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Evaluating the Flexural Strength of Different Timbers Using the Three-Point Bending Test

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Authors' contributions

This work was carried out in collaboration among all authors. Author AR contributed to conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing the original draft, visualization, project administration, and funding acquisition. Author TPS contributed to conceptualization, methodology, formal analysis, investigation, resources, writing, reviewing and editing, and supervision. Author JS contributed to data curation, software, validation, writing, reviewing and editing, and visualization. Author AK contributed to investigation, resources, writing, review and editing, and supervision. Author MKC contributed to organize resources, writing, review and editing, and supervision. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was carried out to determine the mechanical properties of various types of timber. This study provides information for selection criteria of timber to make a different component of agriculture implement and tools. The Flexural Strength of Yellow Teak, Red cedar, North Indian

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rose timber, Lebbeck, Java plum, Margosa, Eucalyptus, Teak, Mango and Sal was found as 79.00, 54.3, 104.2, 78.00, 84.00, 73.00, 65.9, 94.00, 88.6 and 98.00 MPa respectively. The test of selected timber species shows that the strength of a timber depends on its species and hence different timber have different strength characteristics. The results obtained in this study has provided quantitative information on the Mechanical properties of various types of timber, which can be used in determining the application of these timber for either heavy work load carriage and for agricultural implements and tools.

Keywords: Flexural strength; agricultural implements; tools; mechanical properties; timbers; strength.

ABBREVIATIONS

ASTM : American Society for Testing and Materials
ISI : Indian Standards Institution
BIS : Bureau of Indian Standards

1. INTRODUCTION

"Agriculture in India had developed in remote antiquity, and down to the 18th century, India ranked among a few developed countries of the globe. Indigenous tools were basic but well-designed suit farmer's needs. Traditionally farmers have been using a variety of tools in their everyday life, often for agricultural operations and household purpose" [1,2]. "Agricultural implements used in 18th and 19th centuries were mostly hand operated and animal drawn. The fresh development in new designs of implements and tools was noticed around independence. Most of the timber tools, implements use local timber materials – different timbers for particular tools and strings for various uses come from different plants" [3].

"Agricultural practices require certain traditional techniques including tools and implements due to steep and hilly terrain comprising of shallow and stony soils. Present study has been undertaken to describe agricultural tools and implements from the local plants to facilitate the agriculture during harsh condition. Besides these agricultural implements" [3], "Use of plants in making the handles of harvesting tools based on their preference and choice. Traditional agricultural tools and implements were made up of locally available materials like stone, timber, and iron, constructed at local level or standardized factory-made implements. These tools and implements were economical in term of labor, money and time saving" [3]. In addition, each of these tools and implements are usually used in connection with specific operation in the sequence of agricultural operations; land preparation, sowing, weeding, irrigation, harvesting, post-harvesting operations and transportation.

Forests of Uttarakhand support locals in perspective of traditional agriculture and animal husbandry. Forest is the most precious gift, nature has provided to us, as it is meeting all kinds of essential requirements of the humans in the form of food, fodder, fuel, and timber. Among these requirements, high quality of timber is always in great demand for making of agricultural implements and handles of harvesting tools. The main occupation of people residing in this region is traditional agriculture which is their major source of income.

"In addition, they are operated easily without any special skills. Each of these tools and implements are usually used in connection with specific operation in the sequence of agricultural operations; land preparation, sowing, weeding, irrigation, harvesting, post-harvesting operations and transportation. The strength of a timber depends on its species and the effects of certain growth characteristics. Different timber species have different strength characteristics, and within a species, these characteristics may vary. Therefore, in practice, a classification system of strength classes is used" [4]. "timber is a fibrous rigid material of plant origin. It is broadly classified as hard timber and soft timber. Hard timber is derived from angiosperm or broad-leaved trees such as Mango (*Mangifera indica*), Sal (*Shorea robusta*), Lebbeck (Albizia), North Indian rose timber (*Dalbergia sissoo*), Red Cedar (*Toona ciliate*) and Teak (*Tectona grandis*). Hard timber timbers are mainly used for structural application because of their high strength and durability. Soft timber is obtained from coniferous trees, which have needle-like leaves. Examples of soft timber trees are: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and Douglas fir (*Pseudotsuga menziessii*)" [5].

