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Mechanical properties of palmyrah (*Borassus flabelifer*) leaf base

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Abstract
Natural fibres are becoming more popular due to their recyclability, eco-friendliness, low weight, and moderate strength. The tensile and flexural properties of palmyrah (*Borassus flabellifer L.*) leaf base are evaluated. Weibull analysis was used to test the statistical significance of the data acquired in the preceeding article. The test specimens were produced in accordance with ASTM guidelines. The palmyrah leaf base had an average length, thickness and weight of 436±0.72, 7.89±0.01 and 477.25±3.32 mm on zeroth day and 519±11.09, 7.32±0.01 and 439.2±11.68 mm on seventh day. The tensile and flexural strength was 0.008±0.0001, 0.441±0.01 GPa on zeroth day and 0.149±0.002, 0.343±0.001 GPa on seventh day of harvest. The study helps to design and develop fibre extraction machine and eventually the livelihood of palmyrah farmers will be improved.

Keywords: Tensile strength, flexural strength, weibull, natural fibre, palmyrah leaf base

Introduction

Borassus flabellifer, often known as the palmyrah palm, is derived from the Greek words Borassus and flabellifer, which indicate "fruit with a leathery coating." The species is native to the Indian subcontinent and Southeast Asia, and it can adapt to and survive in both dry and semi-arid environments. With 85.9 million palmyrah palm trees, India ranks first in the world, with 51 million trees in Tamil Nadu. Thoothukudi has the largest palmyrah tree population in Tamil Nadu (Krishnaveni *et al*., 2020) [12] (Rao *et al*., 2021) [16].

When the palmyrah tree begins to produce after 12 to 15 years in semi-arid locations and 25 years in dry regions, the sex of the tree may be determined. Toddy is produced by both male and female plants. The tree may reach a height of 15 to 18 meters and has a trunk diameter of 0.6 metres (Burkill, 1966, Davis and Johnson, 1987) [4, 7]. The crown of the tree contains 30 to 40 palmate leaves. Neera is taken from February to July and leaf base can be collected after August (Krishnaveni *et al*., 2020) [12]. Palmyrah leaves, mature fruit, trunks, timbers, and rind are non-edible parts of palmyrah tree that are used. A single palm produces five forms of fibre: a loose fibre from the leaf stalk's base, a long fibre in the leaf stalk, a fibre from the stem's center, a fibre from the pericarp, and the fibrous material of the leaves. Other domestic fibre uses include rope, brushes, baskets, and matting (Burkill, 1966) [4].

Retting is a traditional technique that uses anaerobic and biological organisms as a medium to breakdown lignin, pectin, and other compounds over a period of 2 to 6 weeks. Other techniques for extracting fibre include collecting the leaf base and soaking it in water for 8 to 12 hours, followed by scrubbing the pith layer with sickle, brush like tools with sharp edges (Amanuel, 2020) [1]. The physical properties of the leaf base will be useful for machine designers to determine the dimensions of the machine parts. Tensile and flexural properties will be useful in estimating the load and power required for de-fibering the leaf base. In the view of above contest physical, tensile and flexural properties of the palmyrah leaf base was estimated and recorded.

2. Materials and Methods

The palmyrah leaf base sample was collected from Vembar village, Thoothukudi, Tamil Nadu, India. The leaf base of 550 mm long from trunk of the tree was taken from five Indian palmyrah trees by traditional method with sickle. Since palmyrah trees were not available at one place, it took about seven to ten days from harvest, hence mechanical properties of palmyrah leaf base taken on zeroth day and seventh day of harvest.

2.1 Physical Properties
The Indian Palmyrah palm leaf base was measured for length, weight, and thickness. The thickness of the Palmyrah leaf base was measured using Insize 150mm digital caliper (1139-150), and the length and height were measured with a rule tape.

2.2 Moisture Content Determination
The samples moisture content were taken using oven dry method at 104 ºC for 24 hours (Henderson and Perry, 1997) [9]; (Dauda *et al*., 2014) [6]. Since the leaf base is of irregular in shape with differing thickness, they were divided into three segments and moisture content determined (Ghahraei *et al*., 2011; Hoque, 2019) [8, 10]. The experiments were conducted in laboratory at 28 ºC and 73% RH. The moisture content was determined using the equation (1) (Shinoj *et al*., 2010) [18]

$$M.C.(wb) = \frac{M_i - M_d}{M_i} \quad (1)$$

Where
M.C. (wb) = Moisture content in wet basis (%),
M_i = Initial moisture content (%),
M_f = Final moisture content (%).

