trees are mainly classified into two species. (As is shown in Table 9.1)

Table 9.1 Classifications and Characteristics of Trees

Classification	Characteristics	Usage	Examples
Conifer	The leaves are slime and long and needle-like, the trunks are straight and tall, and ligneous tissue is soft, liable to process. Of superior strength, apparent density is low, and shrinkage deformation is low.	The major trees used in architecture, mainly for load-carrying members, doors or windows etc.	Pine, juniper, cypress etc.
Broadleaf	Leaves are broad and shape in sheets, most of which are hardwood. The straight parts of the trunks are short, and ligneous tissue is hard, not easy to process. The apparent density is high, and the shrinkage deformation is high, easy to crack or warp	Used for minor load-carrying member in interior decoration or veneer, etc.	Elm, birch, Manchurian ash, etc.

The performance of wood derives from the structure of the wood, and the structure of the wood can be classified into macro structure and microstructure.

9.1.2 The Macro-structure of wood

The wood structures that can be seen by eyes or through magnifying glass are called the macro structure of wood. In order to observe closely, the trunks are cut into three different sections. As is shown in Figure 9.1:

Transverse section: the section that is vertical against the trunk axis;

Radial section: the section that passes the trunk axis;

Tangential section: the section that parallels with the trunk axis and tangent with the annual ring.

As it is shown in Figure 9.1, the wood is made up of bark, xylem and pith. Bark is mainly used for burning except certain species of trees (cork oak, and yellow pineapple tree) whose bark can be used to make heat-proof materials. Pith is in the central part of the trunk, whose texture is loose and fragile, and is liable to be corrupted or eaten by insect worms. So the best part for use is the xylem of trunk. In the xylem, the darker part near the pith is called duramen, while the light part outside is called alburnum. The duramen contains little water so that it is not liable to reshape, and it has high corrosion resistance. While the alburnum contains more water that it is easy to deform and has worse corrosion resistance than duramen.

On the transverse section many centric circles can be seen, which are called annual rings. Of them the part in dark color and lie close are grown in summer, called summerwood. And the converse part is grown in spring, called springwood. The more summerwood wood has, the better the wood is. The more intense and evener annual rings the wood has, the better quality the wood has.

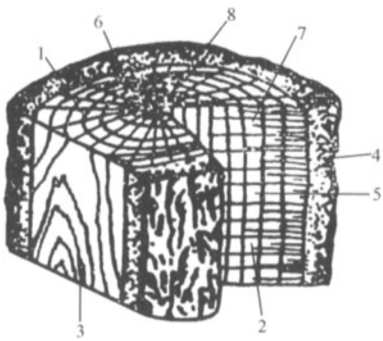

Figure 9.1 Three Sections of Trunk

1. transverse section; 2. radial section; 3. tangential section; 4. bark; 5. xylem; 6. annual ring; 7. pith ring; 8. pith

9.1.3 The Microstructure of Wood

The wood structures that can be seen through microscope are called microstructure of wood. There are differences between the structures of conifer and broadleaf, just as shown in Figure 9.2. Every cell can be classified into two parts: the cell wall and the lumen. The cell wall is composed of fibrils. The longitudinal combination is firmer than the transverse combination. So the cell wall is of high strength in lengthways, but of low strength in transverse. There are very little spaces among the fibrils composed of cell wall, which enables the material to absorb or leak water.

The structure of the cell determines the physical characteristics of wood. For example: the wood with thick cell wall and small lumen is intense and hard, and its bulk specific gravity is high and it is of high strength.

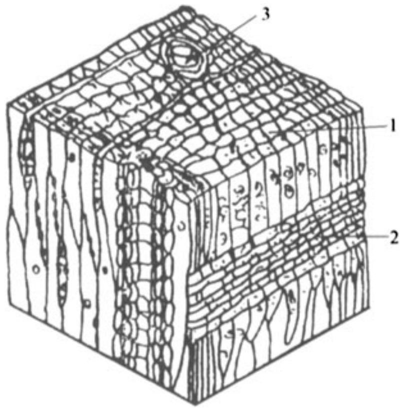

Figure 9.2 Microstructure of Masson Pine

1. tracheid; 2. pith ring; 3. resin canal

9.1.4 Disadvantages of Wood

During the process that wood are growing, cut down, stored and carried, processed and used, there may be such defects arise as knots, splits, bark pockets, disorder grains, curves, scars, decay rot and worm holes. Those defects not only reduce the mechanical property of wood, but also affect their appearance quality. Among them the knots, the splits and the decay rot play the most harmful part.

