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An Observation of Direction of Load on Bending Strength of *Psedotsuga taxifolia (Douglas fir)*

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ABSTRACT: Study of stiffness (modulus of elasticity-MOE) and Bending strength/flexural strength (modulus of rupture-MOR) in *Psedotsuga taxifolia (Douglas fir)* wood on radial and Tangential surface were evaluated. The Tree itself grows to be very large, and yields a large amount of usable lumber and veneer for plywood. It is an incredibly valuable commercial timber, widely used in construction and building purposes. The wood is very stiff and strong due to its weight, and is also among the hardest and heaviest softwoods (dried weight is 510 kg/m^3). 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. So it was very much important to study the direction of loading so that we can use the timber and appropriately place the timber in construction purpose. It was observed that always MOE and MOR have greater value in Radial 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 from15% to 17% for *Psedotsuga taxifolia (Douglas fir)*.

Keywords: Bending strength, Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and *Psedotsuga taxifolia (Douglas fir)*

INTRODUCTION

From beginning to now, timber is one of the mostly used construction materials. It is non-homogeneous and orthotropic in nature having 3D figure (Green *et al.,* 1999). Although now a days it is largely replaced by the concrete, steel, plastic and fiber etc., but the use of timber remains quite extensive. Timber is subjected to the various types of loading condition such as bending, compression, tension, shear, hardness, toughness, stiffness etc. The Variations in mechanical behavior due to changes are not only in the inherent qualities of wood and conditions of testing, but also in size of specimens and direction of load applied (Obe, 2002). 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. Not only in the solid wood but also if we also make a board made up of wood fibre shows the local fibre orientation on face and edge surfaces of wooden boards very much important factor to decide it's bending properties. Variation in bending stiffness along an individual board was very accurate indicating properties with respect to bending strength can be defined. However, information regarding basic wood material properties, in particular MOE in the fibre direction, needs to be available for each individual board (Olsson *et al.,* 2013). The direction of application of load has an appreciable effect on strength properties of wood and it was evident in the species of *Melia compositae* (Ezhumalai *et al.,* 2021). 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 (David E. Kretschmann, 2010). One case study was investigated in which tension perpendicular to grain properties in three different orientations, for radial, tangential and 45-

degree directions, using Sugar Maple specimens (Mascia *et al.,* 2020) was done and it was observed that the typical failures were related to tension failure in the early wood (juvenile wood) region of the specimens and the tension failure was accompanied by shear failure along a growth ring and similar observation also got in to analysis of the compressive strength of column and beam, it was 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 (Benabou, 2008).

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 fibers, and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axis: longitudinal (L), radial (R), and tangential (T) (David E. Kretschmann, 2010). 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 (Ritter MA, 1990). 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 was revealed 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 (Mendis *et al.,* 2019). 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 (Bal & Ibrahim 2012).

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.

Eucalyptus Strand Wood material, full-scale component tests were performed to observe the structural performance of ES Wood beams and its mechanical properties of ES Wood with other wood/bamboo-based materials was compared. From the results, it appears that the strength and stiffness properties of ES Wood are affected by grain directionality and glued layers (Chen *et al.,* 2019). So it implies that even in wood composite also strength properties may change due to the grain direction.

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 *Psedotsuga taxifolia* (*Douglas fir*) 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

A. Sample preparation

The study was undertaken on *Psedotsuga taxifolia (Douglas fir)* wood species in the lab of Timber Mechanics and Engineering Discipline, Forest Research Institute, Dehradun India on May-2018, now a days these species are 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 evaluated 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.

B. Marking and Conversion of Logs into Sticks

All logs were marked on the small end (top end) into 6 × 6cm squares as mentioned in IS: 2455-1974 and sawn into nominal 6 × 6cm scantlings parallel to pith to pith axis. Each log was been 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 fig. 2 of IS: 2455-1974 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 were 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 were selected for conducting the physical and mechanical tests in green, kiln dry and/or air-dry conditions-Here the specimens were 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 "Indian Standard-Method of testing of small clear specimens of timber" and also by ASTM-D-143. Each specimen was 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 2×2×6cm were taken for determination of specific gravity and moisture content of *Psedotsuga taxifolia* (*Douglas fir*) wood.

C. Moisture content of the Samples

Procedure: *Psedotsuga taxifolia (Douglas fir)* 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 was recorded at regular intervals. The drying was 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.

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

Moisture content = Initial weight-Final weight/ final weight × 100

D. Specific gravity of samples

Procedure. The specimen was weighed correct to .001 gm. The Dimensions of rectangular specimen were measured correct to .01 gm and volume were calculated.

Calculation Specific gravity

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

E. 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 as 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 × 5 × 75cm, Span -70cm,

Size 2 × 2 × 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 max. 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 *Psedotsuga taxifolia (Douglas fir)* eight replicates (total 64 samples) were tested.

