CHAPTER 5

Mechanical Properties Of Some Species Of Wood.
MECHANICAL PROPERTIES OF SOME SPECIES OF WOOD.

ABSTRACT:

Some selected important mechanical properties, viz. compressive strength along and across the grain, strength in static bending, tensile strength along the grain and, end and side hardness of various species of wood grown in the forests of Raipur Division, at two different moisture contents have been measured. The average values of compressive strength along and across the grain, static bending strength, tensile strength along the grain and B.H.N. for end and side hardness at 15 P.C. moisture content are found to be 425 kg/cm², 200 kg/cm², 588 kg/cm², 850 kg/cm², 8.87 and 4.93 respectively. Similarly the respective quantities at 25 P.C. moisture content are found to be 370 kg/cm², 124 kg/cm², 382 kg/cm², 693 kg/cm², 7.1 and 4.2.

INTRODUCTION.

Since the selection of a material for a particular structural application depends on its mechanical properties, it is important to be familiar with some of the standard tests used to measure these properties and to understand the significance of the information obtained from these tests. The capacity of a material to withstand a static load can be determined by testing that material in tension or compression (Wayne, 1965). Information about its resistance to permanent...
deformation can be gained from hardness tests.

The mechanical properties of wood, a widely used material for diverse purposes, are of paramount importance in determining its ability to resist the effects of external mechanical forces.

The diversity (Pelevgin, 1965) of external mechanical forces acting on a body can be reduced to the action on a prism, firstly of a force proper, and secondly of a couple or moment, in accordance with which the following main factors of action of mechanical forces are distinguished:

(i) Tension, (ii) Compression, (iii) Shearing (iv) Bending, (v) Torsion, and (vi) Buckling.

With reference to wood almost every one of these main forms is subdivided into a few more classes, depending on the direction of force relative to the grain direction. Thus tension and compression may be along and across the grain, in the latter case - radially and tangentially, bending (transverse) may be radial (the acting force being directed along medullary rays) and tangential (the force being directed tangentially to annual rings) etc.

Wood hardness is subdivided into three kinds: hardness of end, radial and tangential surfaces.

EXPERIMENTAL:

1) **Distinguishing features of Mechanical tests of wood:**

To begin with, the dimensions of specimen have to be determined for mechanical tests of wood. It would seem
that the practical value of results would call for dimensions of specimens which are near to the actual dimensions of gradings being used; however in testing large specimens we cannot eliminate the effect of flaws and hence cannot obtain true characteristics of wood properties. At the same time we have to take into consideration the large expenses and the complexity of testing large size specimens, connected with the consumption of great quantities of material, in addition to requiring powerful testing machines and large space for the laboratory. Because of these reasons, it is most expedient to apply the standard test method with small clean (i.e. free from flaws) wood specimens. This method allows to compare the mechanical properties of wood of various species; to study the effect of different factors on wood mechanical properties; to obtain data for determining the permissible stresses.

All kinds of test results of wood can be compared only when the tests are performed by one and the same method; this necessitates the standardization of test methods.

Mechanical properties (Karlsen, 1965) of wood depend greatly on its moisture content, being affected only by bound moisture which saturates the cell walls. In mechanical tests, the moisture content of wood is, therefore, always determined.

11) Testing Machine:

The universal testing machine, and others which
perform one or more of its functions, are of many types, all of them consisting essentially of two parts—

1. The straining mechanism, and

2. The load weighing mechanism.

With suitable arrangements of gripping or bearing devices, the specimen to be tested is interposed between a fixed head and a movable head. The specimen is strained by controlling the motion of the movable head. The measurement of the load on the specimen is accomplished by means of lever systems, by pressure cells, or by other devices through which the straining load or some known portion of it must pass.

The universal machine (Fig) of 5000 kg. limit load which is unit with screw actuating force, is most suitable for mechanical tests of small wooden specimens under static loads. Depending on the direction of rotation of the machine screw, either compressive or tensile stresses are applied to the specimen; the machine diagram and general view are shown (Fig.A). The load is transmitted to the specimen through the long vertical pressure screw 1; passing through the fixed nut 2 and terminating on top with a clamping head (lower one). Two handles serve for turning the screw: first one (on the right) for rapid shifting of the lower head when placing a specimen, and the second one (to the left), for turning the screw slowly during the test. Depending on the direction of rotation, the screw will either go up or down. The upper clamping head is suspended from the end of the short arm of the horizontal lever 3, which has a supporting at the top of the frame. The end of
the lever's long arm is coupled with the vertical connecting rod 4, transmitting stress to a projection which is fastened permanently to the pendulum 5, whose deflections are registered by the pointer of the strength measuring device 6. Specimen 7 is arranged between the machine heads and depending on the direction of rotation of the screw 1, the specimen will be subjected to tension or compression.