"The mechanical property values of timber are obtained from laboratory tests of lumber of straight-grained clear timber samples (without natural defects that would reduce strength, such as knots, checks, splits, *etc"*. [6]. "Strength properties mean the ultimate resistance of a material to applied loads. With timber, strength varies significantly depending on species, loading condition, load duration, and a number of assorted material and environmental factors. Because timber is anisotropic, mechanical properties also vary in the three principal axes. Property values in the longitudinal axis are generally significantly higher than those in the tangential or radial axes" [7]. Flexural (bending) properties are critical. Bending stresses are induced when a material is used as a beam, such as in a floor or rafter system. In fact, mechanical properties within a species tend to be linearly, rather than curvilinear, related to specific gravity; where data are available for individual species, linear analysis is suggested.

Observing the above facts, the mechanical properties of timber are important factors used in determining the suitability and application of timber material, these in turn depends on the timber species.

2. MATERIALS AND METHODS

2.1 Flexural Testing

The 3-point bending flexural test contributes the values for Flexural stress-strain response and flexural modulus of the material. The main benefit of a 3-point bending test is the ease of preparing specimens and testing. The test setup and specimen geometry is shown in the Fig. 2 and test setup is presented in Fig. 3. The results of this test are sensitive to the specimen properties, loading and strain rate. The temperature at the time of test was 24.5°C and relative humidity (RH) was 47%. The Flexural stress (σ_f), Flexural modulus (E_f) and Flexural strain (ε_f) for a rectangular cross section are determined by the formula.

Static bending test of air-dried 12×12 mm (cross section) and 30 mm long specimens was carried out using an "All the compression tests" of different timbers are conducted on 25kN servo hydraulic UTM machine (AMT-SC, A.S.I make). Deflections and the corresponding loads were recorded and load deflection curves prepared. Using the load deflection curves for air-dried specimens (12×12 mm cross section and 55 mm long), compressive stress at the limit of proportionality, compressive stress at the maximum load and modulus of elasticity in compression parallel to grain were estimated. Likewise, from the load deflection curves for air dried 12 x 12 mm (cross-section) and 10 mm long specimens, compressive stress at the limit of proportionality, crushing strength at maximum load, and modulus of elasticity in compression perpendicular to grain were computed.

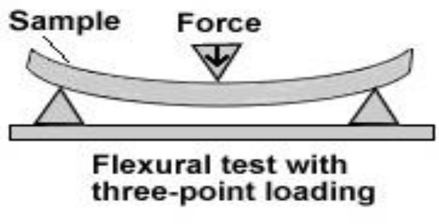

Fig. 1. Three-point flexural test setup

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

$$E_f = \frac{L^3 m}{4bd^3} \quad (2)$$

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (3)$$

Where,

P= Load, kN
L= Gauge length of the sample, mm
m= Slope of the load and deflection curve

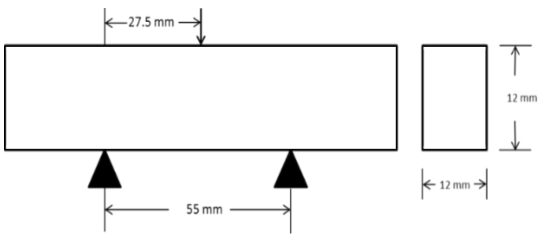

Fig. 2. Specimen geometry of the flexural strength test (IS 1708 (part-5:1986))

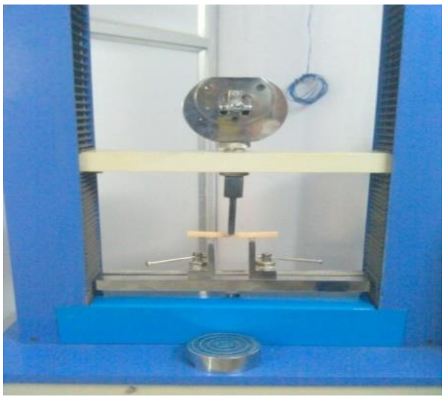

Fig. 3. Test setup for flexural strength

3. RESULTS AND DISCUSSION

3.1 Flexural Strength

3.1.1 Effect of timber on flexural strength

Flexural strength is distinct as the maximum stress in the outermost fiber of the timber. This is calculated at the surface of the specimen on the convex or tension side. This measure behavior of materials subjected to simple beam loading. It is also called a transverse beam test with some materials. 3-point bending test conducted according to the IS 1708 Standard Test method to determine the flexural modulus, flexural strength (stress) and the flexural strain of timber.