1. Knots

The branch grow in trunk is called knot. Intergrown knots are composed of branches alive, and they live closely together with wood neighborhood. They are hard in texture and normal in structure. Dead knots are composed of dead branches, and they are separate from the wood nearby. Their texture may be either hard or loose and soft. Sometimes they may also fall off and holes may arise. The knots with sound texture are called sound knots. And the knots with rotten texture are called rotten knots. The streaks are not only rotten themselves, but spread the rot into the interior part of wood, and the interior rot of wood may be caused. The knots' influences on the application of wood usage vary for their species, position, size and intensity, and the ways to use wood. Sound intergrown knots have little negative influences on the mechanical property of wood, while dead knot, rotten knot and streak do the worst harm to the mechanical properties and the outer appearance of wood.

2. Splits

The splits are caused by the separation among wooden fibers. The splits that split from the pith along with the direction of radius are called radius splits. The splits split along with the direction of annual rings are called ring splits. The splits split along with the direction of grains, from surface to interior are called longitudinal splits. The splits of wood are caused by the growing surroundings and factors of growing stress; moreover the reasons may also be the improper drying after cutting. Splits destroy the integrality of wood, influence the usage ratio and decorative value of wood, reduce the strength of wood, and meanwhile they are also access for fungus to invade the wood.

9.2 Physical and Mechanical Properties of Wood

9.2.1 Moisture

The moisture of wood is measured in the percentage of water content, which is the percentage of the mass of water to the mass of dry wood.

1. The Water in Wood

The water in the wood can be classified into the free water that lies in intercellular space and the absorbed water that lies inside the cell wall. The newly-cut wood is green wood. There is a plenty of free water and absorbed water in it. And the percentage of water content ranges from 70 % to 140%. When wood becomes dry, the free water is the first to evaporate, but at this time the size and mechanical property of wood are not influenced. When the free water finishes evaporating, the absorbed water begins to evaporate. The process of absorbed water evaporating is slow, and during it the bulk and the strength change regularly.

2. Fiber Saturation Point

The status when there is no free water in wood, but the cell walls are saturated with absorbed water, is called the fiber saturation point. In general the fiber saturation point of wood is from 25% to 35%.

3. Equilibrium Water Content

The status that the percentage of water content of wood keeps balance with the surrounding moisture is called equilibrium water content. In order to avoid deformation and splits of wooden products caused by the change of moisture of wood, the wood must be dried until the percentage of water content reaches the equilibrium water content. In the north area of China the equilibrium water content is about 12%, while in the south area the balanced percentage of water content is 15%~20%. The kiln-dried wood's percentage of water content is 4%~12%.

9.2.2 Wet Swelling and Dry Shrinking (Deformation)

When absorbed water content in cell walls changes, the deformation of wood may arises, which is wet swelling and dry shrinking.

During the process that wood are dried from damp status to the cellar saturation point, the size of wood remains still but the mass decreases. Only when the wood remains being dried until the absorbed water in cell wall begins to evaporate, do the wood begin to shrink. And when the absorbed water in wood begins to increase, the wood will start to expand, as shown in Figure 9.3.

Because the structure of wood is not even, so the shrinkage value also varies from direction to direction. The shrinkage value is the smallest in the direction of long grain, and bigger in the radial direction, and the most in the chordwise direction. So when the green wood becomes dry, the size and the shape of section may change a lot, as shown in Figure 9.4.

The shrinkage effect makes a great difference to the usage of wood. It may cause the wood split or warp, even make the structure of wood loosen or heave.

