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EFFECT OF DIRECTION OF LOAD ON FLEXURAL STRENGTH OF PINUS RADIATA WOOD

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ABSTRACT

Empirical study of stiffness (modulus of elasticity-MoE) and Bending strength/flexural strength (modulus of rupture-MoR) in wood, mainly on radial and Tangential surface of Pinus radiata wood were evaluated. Here loading in the radial direction means that load is applied to the tangential surface and loading in the tangential direction means that load is applied to the radial surface. Radiata pine is commonly regarded as 'medium' density softwood, with typical average tree basic density values of 350-550 kg/m3. The strength properties vary with species to species and application of direction of load. Loading direction appreciably affects the bending properties remarkably due to the anisotropic /orthotropic nature of timber. The bending strength of timber when loaded parallel to the direction of load is greater than that of timber loaded perpendicular to the direction of load. It was observed that always MoR have greater value in Radial surface and MoE have greater value in tangential surface. The direction of application of load has an appreciable effect on strength properties of wood. While this is generally attributable to the presence of medullary rays in the radial direction. The ratio of flexural strength values varied from 8 % to 10 % for Pinus radiata.

KEYWORDS: *Bending Strength, Modulus of Elasticity (MOE) and Pinus Radiata*

INTRODUCTION

From beginning to now, timber is one of the mostly used construction materials. It is non-homogeneous and [7] orthotropic in nature having 3D figure. Although nowadays it is largely replaced by the concrete, steel, plastic and fibre etc., but the use of timber remains quite extensive. Timber is subjected to the various type of loading condition such as bending, compression, tension, shear, hardness, toughness, stiffness etc. The Variations in mechanical behaviour due to changes not only in the inherent qualities of wood and conditions of testing, but also in size of specimens and direction of load applies [12]. The capability of timber to resist this loading condition is measured by the strength properties. It is the mechanical properties that make wood suitable for different purposes i.e. construction and building and number of other uses of which furniture, vehicle, flooring etc. are few examples. Dependence of mechanical properties on factors like specific gravity, moisture content and temperature has attracted considerable attention of a few workers but dependence on size and shape of specimens and on the direction of application of load has not received as much attention though it is fairly recognized in evaluating standard for tests. As a result, wood possesses material properties that may be significantly different from other materials normally encountered in structural design. Although, it is not necessary for the engineer to have a general understanding of the properties and characteristics that affect the strength and performance of wood. Similarly in case of board made up of wood shows, the local fibre orientation on face and edge surfaces of wooden boards were identified using high resolution laser scanning. In combination with knowledge regarding basic wood material properties for each investigated board, the grain angle information enabled a calculation of the variation of the local MOE in the longitudinal direction of the boards and they find that lowest bending stiffness determined along the board [13]. The direction of application of load has an appreciable effect on strength properties of wood. While this is generally attributable to the presence of medullary rays in the radial direction and the difference in the alignment of cells, as viewed in the radial and tangential direction, it is interesting to note that in a large number of cases the properties in one direction can be predicted with a fair amount of accuracy from the properties in the other direction [15] and similar observation also got in to analysis the compressive strength of column and beam, it is shown that compressive kinking strength of wood is governed mainly by its yield strength in shear and by certain features of its anatomy related to the so-called ray cells[3].