It was concluded from Fig. 5 that the flexural strength of different types of timber Sal (98±1.59), Teak (94±1.29), North Indian rose timber (104.2±3.32), Mango (88.6±1.80), Red cedar (54.3±0.88), Yellow teak (79±0.88), Margosa (73±1.69), Java plum (84±0.69), Eucalyptus (65.9±0.70) and Lebbeck (78±1.55) MPa respectively. These values indicate that North Indian rose timber has the highest maximum load carrying capacity and red cedar *has* low load carrying capacity followed by other types of timber it is clear that North Indian Rose timber has maximum flexural strength as compared to other timber. Yellow teak and Lebbeck had similar behaviors and presented least strength amongst all other timber. Therefore, North Indian Rose timber had good flexural strength. North Indian Rose timber had the greatest value of standard deviation as compare to others. Timber has good efficiency to provide good strength to the agricultural implements. The effects of timber on flexural strength were analyzed using Analysis of Variance. The results of Statistical analysis are presented in Appendix-A. Timber significant effects on the flexural strength at the 5% level of significance. There was no significant difference observed between the Flexural strength of (Yellow teak and Teak), (Yellow teak and Java plum), (Yellow teak and Eucalyptus), (Yellow teak and Margosa), (Yellow teak and mango), (Red cedar and Java plum), (Red cedar and Margosa), (North Indian Rose timber and lebbeck), (North Indian Rose timber and Sal), Teak and Java plum), (Teak and Eucalyptus), (Teak and Margosa), (Teak and mango), (Lebbeck and Margosa), (Java plum and Eucalyptus), (Java plum and mango), (Eucalyptus and Margosa) and (Eucalyptus and mango) and other types of timber have significant difference.

After optimizing the value of flexural modulus, variation in the timber had been done. It was evident from Fig. 5 that the flexural modulus also affected by timber. Flexural modulus of various types of timber red cedar, Java plum, Teak, Mango, Eucalyptus Margosa, North Indian Rose timber, Lebbeck, Sal and Yellow teak were found (0.00053±0.00010), (0.00054±0.00016), (0.00060±0.00004), (0.00061±0.00005), (0.00060±0.00009), (0.000700±0.00007), (.00076±0.00009), (0.00083±0.00018), (0.00091±0.00013) and (0.00111±0.00009) respectively. Yellow teak timber shows largest value flexural modulus whereas all other nine different types of timber and lebbeck had maximum but Teak had minimum standard deviation compared to all other timber. The Flexural modulus and Flexural strength depend on the volume fraction void contents Therefore, high void content causes more stress concentration which results in micro cracks and fine debris formation on the surface of the specimen this degrades for the timber.