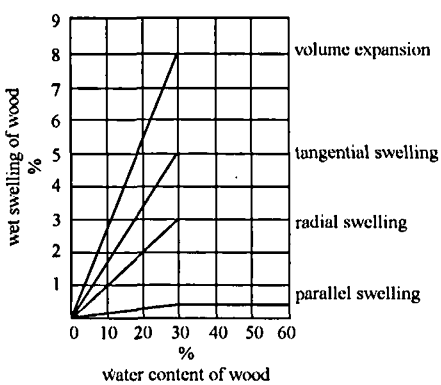

Figure 9.3 The Wet Swelling of Pine

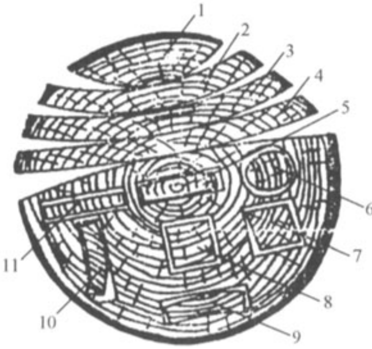

Figure 9.4 Deformation of Wood's Section Shape after Drying

1. arching like an olive nucleus; 2,3,4. springing; 5. shrinking like a spinning cone through pith; 6. round or oval; 7. square in a diagonal direction to the annual ring changing into diamond; 8. square with two sides paralleling with the annual ring changing into rectangle; 9,10. warping of the rectangle board; 11. the laburnum through saw plate is even

9.2.3 The Strength of Wood

1. All kinds of Strength

According to the ways that wood bears force, the strength of wood can be classified into tensile strength, compression strength, bending strength and sharing strength. And the tensile strength, compression strength and sharing strength also vary with the parallel grain (the direction of force parallels with the fiber direction) and transverse grain (the direction of force is vertical against the fiber direction). The parallel grain strength is quite different from the transverse grain strength. According to the Table 9.2, you can see how to make good use of all species of wood on the basis of their strengths separately.

Table 9.2 The Relationships between Strengths of wood

Compression strength		Tensile strength		Bending strength	Sharing strength	
Parallel grain	Transverse grain	Parallel grain	Transverse grain		Parallel grain	Transverse grain
1	1/10~1/3	2~3	1/20~1/3	1.5~2	1/7~1/3	1/2~1

The wood' strength grade are measured through tangential static bending strength of flawless standard specimens (see Table 9.3). The values of the strength grades of wood are the design strength values when wood structures are designed. They are several times lower than the actual strength, because the actual wood strength is determined by many factors.

Table 9.3 Measurement Standards of Wood Strength Grades

The species of wood	Conifer wood				Broadleaf wood				
Strength Grade	TC11	TC13	TC15	TC17	TB11	TB13	TB15	TB17	TB20
Minimum Value of Static Bending Strength (MPa)	48	54	60	74	58	68	81	92	104

2. Factors Affecting the Wood Strength

Besides its own structure, the strength of wood is also determined by such factors as the percentage of wood moisture, the defects (knots, irregular grain, splits, decay rot and worm rot), the duration of outside force and temperature.

(1) Water Content of Wood

When the wood contains less water than the saturation point, the percentage of moisture reduces, and the absorbed water becomes less and less, so that the strength of wood rises. To the contrary, the absorbed water increases and the cell walls expand, then the structure loosens and the strength of wood lowers. When the percentage of moisture exceeds the fiber saturation point, only free water is changing, and the strength of wood remains still. The influence of water content on the strength of wood see Figure 9.5.

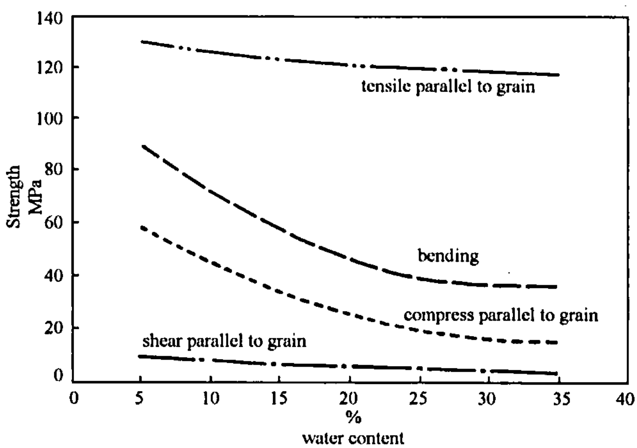

Figure 9.5 The Influence of Water Content on the Strength of Wood

In order to judge the wood strength and compare the results of experiment correctly, the wood strength should be calculated into the strength value in the state of standard water content (which is 12%) through following formula:

$$\sigma_{12} = \sigma_w[1+\alpha(W-12)]$$

In the formula, σ_{12} stands for the wood strength when the water content is 12% (MPa);