2.3 Tensile Properties
The ASTM standard was used to test the tensile strength of the palmyrah palm leaf base. Sample dimension taken for test was 3.0x12.7x64 mm. The tensile strength test was performed with a 0- 20 mm gripper flat surface tensile probe on a Universal testing machine (Model: UNITEX 9410; Max Capacity:10 kN; Max heat travels: 600 mm; Make: FUEL INSTRUMENTS & ENGINEERS PVT. LTD, Maharashtra, India) at a crosshead speed of 5 milliseconds as shown in Plate.1 (Shinoj *et al*., 2010, Bhoopathi *et al*., 2017) [18, 3]. Tensile strength and tensile modulus was derived from equation (2) and (3)

$$\sigma_t = \frac{F_{max}}{A} \quad (2)$$

Where
F_{max} is maximum load, N
A is the cross sectional area, m^2
The percentage elongation (E) of the sample is the percentage of increase in the length of the sample at its breaking point, and is calculated from the equation (3),

$$E = \frac{(L - L_O)}{L_O} X\ 100 \quad (3)$$

Where
E- Percentage of Elongation
L_O- Actual length of the sample(m)
L- Length of sample at breaking Point(m)
Tensile stress (MPa), Tensile modulus (MPa), and Elongation at break (mm) were measured by the data acquisition system of Universal Testing Machine (UTM).

Plate 1: UTM machine loaded with sample for tensile test.

3.4 Flexural Strength
The flexural strength and modulus were determined using the ASTM D790 three-point bending test as shown in Plate.1 (ASTM, 2007) [2]. The probe and additional attachments required for 3 point bending testing are included with the UTM machine (Bhoopathi *et al*., 2017) [3]. 3.0x12.7x64 mm was the size of the sample collected for analysis. For the experiment, a Universal testing machine (Model: UNITEX 9410; Max Capacity: 10 kN; Max heat travels: 600 mm; Make: Fuel Instruments & Engineers PVT. LTD, Maharashtra, India) was utilised. Five times the tests were recorded, and an average value was computed. The flexural strength was determined using the equation (4)

$$S = \frac{3P^{I}L}{2bd^2} \quad (4)$$

Where
S- Flexural strength (Pa),
P^1- Load (N),
L- Span length (m),
b- Width of leaf base (m),
d- Thickness of leaf base (m)

Plate 2: UTM machine loaded with sample for flexural test.

4. Result and Discussion

Results obtained during the experiment with respect to the parameters considered are mentioned elaborately in this section.

4.1 Physical Properties

The mean values and standard deviation values of palmyrah leaf base was measured and the percentage reduction of physical properties from zeroth day to seventh day was recorded. The obtained results are presented in Table.1.

Table 1: Physical properties of palmyrah leaf base from zeroth day to seventh day of harvest.

Portion	Percentage reduction (%) from zeroth day to seventh day of harvest.		
	Length (%)	Weight (%)	Thickness (%)
Upper	1.7	7.3	5.1
Middle	3.5	8.1	5.8
Lower	4.3	8.6	1.3
Total	3.2	7.9	7.2

4.2 Moisture Content: The moisture content of the three portions was measured in triplicate and average values were recorded. The moisture portion of the middle portion of palmyrah leaf base was 73.1% (w.b) on zeroth day 56.4% (w.b) on seventh day of harvest which is high when compared with upper and lower portion. The moisture content of upper and lower portion was 33.3% (wb), 19.7% (w.b) and 56.4% (w.b) on seventh day of harvest. The average moisture content of the whole palmyrah leaf base was 57.3% (w.b) on zeroth day and 39.1% (w.b) on seventh day. The moisture content of fresh oil palm base was 63.1% (w.b) (Mandang *et al.*, 2018) [14]. The moisture content of palmyrah leaf base decreased by 38% on seventh day when compared with the zeroth day, this id due to loss of moisture content to the surroundings.