Now the question is how to use the timber for particular purposes? The answer is, where less surface area required, we can select longitudinal direction, for example, as poles or posts or columns. The same way while using wood for more surface area supporting to load bearing structure as a beam or joist, we have to go for radial or tangential direction. In this care there are no proper results which can insist the best direction (radial or tangential) in wood which can hold maximum load. Wood is an orthotropic material with unique and independent properties in different directions. Because of the orientation of the wood fibres, and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axes: longitudinal (L), radial (R), and tangential (T). Although wood properties differ in each of these three directions, differences between the radial and tangential directions are normally minor compared to their mutual differences with the longitudinal direction. In Sri Lanka similar type of study was conducted in Ambalam structures; a cherished heritage structure originated from the vernacular architecture in Sri Lanka and It is reveal that that mediaeval constructors were knowledgeable on the deformation. Grain orientation is important for three reasons. The direction of the grain affects the amount of deflection that occurs when loads are applied. It compromises on load bearing ability. Load bearing timber is stronger when forces are applied parallel to the grain than when force is applied perpendicular to the grain [14]. The bending strength and stiffness of laminated veneer lumber (LVL) produced from eucalyptus (Eucalyptus grandis W. Hill ex Maiden) were analysed. The results showed that the type of adhesive did not influence the bending properties of laminated veneer lumber. It can be stated that the differences among groups were due to differences in their densities. The direction of the load and the species of the tree had significant effects on the bending properties [4].

Due to changes in the anatomical structure, it's essential to know that, is there any particular direction (radial or tangential) to be used? If use. There will be good opportunities in making the best use of wood. If no then without any effort wood can be used.

In the wooden board it was evaluated that integration over cross-sections along the wooden board, an edgewise bending stiffness profile and a longitudinal stiffness profile, respectively, were calculated. A new Indicating Properties and bending strength was defined as the lowest bending stiffness determined along the board [11].

To address the above problem, in this paper, empirical study of stiffness (modulus of elasticity-MoE) and Bending strength/flexural strength (modulus of rupture-MoR) in wood, mainly on radial and tangential surface of *Pinus radiata* wood were evaluated. Here loading in the radial direction means that load is applied to the tangential surface and loading in the tangential direction means that load is applied to the radial surface

METHODOLOGY

Sample Preparation

The study was undertaken on *Pinus radiata* wood species, now days these spp. were widely used for furniture and construction sector. For standard evaluation of physical and mechanical properties, it is necessary to adopt a fixed methodology for selection of material, preparation of test samples and evaluation of results. The method of sampling model trees and logs for timber testing, followed at Forest Research Institute has since been standardized at national level (IS: 2455-1974). Normally 5 to 10 trees of the species to be evaluation are selected from a locality randomly and one log of length 3 meters is taken from each tree. Logs are converted in the manner shown in IS: 2455-1974 and the scantlings so obtained are marked and numbered accordingly.

Marking and Conversion of Logs into Sticks

All logs were marked on the small end (top end) into 6 x 6cm squares as mentioned in IS: 2455-1974 and sawn into nominal 6 x 6cm scantlings parallel to pith to pith axis. Each log shall be divided into bolts of 1.5m length and each bolt was indicated by a letter of the alphabet in order, beginning with the one nearer the stump. (Thus the 1.5cm bolt above the stump was designated as bolt 'A' and the next above it as bolt 'B' and so on). When sticks as marked out in Figure 2 are taken out, each test stick shall have the complete identity mark of consignment number, tree number, the bolt designation and the stick number. All the connected sticks shall be matched for tests in the green and dry conditions as follows:

Green: All even numbered sticks from upper bolt and odd numbered sticks from lower Bolt. Dry: All even numbered sticks from lower bolt and odd numbered sticks from upper Bolt.

From these sticks small clear specimens are selected for conducting the physical and mechanical tests in green, kiln dry and/or air-dry conditions

Here the specimens are prepared from the materials available in Laboratory considering the different specific gravity range. The care was taken that the moisture content of all the species may nearly be same to avoid the effect of moisture in strength. And converted in to the desired size for testing purpose as per IS: 1708(part 1-18) -1986 [8] "Indian Standard- Method of testing of small clear specimens of timber" and also by ASTM-D-143[1]. Each specimen is initially weighted correct to nearest gram and its dimensions measured correct to two decimal place of a centimetre.

Before testing, four small discs of about 2x2x6cm were taken for determination of specific gravity and moisture content of *Pinus radiata* wood.