σ_w is the wood strength when moisture content is W% (MPa);

W stands for the moisture content in experiment (%);

α stands for the coefficient of moisture content, when the water content is 9%~15%, the numeral values are determined according to Table 9.4.

Table 9.4 Numeral Values of α

Strength type	Compression Strength		Tensile Strength parallel to grain		Bending Strength	Sharing Strength parallel to grain
	Parallel grain	Transverse grain	Broadleaf wood	Conifer wood		
α	0.05	0.045	0.015	0	0.04	0.03

(2) Environment Temperature

Temperature has direct influence on the wood strength. The experiment shows that when the temperature rises from 25 ℃ to 50 ℃, the wood compression strength will be reduced by 20%~40% and the wood sharing strength will be reduced by 12%~20% because the collide among wood fibers is softened. In addition, if the wood is in hot and dry surrounding, it may become fragile. During the processing of wood, boiling method is often employed to reduce its strength contemporarily to meet the needs of processing (such as the production of plywood).

(3) The Duration of Outer Force

The limit strength of wood stands for the capability of standing the outer force in a short time. The limit that the wood can stand in a long run is the rupture strength of wood. Because plastic-flow deformation will occur to wood, the strength of wood will be reduced with the lasting of loading time, and the rupture strength of wood may be only 50%~60% of the limit strength of wood (as shown in Figure 9.6).

(4) Defects

The wood strength is judged by the samples without defects. In fact, during the growing, cutting and processing process of wood, there may be such defects as knots, splits and worm rot. These defects make the wood uneven, and destroy wood structures; all these influences may reduce the strength of wood, especially the tensile strength and the bending strength.

Besides the factors above, the species of trees, growing surroundings, the age of trees, and different parts of trees all influence the wood strength.

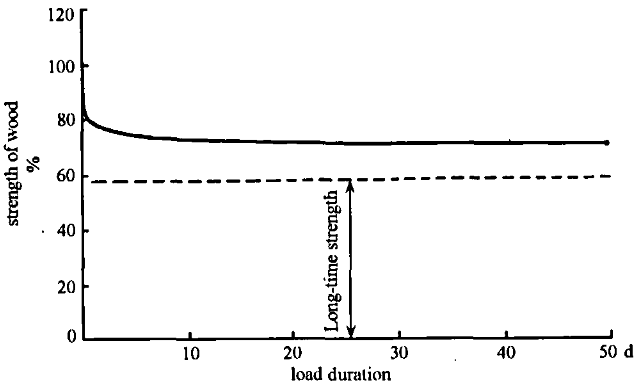

Figure 9.6 The Creep Rupture Strength of Wood

9.3 Wood Preservation

In order to increase the wood strength, keep the original size and shape of wood, improve the usage property and lengthen the useful time; the preservative treatment and the drying treatment must be made before wood is processed and used.

9.3.1 The Drying Treatment of Wood

The ways to dry the wood are natural drying and artificial drying:

1. Natural Drying

The natural drying is to store the plates and square timber that are just sawed off at the drafty place in a certain manner, and the direct sunlight and the rain should also be avoided, so that the water in the wood can evaporate naturally. This method is easy and no special equipment is required, and the quality of dried wood is good. But it takes up too much time and space to dry the wood, and the drying status can only reach the weathered status.

2. Artificial Drying

Artificial drying makes use of artificial ways to remove the water from wood. The usually used methods are heated stream drying and hot air drying.

9.3.2 Wood Preservation

The decay of wood is caused by fungi or insects. There are three factors needed by epiphyte to live. They are the water, oxygen and temperature. In proper circumstances with proper temperature (25~30℃) and proper moisture (the percentage of water content is 35%~50%), etc., fungi and insects will reproduce in wood and at the same time destroy the wood structure and influence the usage of wood.