4.3 Tensile Strength

From 1(a) the palmyrah leaf base sample recorded a tensile strength of 0.0088±0.0001 GPa on zeroth day and 0.441±0.01 GPa on seventh of harvest. The palmyrah fibre produced from the palmyrah tree's leaf stem has a tensile strength of around 280MPa (Manikandan *et al.*, 2004). The tensile strength of treated palmyrah petiole fibre, raw and alkali treated Coccinia grandis L. was 56.56MPa, 273±27.74 MPa and 316.3±36.63 MPa. (Srinivasababu *et al.*, 2014; Senthamaraikannan and Kathiresan, 2018) [19, 17]. The tensile modulus of palmyrah leaf base was 0.34±0.31 GPa on zeroth day and 17.17±0.44 GPa on seventh day of harvest. Research articles indicates that tensile modulus of natural fibre *Coccinia grandis* L. had tensile modulus of 10.17±1.261 GPa for raw fibre and 14.29±2.87 for alkali treated fibres (Senthamaraikannan and Kathiresan, 2018) [17]. The tensile strength of the palmyrah leaf base is high since the experiment was conducted in leaf base harvested one week earlier. Moisture is reduced and the leaf base and fibres inside them become stiffer and non-fibrous layers bind well to the fibres, hence the tensile strength is high. The tensile properties of palmyrah leaf base is given in Table. 2. Tensile strength of leaf base help designers in determining the force required for disintegration. From Figure 1(a) and 1(b), it is seen that the tensile strength values of leaf base samples are uniformly distributed, thus data's are statistically significant ($P < 0.05$). Scale value: 0.0088 and 0.442, nearer to the experimental data.

Table 2: Tensile properties of palmyrah leaf base.

S. No	Properties	Values	
		Zeroth day	Seventh day
1	Tensile strength, GPa	0.0088±0.0001	0.441±0.01
2	Youngs modulus, GPa	0.34±0.31	17.14±0.44
3	Percentage Elongation, %	38±0.49	7.1±0.18
4	Elongation at break, mm	18±0.29	9±0.22

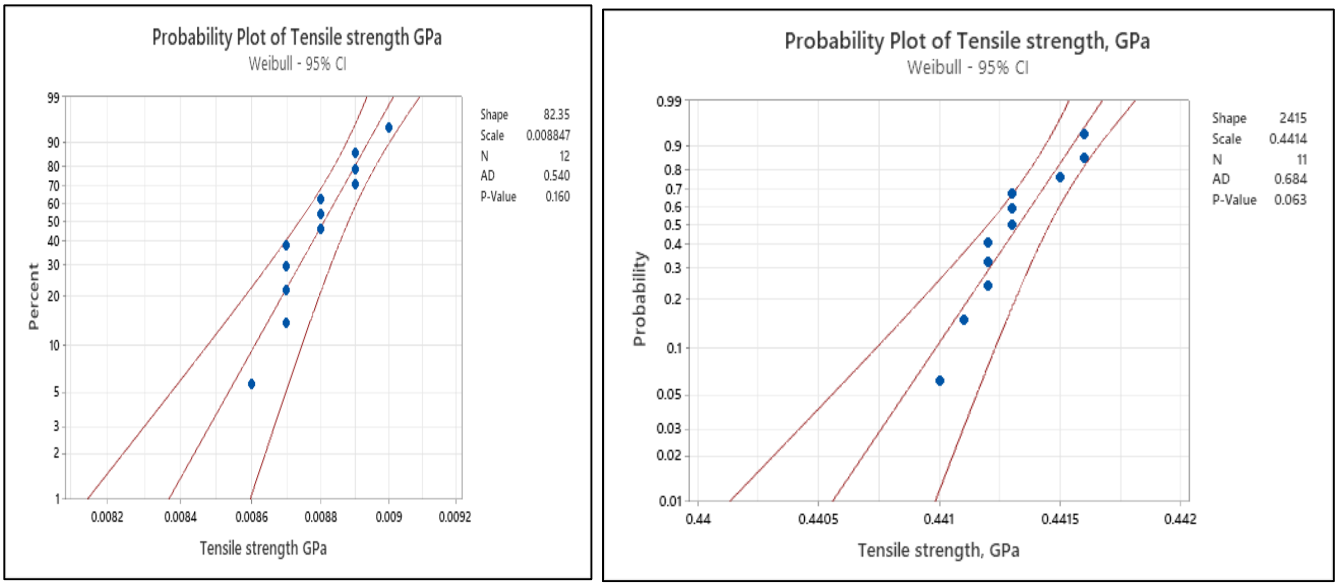

Fig 1: Weibull distribution (a). Tensile strength of palmyrah Lreaf base at Zeroth day (b). Tensile strength of palmyrah leaf base at seventh day.