The maximum force of machine (6000 kg) can be reduced to 2500 kg., 1000 kg. and 500 kg. by replacing the pendulum weight; the scale of the strength measuring device has to be changed simultaneously.

The machine can be actuated by hand or electric motor which is attached to the frame at the bottom of the machine.

By using interchangeable appliances and devices, it is possible to perform on this machine many of the static tests.

iii) Compressive strength:

(a) Along the grain:— The most typical of wood mechanical properties and practically significant is its compressive strength along the grain. A specimen in the form of a rectangular prism with a base of 20 x 20 mm and 30 mm. (in the direction of grain) and free from any defect was used for tests. After measuring the dimensions of section by half of the height, the specimen was so placed that the centre of the cross-section of the specimen was vertically below the centre of the moveable head. The
ends of the rectangular test specimen were smooth, parallel and normal to the axis. After placing the test specimen between the bearing surfaces of the testing machine, it was uniformly loaded along the grain at an average rate of 4000±25 kg. per cent per minute along the entire specimen. The test was conducted until obvious failure of the specimen and readings were taken of the maximum load $P_{\text{max}}$ to 5 kg. from the machine scale. The ultimate strength was calculated from the formula:

$$\sigma = \frac{P_{\text{max}}}{ab} \text{ kg/cm}^2$$

where $P_{\text{max}} = \text{maximum crushing load in kg.}$

and $ab = \text{cross-section area in cm}^2$.

(b) Across the grain: - Compressive strength of wood across the grain is of practical importance in points of notches or joints of wooden and metal members (under shoes, bolts etc.). Sleepers (under rails) can serve as a classical example of the work of wood in compression across the grain. With recent developments in pressing wood, the compression of wood across the grain and the resulting phenomenon became of great importance.


<table>
<thead>
<tr>
<th>S. No</th>
<th>Species</th>
<th>Along the grain: Ultimate strength in kg/cm² at a moisture content, per cent</th>
<th>Across the grain: Ultimate strength in kg/cm² at a moisture content, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tectona Grandis (Teak)</td>
<td>570 410 170 95</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Acacia Arabica (Babul)</td>
<td>545 400 235 132</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Anogeissus Latifolia (Dhaora)</td>
<td>496 360 300 170</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Lagerstroemia Parviflora (Senha)</td>
<td>476 341 210 120</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Emblica Officinalis (acuila)</td>
<td>415 309 194 103</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Cleistanthus Collinus (Karra)</td>
<td>408 300 208 100</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Diospyros Melanoxylon (Tendu)</td>
<td>380 290 240 145</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Shorea Robusta (Sarai)</td>
<td>295 201 155 -</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Boswellia Serrata (Salia)</td>
<td>230 155 100 -</td>
<td></td>
</tr>
</tbody>
</table>
Result: Data, which characterize the strength of tested species in compression along and across the grain are given in Table-1. Tested species show a fairly high resistance to compression along the grain, which determines frequent use of wood for work under these conditions (piles, pit props, roof rafters etc.). In comparison with the compressive along the grain, the compressive strength across the grain is less. On the average for investigated species, the compressive strength along the grain at 15 and 25 per cent moisture content works out to be 425 and 310 kg/cm$^2$ respectively. The mean correction factor for moisture content for the tested species equals 0.04. Similarly the average compressive strength across the grain constitute: 200 and 125 kg/cm$^2$ at 15 and 25 per cent moisture content respectively and the average moisture content correction factor equals 0.045.

iv) Tensile strength of wood along the grain is determined by specimens, the form and dimensions of which are given in Fig.1. Pieces for specimens are prepared by pricking out (and not sawing) in order to avoid cutting off the grain. The complex shape of the specimen (massive heads and thick work area) prevents premature rupture of the specimen due to bearing and shearing stresses which develop in the specimen heads (Perelvgin, 1965) while testing it (when clamping it in the machine heads). After measuring the section of work area (middle of the length), the specimen is clamped between the grooved jaws of the machine. Loading of the specimen is effected uniformly at an average rate of 4000+25 kg per cent per minute along the entire specimen.
The specimen is kept until rupture and readings are taken of the maximum load value $P_{\text{max}}$ to 5 kg. from the machine scale. Ultimate strength is calculated from the formula

$$\sigma = \frac{P_{\text{max}}}{ab} \text{ kg/cm}^2$$

where $\sigma = \text{ultimate strength, kg/cm}^2$

$P_{\text{max}} = \text{maximum load, kg.}$

$ab = \text{work area in cm}^2$.