Moisture Content of the Samples

Procedure

Pinus radiata specimen was weighed to accuracy of.001 gm in a weighing balance and dried in oven. The specimens were dried in an oven at a temperature of 103 ±2° C. The weight shall be recorded at regular intervals. The drying shall be considered to be complete when the variation between last two weighing, does not exceed 0.002 gm until the mass is

constant to ± 0.2 % between two successive weightings made at an interval of not less than one hour.
2.3.2 Calculation:

The moisture content expressed as percentage of the oven dry mass is given by the formula:

Moisture content=

$$intial\ weight - Final\ weight / final\ weight \times 100$$

Specific Gravity of Samples

Procedure

The specimen shall be weighed correct to.001 gm. The Dimensions of rectangular specimen shall be measured correct to.01 gm and volume shall be calculated.

Calculation

$$\text{Specific gravity}=\frac{weigh\ \ of\ specimen}{volume\ of\ the\ speciment}\times\frac{100}{100+Moisture\ Contnet}$$

Rate of Loading

The load shall be applied continuously during the test such that the movable head of the testing machine travels at a constant rate of 1mm per minute irrespective of direction. The speed of the movable head of testing machine is calculated by the following formula.

$N = ZL^2/6D$

Where:

N= Rate of loading in mm/min.

Z= Unit rate of fibre strain of outer fibre length /min=0.0015 L= Span in cm

D= Depth of the specimens

Recording of Data and Calculations: Static Bending Test

(As per IS: 1708 (Pt-5)-1986.

Size 5 x 5 x 75cm, Span -70cm,

Size 2 x 2 x 30cm, Span - 28cm

Continuously increasing load is applied centrally on the specimen such that the movable head of the testing machine moves at a constant rate of 2.5 mm/min. in case of standard size specimen and 1.0 mm/min. in case of small size specimen. Deflection is measured at suitable load intervals up to the maximum load. Beyond maximum load the test is continued until a deflection of 15cm for standard size and 6cm for small size is attained or the specimen fails to support 100 kg load (standard size) or 20 kg load (small size) whichever is earlier. From load deflection data, load and deflection at proportional limit and maximum load are noted.

Test Procedure

- Bending tests were undertaken on testing machine as per the standard test procedure. For *Pinus radiata* eight replicates (total 64 samples) were tested.
- The size of sample is 30 cm in length and 2x2 cm cross - section. The distance between points of supports (span) is 28cm.
- Test specimen shall be so placed on a rig that the load is applied through a loading block. The specimen shall be supported on the rig in such a way that it will be quite free to follow the bending action will not be restrained by friction.
- Modulus of rupture (MOR) = $3p^1l/2bh^2$
- Modulus of elasticity (MOE) = $pl^3/4Dbh^3$

Where,

- p: Applied load in kg at elastic limit

Test span in cm

- b: Breadth of specimen in cm
- h: Height of specimen in cm
- P1: maximum load in kg
- D: Deflection at elastic limit in cm

RESULTS AND DISCUSSIONS

Table 2 shows Here in our case, the bending strength of timber when loaded parallel to the direction of load is greater than that of timber loaded perpendicular to the direction of load. The ratio of flexural strength values varied from 8% to 10% for pinus radiata. The statistical analysis shows that significantly difference between radial and tangential direction in MoR but there is no significant different between MoE and more over MoE are greater in tangential Direction. The ANNOVA test has been applied for analysis of data to check whether there is a significant difference of effect of force on loading directions from our results it is observed at 95% confidence level that the application of force direction of load shows the significant difference MoR in radial and tangential direction (Table 3).

we can conclude that for all construction purposes there is significant difference is exist if we placed on the tangential or radial faces when we calculated strength and deflection of timber. But for safety point of view it is better to apply load on tangential surface in lab. Investigations, as the samples take the less loads in this direction. However more attention should be placed on knots, sloping grain, shakes and other timber defects which have more affect on the strength of a timber