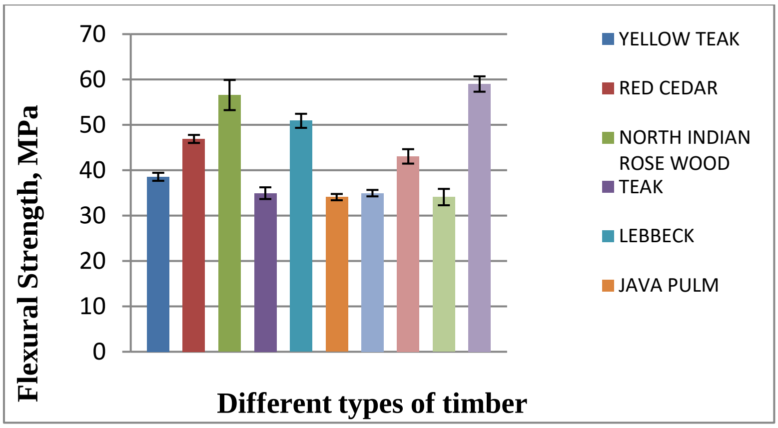

Fig. 4. Flexural strength for different types of timber

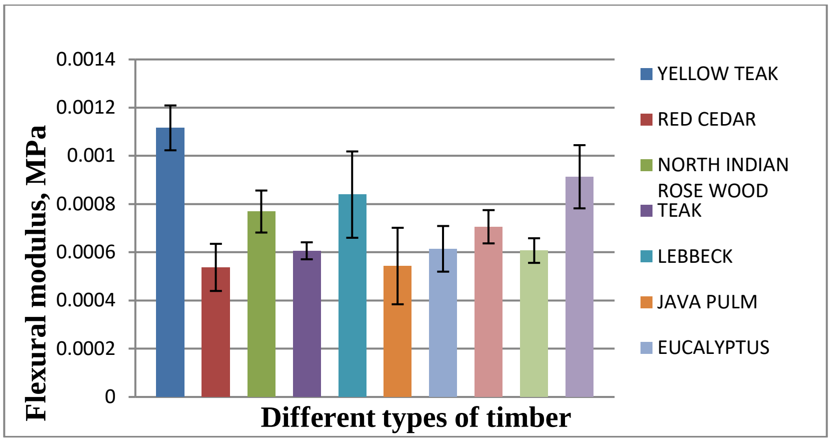

Fig. 5. Flexural modulus for different types of timber

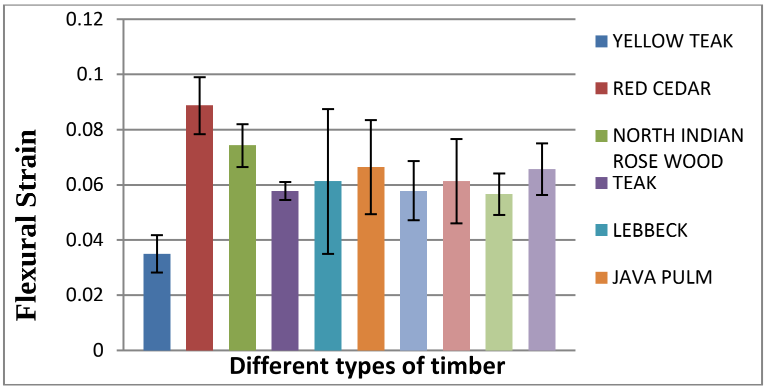

Fig. 6. Flexural strain for different types of timbers

It was concluded from Fig. 6 results were drawn that flexural Strain of various types of timber Yellow teak, Red cedar, North Indian Rose timber, Teak, Lebbeck, Java plum, Eucalyptus, Margosa, Mango and Sal were found to be (0.034±0.0067), (0.056±0.0103), (0.057±0.0077), (0.057±0.0032), (0.061±0.0262), (0.061±0.0170), (0.065±0.0107), (0.066±0.015), (0.074±0.0074) and (0.088±0.0093) respectively [8]. Flexural strain was great in red cedar timber and the least was yellow teak compared to other types of timber. In case of standard deviation, Lebbeck timber has a maximum value of standard deviation.

ANOVA results show that interactions among the linear term Yellow Teak, Red cedar, North Indian rose timber, Lebbeck, Java plum, Margosa, Eucalyptus, Teak, Mango and Sal timber over the Flexural strength is significant at the 0.05 % level of confidence.

4. CONCLUSION

The mechanical properties of various types of timber were evaluated. The Yellow Teak, Red cedar, North Indian rose timber, Lebbeck, Java plum, Margosa, Eucalyptus, Teak, Mango and Sal were used for testing of physical and Mechanical properties for wood used for Agricultural Implements as well as for other Tools. The mechanical property, i.e. Flexural strength was measured by Universal Testing Machine, hardness by Rockwell Hardness Testing Machine and Impact strength by Impact Testing Machine. The Flexural Strength of Yellow Teak, Red cedar, North Indian rose timber, Lebbeck, Java plum, Margosa, Eucalyptus, Teak, Mango and Sal were observed as 79.00, 54.3, 104.2, 78.00, 84.00, 73.00, 65.9, 94.00, 88.6 and 98.00 MPa respectively.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that no generative AI technologies, such as large language models (ChatGPT, Copilot, etc.), and text-to-image generators were used during the writing or editing of this manuscript. The content of this research paper is the result of the authors' original work. Any assistance received from AI tools has been explicitly acknowledged and limited to non-generative functions, such as data analysis, proofreading, or formatting support.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX-A

Table 1. ANOVA table for the effect of different types of wood on ultimate compressive strength

Test of between –Subject Effects						
Dependent Variable: Ultimate Compressive Strength						
Source	**Df**	**Sum of Square**	**Mean Square**	**F value**	**R squared**	**Sig**
Replication	4	126.0875	31.52188	0.556	0.9945	
Treat	9	18718.96	2079.885	36.92		**
Error	36	2027.012	56.30589			
Total	**49**	**20872.06**				
Critical difference at 5 %	**9.624**					
Table value of $F_{0.05}$ (4,36)	**3.89**					
Coefficient of variance	**9.991**					

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