Table-2 below presents data of tensile strength of some species of wood grown in the forests of Raipur Division.

**TABLE-2.**

**OBSERVATIONS. TENSILE STRENGTH ALONG THE GRAIN.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Ultimate tensile strength in kg/cm$^2$ at a moisture content per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tectona Grandis (Teak)</td>
<td>980</td>
</tr>
<tr>
<td>2</td>
<td>Diospyrosmelanoxyylon (Tendu)</td>
<td>945</td>
</tr>
<tr>
<td>3</td>
<td>Acacia Arabica (Babul)</td>
<td>885</td>
</tr>
<tr>
<td>4</td>
<td>Anogeissus Latifolia (Dhesra)</td>
<td>823</td>
</tr>
<tr>
<td>5</td>
<td>Cleistanthus Collinus (Karra)</td>
<td>804</td>
</tr>
<tr>
<td>6</td>
<td>Shorea Robusta (Sara)</td>
<td>784</td>
</tr>
<tr>
<td>7</td>
<td>Emblica Officinalis (Aonla)</td>
<td>724</td>
</tr>
</tbody>
</table>

Results: For tested species, the average value of the tensile strength along the grain at a moisture content of 15 and 25 per cent works out to be 850 and 668 kg/cm$^2$. 

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respectively. The correction factor for moisture content along the grain is found to be 0.02.

From the table it is obvious that wood possesses high tensile strength along the grain. It is however very difficult to fully utilize this property due to the complexity of securing the ends of the member where shearing stresses originate and crumpling of the wood occurs. Since wood resists poorly to such actions of forces, failures generally occur not in the form of rupture but in the form of shearing or crumpling at points of member fastening. On this account wood is scarcely used for work in tension along the grain.

v) **Static Bending Strength**

Flexural acceptance tests may be specified for materials such as timber, concrete, cast iron and clay products. In most cases the modulus of rupture is required, but other properties may also be evaluated (Marin, 1966).

Within the proportional limit, the flexural test is often useful for the ready determination of Young's modulus from the known load and the observed deflection. An indication of the relative stiffnesses of two materials above the proportional range may be obtained by comparing the deflection of geometrically identical specimens of the two materials when loaded in flexure. In a similar manner deflections and loads together give indications of relative toughness.
A bar of $20 \times 20 \times 300$ mm was used as a specimen (Fig. 2) for static bending test. After measuring at the middle of section length of the specimen (width $b$ and height $h$), it was placed on two bearings (the centre distance between bearings = $240$ mm.) and the load was applied gradually at the centre of the specimen till it failed. The ultimate strength was calculated from the formula:

$$
\sigma = \frac{P_{\text{max}}}{bh^2} \text{ kg/cm}^2
$$

**TABLE-2.**

**OBSERVATIONS: STATIC BENDING STRENGTH.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Ultimate strength in kg/cm$^2$ at a moisture content, per cent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anogeissus Latifolii (Dhaora)</td>
<td>736 ± 0.5, 485 ± 0.5</td>
</tr>
<tr>
<td>2</td>
<td>Lagerstroemia Parviflora (Senha)</td>
<td>784 ± 0.5, 502 ± 0.5</td>
</tr>
<tr>
<td>3</td>
<td>Tectona Grandis (Teak)</td>
<td>670 ± 0.5, 430 ± 0.5</td>
</tr>
<tr>
<td>4</td>
<td>Acacia Arabica (Babul)</td>
<td>625 ± 0.5, 405 ± 0.5</td>
</tr>
<tr>
<td>5</td>
<td>Shorea Robusta (Sarai)</td>
<td>610 ± 0.5, 408 ± 0.5</td>
</tr>
<tr>
<td>6</td>
<td>Cleistanthus Collinus (Kerra)</td>
<td>553 ± 0.5, 330 ± 0.5</td>
</tr>
<tr>
<td>7</td>
<td>Emblica Officinalis (Aonla)</td>
<td>485 ± 0.5, 295 ± 0.5</td>
</tr>
<tr>
<td>8</td>
<td>Diospyros Melanoxylon (Tendu)</td>
<td>460 ± 0.5, 280 ± 0.5</td>
</tr>
<tr>
<td>9</td>
<td>Boswellia Serrata (Salia)</td>
<td>423 ± 0.5, 258 ± 0.5</td>
</tr>
</tbody>
</table>