-The size of sample is 30 cm in length and 2×2 cm cross - section. The distance between points of supports (span) is 28cm.

-Test specimen were so placed on a rig that the load is applied through a loading block. The specimen were supported on the rig in such a way that it will be quite free to follow the bending action and will not be restrained by friction.

1. Modulus of rupture (MOR) $=3p^1l/2bh^2$
2. Modulus of elasticity (MOE) $=pl^3/4Dbh^3$

Where,

p - Applied load in kg at elastic limit

1- Test span in cm

2- b - Breadth of specimen in cm

3- h - Height of specimen in cm

4- P^1 - maximum load in kg

5- D - Deflection at elastic limit in cm

RESULTS AND DISCUSSION

Bending test was performed in the lab of Timber mechanics and engineering discipline, FRI, Dehradun and the result was presented in the table.1, 2 under the heading of Span length, load at elastic limit, maximum load, size of the sample MOR and MOE of Douglas Fir timber of Radial and Tangential Direction. The statistical analysis was done between MOR and MOE of Radial and Tangential sample of Douglas fir.

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). From 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 than tangential surface. Modulus of elasticity also shows the same trend. But over all values of both the properties are higher, when load applied on radial surface. The above was evident by Conrad, M. P, in his review paper, the major conclusions are that fracture toughness perpendicular to the grain is greater than that parallel to the grain (Conard *et al.,* 2003). The similar result was also shown in poplar; fir, pine and hornbeam commonly used in Turkey when 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 (Aydin *et al.,* 2007). 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 (Chen *et al.,* 2019). Similar trend was observed in doulas fir when brittle fracture load is applied to the determination of strength of Douglas-fir wood in tension perpendicular to the grain (Barrett *et al.,* 1975). Timber-concrete composite (TCC) was used in 20th century buildings and its load distribution capacity of analysed in transversally and longitudinally and found that mechanically "loaded beam" can receive less than 50% of the concentrated point load (Sandra *et al.,* 2020). With above reference and also experiments result shows that there is a significant difference was observed in direction of loading in Douglas fir spp (Table 1, 2).

Table 1: MoR and MOE values of Douglas fir(Radial).

Sample No.	Load at E.L.	Def. at E.L.	Max. Load	Span	Width	Thickness	MOR	MOE
1	120	0.30	210	28	2.07	2.11	957	112.9
2	100	0.26	200	28	2.04	2.09	943	113.3
3	120	0.20	180	28	2.06	2.10	897	172.6
4	160	0.48	200	28	2.08	2.07	942	150.4
5	120	0.30	190	28	2.04	1.99	988	136.5
6	80	0.16	130	28	2.03	2.06	834	154.6
7	120	0.30	190	28	2.07	2.00	*964..*	132.6
8	100	0.22	180	28	2.10	2.05	857	137.9
Avg.							913	138.14

Table 2: MOR and MOE values of *Douglas fir* (Tangential).

Sample No.	Load at E.L.	Def. at E.L.	Max. Load	Span	Width	Thickness	MOR	MOE
1	100	0.38	120	28	2.01	2.05	597	83.4
2	100	0.38	140	28	2.07	1.98	725	89.9
3	100	0.30	180	28	2.00	1.90	850	90.4
4	60	0.12	180	28	2.12	2.06	840	98.4
5	120	0.30	200	28	2.08	2.09	925	115.6
6	120	0.32	200	28	2.11	2.09	911	106.8
7	100	0.30	140	28	2.05	2.09	657	97.7
8	120	0.30	200	28	2.08	2.04	750	124.3
Avg.							781.8	100.8

CONCLUSION

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 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 (Jorge Crespo *et al.,* 2020) and one more study in India shows that Radial direction wood sample of *Melia compositae* bending strength was more in tangential direction (Ezhumalai *et al.,* 2021).

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 from15% to 17% for *Doglas fir.* The statistical analysis shows significant difference between radial and tangential direction in MoE and MoR. 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 in direction of load shows the significant difference in radial and tangential direction (Table 3, 4). From our study we can conclude that for all construction purposes there is significant difference that exists 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.

Overall strength properties of wood depend on the individual cells and its orientation. Further study is needed for micro structure of the wood and its strength properties.

Table 3: ANOVA between MOR of Radial and Tangential.

ANOVA					
MOR					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	79383.062	1	79383.062	9.263	.009
Within Groups	119976.375	14	8569.741		
Total	199359.438	15			

Table 4: ANOVA between MOE of Radial and Tangential.

ANOVA					
MOE					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5787.406	1	5787.406	19.089	.001
Within Groups	4244.609	14	303.186		
Total	10032.014	15			

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