In order to lengthen the useful life of wood, three wood preservative treatment methods can be used.

1. Drying Treatment

Reduce the percentage of water content as much as possible by air-drying or kiln drying. And during drying process all species of damp-proof and drafty measures should be adopted. Such as add the damp-proof pad between wood and other materials, seal no joint or wooden member into the wall, set the drafty hole under the wooden floor, adopt gable to keep drafty, and set the dormer window, etc..

2. Antiseptic Treatment

This method is making the wood poisonous through brushing or immerging into antiseptic to keep the wood from decaying or worm rotting. The common preservatives are water agents (sodium chloride, zinc chloride, copper sulfate, monohydrate, Na-CPC, etc.), oil agents (lindane five chlorophenol mixture), and emulsion agents. The methods to inject wood preservative are external coating, immersion at room temperature, immersion in hot and cold bath and pressure treatment, etc..

3. Paint Coating

There are many species of paints, but in wood preservative treatment the adopted paint should possess good waterproof property. The function of paint is to form a complete and hard protective coat on the surface of wood to separate the water and air from wood, and therefore, the fungi and insects can also be avoided.

9.3.3 Fire Protection of Wood

Flammability is the biggest disadvantage of wood, and the following methods are often adopted to protect wood from fire.

1) Put the wood into flameproof infusion and ensure a proper amount of infusion and the filtration depth to meet the demand of fireproofing.

2) Paint or spray the flameproof coating on to the surface of wood until the coating becomes dry. The flameproof effect depends on the thickness of coating or the amount used in every square meter.

With the passing of time and the influence of surrounding factors, the fireproof components in fireproof paints or infusion may decrease or decay that the fireproof ability of wood will decrease if the above two methods are adopted.

9.4 Applications of Wood in Architecture

During the construction process, the wood should be used rationally according to the species, the grade and the structure. And we should also try to avoid using the big ones for fraction and the good ones for trifles.

9.4.1 Species and Specifications of Wood

The wood used in architecture can be classified into primitive streak, log, sawn timber and crosstie according to its usage and status of processing.

Primitive streak means the wood without bark, root and treetop. And usually it is not processed into certain length or diameter by certain size. Primitive streak is often used as scaffold, architecture material and furniture.

Log means the wood without bark, root and treetop. And usually it is processed into certain length or diameter according to certain size. Log is often used as frame, purlin or rafter, etc.. Furthermore it can also be used as pile timber, pole, mine timber, etc.. When processed, it can also be made into plywood, ship model and machine model.

Sawn timber means timber, which has been processed and sawn. The timber whose width is three (or more than three) times of its thickness is called plate. While the timber whose width is less than three times of its thickness is called square log. Sawn timber is often used in architecture, bridge, furniture, ship, automobile or pocking box.

Crosstie means the timber processed according to the section and length of sleeper. Crosstie is often used in railway construction.

9.4.2 Artificial Wood

Artificial wood is made of various leftover materials, small scraps, wood shavings and timbering residues. All those materials are made into sorts of artificial wood to improve the usage of wood. The usual artificial woods are like follows:

1. Plywood

Plywood is made through following procedures, peel the log into laminas and dry them, then pile the laminas whose fibers are transverse to each other together, finally agglutinate and stress them in heat. Generally speaking plywood contains from 3 to 13 levels. 3-plywood and 5-plywood are usually used in architecture. Both conifer and broadleaf can be made into plywood.

Characteristics: It has even texture and high strength, without obvious fiber saturated point, warping or split; it contains seldom defect; usually it has wide surface and is convenient for using; and it makes a good decorative effect.

The glue species, characteristics and using range of normal plywood are shown in Table 9.5.

2. Fiberboard

Fiberboard is also a kind of artificial wood. The procedure is as follows. First break the bark, wood shavings branch and other waste materials into pieces, and then mill them into wood pulp, after that add the glue into it or make use of its own agglutination, through heated pressure and drying treatment, and finally the plywood is made.

Fiberboard makes use of 90% of wood, and its texture is even, the strengths in every direction are equal, especially the bending strength is intense. In addition fiberboard is not liable to warp and split, and it totally avoids the defects of wood.