**Results:** For the tested species, the average lateral static bending strength works out to be $588$ and $382$ kg/cm$^2$ at $15$ and $25\%$ m.c. respectively. The average correction
factor for moisture content equals 0.05. The strength of wood in static bending by magnitude seems to occupy intermediate position between strength in tension and compression along the grain. The high strength and easiness of applying stress explains the wide usage of for members which work in bending (various girders, rafters, trusses, bridges, cross-bars, crates, axles for carriages etc.

vi) **Hardness of wood:**

Hardness of wood is of great importance in machining it with cutting tools (sawing, planing, peeling), as well as in cases when wood is subjected to wear (floors, wooden pavements), to shocks and impacts (Gilkey, 1941).

Depending on the surface under determination, the hardness of wood is distinguished as end, radial and tangential hardness.

The **Brinell Hardness** (Gilkey, 1941) test consists in pressing a hardened steel ball 10 mm. diameter, under a suitable load into the material being tested. The load is maintained for a period of 15 seconds. The ball leaves an impression in the material, and the harder this is, the smaller the impression will be. The Brinell Hardness Number, B.H.N. is given by:

\[
B.H.N. = \frac{\text{Total Pressure, } P \text{ in kg,}}{\text{curved area of impression in mm}^2}
\]

\[
= \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})}
\]

where \(D\) = diameter of the ball in mm.

\(d\) = diameter of impression in mm.
The surface to be indented is so prepared so that a smooth flat area is presented squarely to the pressure of the ball. One type of Brinell machine is shown in Fig. 3. The test piece taken as a rectangular block (3 x 3 x 5 cm.) is placed on the anvil and the ball is brought into contact with it by depressing the screw. The suitable load is then applied and after a suitable period removed. When the test piece is examined, a small impression will be seen. The exact size of the impression is measured by a scale in the eye-piece of a microscope and this gives the diameter. These tests are never taken near the edge of a sample or any closer than three times the diameter of an impression to an existing impression.

The condition (Richards, 1961) of the surface is of great importance in interpreting hardness results. The surface is frequently harder than the interior material, producing a hardness gradient. If the surface is clean and flat, the surface layer is of atomic dimensions and any gradient will be so small that hardness readings will not be affected. If the penetration of the indenter is small compared with the thickness of the surface layer, or if the gradient is not steep, the hardness number can be taken as an indication of the hardness of very surface of the material. If the penetration of the indenter is deep compared with the thickness of the surface layer, the hardness number indicates the hardness of the inner material.

Five samples of each species have been tested and
Table-4 gives mean values of hardness for tested species.

TABLE-4.

OBSERVATIONS: END AND SIDE (TANG.) HARDNESS.

<table>
<thead>
<tr>
<th>No</th>
<th>Species</th>
<th>END HARDNESS</th>
<th>SIDE (TANG.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acacia Arabica (Babul)</td>
<td>11.37</td>
<td>9.10</td>
</tr>
<tr>
<td>2</td>
<td>Cleistanthus Collinus</td>
<td>9.56</td>
<td>7.76</td>
</tr>
<tr>
<td>3</td>
<td>Shorea Robusta (Sarai)</td>
<td>9.32</td>
<td>7.39</td>
</tr>
<tr>
<td>4</td>
<td>Lagerstroemia Purviflora</td>
<td>8.60</td>
<td>6.75</td>
</tr>
<tr>
<td>5</td>
<td>Emblica Officinalis</td>
<td>8.53</td>
<td>6.87</td>
</tr>
<tr>
<td>6</td>
<td>Anogeissus Latifolia</td>
<td>8.24</td>
<td>6.50</td>
</tr>
<tr>
<td>7</td>
<td>Diospyros Melanoxylon</td>
<td>8.10</td>
<td>6.25</td>
</tr>
<tr>
<td>8</td>
<td>Tectona Grandis (Teak)</td>
<td>7.25</td>
<td>5.69</td>
</tr>
</tbody>
</table>

**Results:** The end hardness, determined by this method exceeds the side (tang.) hardness as may be seen from the Table-4. The average correction factor for moisture content for tested species is found to be 0.02 for side (tang.) hardness and 0.03 for end hardness. The above method presents a characteristic of static hardness.
The basic elements of which the body of all plants is composed, are the plant cells. Each cell has a wall which separates it from neighbouring cells. It has been ascertained by X-Raying that the basic structural element of the wall is micell which is a bundle of parallelly located thread-like molecules. The dimensions, number and distribution of wood cells are much diverse; this determines on the one hand, the comparatively complex structure of wood cell walls and on the other hand, the differences in the mechanical properties of wood of various species (Abronn, 1926; Balazlan).