From the data of bending test, the modulus of rupture and modulus of elasticity have been determined by using the given formula on both the surface (radial and tangential surface). Our study it is evident that a strength property depends upon the species and force direction of load. The test results have been presented in Table 1 to 2. From the table it is observed that Modulus of rupture is consistently higher on radial surface from tangential surface. Modulus of elasticity is show the reverse trend. But over all values of MoR properties are higher, when load applied on radial surface. The above was evident by Conrad, M. P on 2003, in his review paper, the major conclusions are that fracture toughness perpendicular to the grain is greater than that parallel to the grain [5]. The similar result was also shown in poplar; fir, pine and hornbeam commonly used in Turkey were investigated. The compressive strength, flexural strength and toughness were determined both perpendicular and parallel to the grain. It was found that loading direction affects all mechanical properties remarkably [2]. A review paper concluded that fracture toughness perpendicular to the grain is greater than that parallel to the grain within a given species. Also, fracture toughness increases with increasing density and strain rate [10]. Similar trend was observed in doulas fir for the brittle fracture load is applied to the determination of strength of Douglas-fir wood in tension perpendicular to the grain [9].

Table-1: MOR and MOE Values of Pinus Radiata (Radial)

Sample No.	Load at E.L.	Def. at E.L.	Max. Load	Span	Width	Thickness	MOR	MOE
1	120	0.67	150	28	2.1	2.16	643	46.4
2	100	0.62	150	28	2.13	2.01	732	51.2
3	100	0.6	130	28	2.11	2.06	690	49.6
4	80	0.37	150	28	2.17	2.1	658	59.0
5	80	0.32	140	28	2.05	2.04	689	78.8
6	60	0.34	130	28	1.94	1.99	711	63.3
7	80	0.4	130	28	2.1	2.04	675	61.6
8	80	0.28	140	28	2.15	2.11	656	77.6
Avg.							**682**	**61.0**

Table 2: MOR and MOE Values of Pinus Radiata (Tangential)

Sample No.	Load at E.L.	Def. at E.L.	Max. Load	Span	Width	Thickness	MOR	MOE
1	90	0.41	140	28	2.15	2.01	623	69.0
2	120	0.48	160	28	2.08	2.1	640	71.2
3	100	0.59	140	28	2.09	2.16	603	44.2
4	80	0.3	140	28	2.07	2.14	620	72.1
5	80	0.3	160	28	2.11	2.14	648	70.8
6	100	0.5	120	28	2.02	2.14	545	55.4
7	80	0.38	140	28	2.04	2.14	629	57.8
8	80	0.44	130	28	2.03	2.03	635	58.8
Avg.							**618**	**62.4**

CONCLUSIONS

Loading direction appreciably affects the bending properties remarkably due to the anisotropic /orthotropic nature of timber. one more study in India shows that non-significant of MoR is difference between radial and tangential direction i.e. there is no much difference in direction of Tangential and Radial direction MoR of *melia compositae* wood but in the case of MoE it was Significantly different [6] and The study about Mechanical tests on small clear specimens of *Eucalyptus globulus* L. were performed in Europe. The best correlations between ultimate stress and modulus of elasticity were found in bending and tension parallel to the grain [10].

Table 3 shows here in our case, the bending strength of timber when loaded parallel to the direction of load is greater than that of timber loaded perpendicular to the direction of load. The ratio of flexural strength values varied from 8 % to 10% for *pinus radiata.* The statistical analysis shows that significantly difference between radial and tangential direction in MoR but there is no significant different between MoE and more over MoE are greater in tangential Direction. The ANNOVA test has been applied for analysis of data to check whether there is a significant difference of effect of force on loading directions from our results it is observed at 95% confidence level that the application of force direction of load shows the significant difference MoR in radial and tangential direction (Table 3).

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Table 3: ANOVA between MOR of Radial and Tangential

ANOVA (Modulus of Rupture)					
MOR					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Radial and Tangential	16320.062	1	16320.062	16.736	.001
Within Groups	13652.375	14	975.170		
Total	**29972.438**	**15**			

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