Hard fiberboard can be used as wall slab, door board, floor, furniture and other decorations instead of wood. And the soft fiberboard whose apparent density is low($<400kg/m^3$) and porosity is high, often used as heatproof or acoustical materials.

Table 9.5 Species, Characteristics and Applications of Plywood

Kind	Species	Name	Glue Species	Characteristics	Applications
Normal Broadleaf Plywood	Species I	NQF(climate tolerant plywood)	phenolic resin	tolerant of age, boiling and steam, dry and heat, fungi tolerant	Outdoor engineering
	Species II	NS (water tolerant plywood)	urea-formaldehyde resin	Tolerant of cool water and hot water immersion, but not tolerant of boiling	Outdoor engineering
	Species III	NC(moisture tolerant plywood)	blood glue, urea-formaldehyde resin with many other ingredients and other glues of the similar capacity	tolerant of cool water immersion in a short period	Indoor engineering in normal circumstances
	Species IV	BNS (moisture intolerant plywood)	Soy-adhesive or other glues of the similar capacity	certain agglutinative strength, but intolerant of water	Indoor engineering in normal circumstances
Normal Pine Plywood	Species I	species I plywood	phenolic resin ak or other synthesis resin of the similar capacity	tolerant of age, heat, and fungi	Enduring outdoor engineering
	Species II	species II plywood	underhydrated or other synthesis resin of the similar capacity	tolerant of water and fungi	Engineering in damp circumstances
	Species III	speciesIII plywood	blood glue or urea-formaldehyde resin with a little ingredient	tolerant of damp	Indoor engineering
	Species IV	speciesIV plywood	Soy-adhesive and urea-formaldehyde resin with plenty of ingredient	intolerant of water and damp	Indoor engineering (in dry circumstances)

3. Particle board, fiberboard and oxychloride

Particle board, fiberboard and oxychloride are artificial wood made by damaging, dipping and grinding wood shavings, wood wool and timbering residue into wood pulp, mixing the pulp with glue, and then heat-pressing and drying the pulp. And the glues used in the procedure are plant or animal glue (soy-adhesive, blood glue), synthesis resin adhesive (phenolic resin, urea-formaldehyde resin), and inorganic gelling material (concrete, magnesite, etc.)

These kinds of wood are of low apparent density and strength. And they are mainly used as heat proof and acoustical material, and after facing treatment they can also be as ceiling board or partition board.

4. Block Board

Block board is made of all kinds of wood comprehensively. The core plate is made up of laths and the surfaces are made of wooden veneer.

The block board can be classified according to its structure into two kinds: block board whose core plate with or without glue.

The block board can be classified according to the status into three kinds: the block board with one sanded surface, the block board with both sanded surfaces and the block board without sanded surface.

The block board can be classified into three kinds according to the texture and the processing quality of the board: I , II and III. The standards and sizes of all kinds of block boards are shown in Table 9.6.

Table 9.6 Standards and Sizes of Block boards

length (mm)						width (mm)	thickness (mm)
915	1200	1520	1830	2135	2440		
915	—	—	1830	2135	—	915	16 19
—	1220	—	1830	2135	2440	1220	22 25

Notes: The crane direction of the core plate is the length of the blockb oard.

Performance and technological indexes of block board: the moisture content is 7% ~ 13%; when the thickness of block board is 16mm, the horizontal static bending strength is not less than 15MPa; and when the thickness of blockboard is over 16 mm, it is over 12MPa; and the sharing strength of the glue level is over 1MPa.

The block board is acoustic, heat-proof, hard in texture and easy to be processed. So that it is mainly used for furniture, carriage and indoor decoration.

Questions

9.1 How many kinds are wood classified, what are they? Please list the characteristics and usages of it.

9.2 What are the main components of wood according to its general structure?

9.3 What are the fiber saturation point, equilibrium water content and standard water content of the wood? What practical meanings do they have?

9.4 How can the change of wood moisture affect the capacities of wood?

9.5 What are the factors affecting the strength of wood? How to influence?

9.6 Briefly list the reason of wood rot and the preservative measures.

9.7 What are the common artificial woods? And what about their characteristics and usages?

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