4.4 Flexural Strength

The trials were repeated three times and the average results were recorded. The average flexural strength (S) of 0.147±0.002 GPa on zeroth day and 0.343±0.001 GPa on seventh day. The flexural strength of Scots pine wood (*Pinus sylvestris L.*) was found to be 72.8 MPa (Buyuksarı *et al.*, 2016) [5]. Flexural properties of leaf base will be useful in designing the inclination of fibre extraction unit. From Figure 2.a and 2.b, it is seen that the flexural strength values of leaf base samples at zeroth and seventh day are uniformly distributed, thus data's are statistically significant ($P < 0.05$). Scale value: 0.148 and 0.343, nearer to the experimental data.

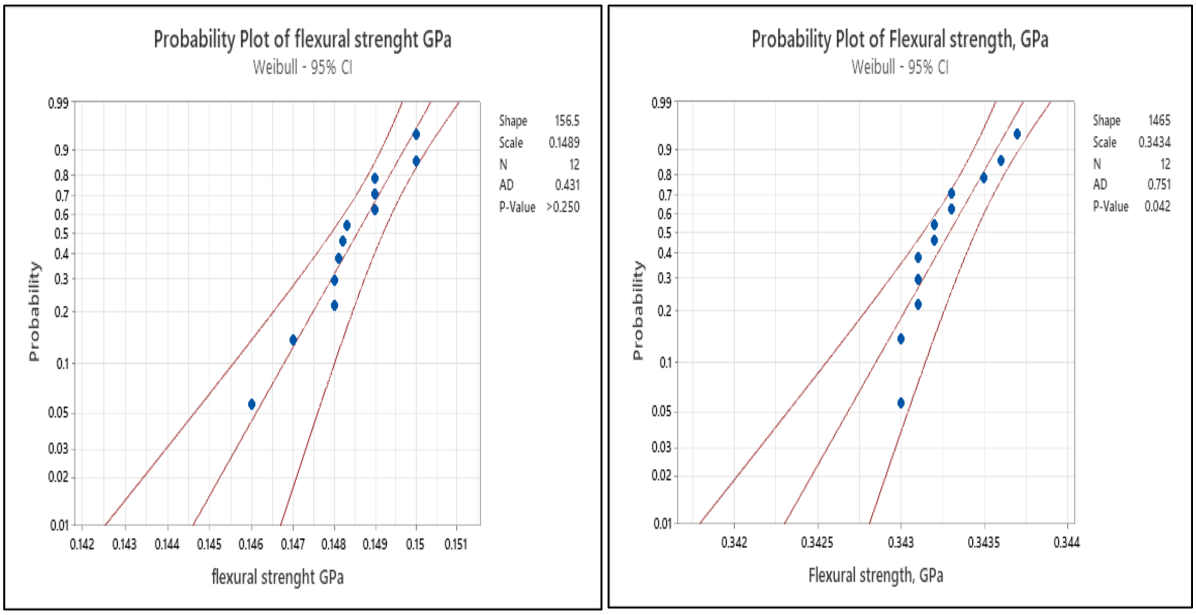

Fig 2: Weibull distribution (a). Flexural strength of palmyrah lreaf base at zeroth day (b). Flexural strength of palmyrah leaf base at seventh day.

4.5 Statistical Analysis

The mean standard deviation and coefficient of variation for mechanical parameters were calculated at a confidence level of 5%. Weibull distribution analyses, a continuous popability distribution designed after Swedish mathematician Waloddi Weibull, was used to examine the experimental data for significance. Minitab 19 statistical software was used to conduct the statistical study (Maache *et al*., 2020; Khan *et al*., 2020) [13, 11].

5. Conclusion

The tensile and flexural properties, of palmyrah leaf base sample after one week of harvesting was considerably high. The tensile and flexural strength of palmyrah leaf base was 0.008±0.0001, 0.441±0.01 GPa on zeroth day and 0.149±0.002, 0.343±0.001 GPa on seventh day, which is 58% increase due to loss of moisture content and increase in stiffness of the leaf base. The physical properties of palmyrah leafbase showed minimum decrease on seventh day when compared with zeroth day due to loss of moisture. This will be useful for machine designers to decide the load and force required for de-fiber the leaf base. The physical properties such as length, thickness, moisture content, etc will be useful in predicting design consideration of machine parts. The state tree of Tamil Nadu, palmyrah tree will be conserved and palmyrah farmers will be benefited.

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