The fibrous structure of wood is attributed to long chain molecules of cellulose (Clark, 1962). The bonds formed within the macro-molecules are interatomic covalent bonds, and the molecules are therefore strong within themselves. Further the long chain molecules may be linked together by becoming entangled, or by forming cross-links between atoms of adjacent chains. Cross-links being inter-atomic bonds, are strong and give entire structure a higher strength. Additional strengthening results from increasing the surface areas of the molecules to provide corresponding larger inter-molecular bonds. For example, if a long chain molecule is held in place by many small secondary bonds, the force necessary to displace it may exceed the strength of the primary bonds within the molecule.

As discussed above, timber has a hollow-fibrous structure; its bulk density depends on the number of voids,
the thickness of the fibre walls and the moisture content. The density of the timber i.e. the amount of woody matter in a unit of volume, varies even within the same species. Test data show a close connection between the bulk density and the mechanical strength of timber in case of some of the tested species. Further a highly dense and uniform grain also increases its strength. Conclusively we may say that timber with a high bulk density is of high strength (Wayne, 1965).

The observed data on the strength of various tested species of timber is more or less in agreement with the above stated facts.

Owing to anisotropic structure of wood, its mechanical properties vary in different directions and depend upon the angle between the direction of the applied force and the direction of the grain. Wood has greater strength in the longitudinal direction than in the transverse direction. Consequently the slope of the grain is of considerable influence when the direction of stress does not coincide with that of the grain. The higher the slope of the grain, the greater the force applied perpendicular to it and lower the strength of the member. The general study of the influence of the slope of the grain on the strength of timber in compression, bending and tension reveals that former is affected the least while the last is affected the most (Karlsen, 1967).

Observed data on various tested species of wood are in close agreement with the above facts. The tests reveal
a considerable scatter of strength characteristics for the same species. This is explained by the non-uniformity of timber, connected with the peculiarities of its anatomical structure.

With an increase in the moisture content of wood from zero to the fibre saturation point (roughly up to 30%), its strength diminishes and liability to deformation increases. A rise in the moisture content of timber over the saturation point has no influence on its strength. Bulk density of timber depends to a high degree on the moisture content, so that the comparison of the bulk density of timbers of different species must only be made at the same standard moisture content—12 or 15%.

The correction of the ultimate strength to agree with the standard is carried out by the formula:

\[ \sigma'_{15} = \sigma'_{w} \left[ 1 + a (w-15) \right] \]  \hspace{1cm} (1)

where \( \sigma'_{15} \) = required ultimate strength at a moisture content of 15%.
\( a \) = correction coefficient.
\( \sigma'_{w} \) = strength at a given moisture content.

The correction formula applies in the range of moisture content changes from 8 to 23%.

As it is known that strength varies appreciably with change in moisture content below the so-called fibre-saturation point, it is very necessary to calculate or adjust the strength figures exactly at 12% moisture in order that the data is truly comparable between various
properties and species. For such adjustments due to small variations in moisture content, a rectangular hyperbola formula for adjustment at 12% moisture content given by the equation:

\[ MS = K \]  \hspace{1cm} (2)

where \( M \) = percentage moisture content,
and \( S = \) ultimate strength

has been developed by Sekhar and Rajput (1968).

Strength data for the various tested species of wood at two moisture contents namely 15% and 25% clearly shows that the mechanical strength of timber decreases with the rise in moisture content.

The decrease in mechanical strength with the rise in moisture content may be accounted for due to the fact that with the presence of water molecules in the interstices between the chain molecules of cellulose and hemicellulose, the molecules recede from one another and van der Waals bonds between molecules become comparatively weaker. The mechanical strength which to some extent depends on van der Waals bonds, accordingly decreases. The presence of moisture doubtless softens up some of the colloids and lubricates the mass making it offer less resistance to the relative movement of the particles and hence mechanical strength decreases. On drying, water molecules are removed from the interstices between the chain molecules of cellulose and hemicellulose, which consequently approach one another rendering intermolecular bonds stronger. For
the reasons discussed above, with air dry throughout, timber is comparatively stronger.

The diagram below indicates the interaction between cellulose and hemi-cellulose molecules through water molecules.

Segment of cellulose molecule

Segment of hemi-cellulose molecule
REFERENCE


