ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 7, Issue 1, 241-251

Investigation of Flexural Strength of African Copalwood (Daniella Oliveri) as Reinforcement in Concrete Slab

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Date Submitted: 28/03/2024
Date Accepted: 23/05/2024
Date Published: 05/06/2024

Abstract: *This study investigates the potential of African Copalwood as a reinforcing material in concrete slabs. The timber rods were randomly selected from the timber market because there is always variation in timber properties with position in stem, location and soil condition. Various test specimen were prepared according to the Code of practices BS EN 408:2003 using structural size specimens. Thirty (30) slabs of size 75 mm x 300 mm x 700 mm were cast in five sets (1 to 4%) for Timber-reinforced concrete slab (TRCS) and Steel-reinforced slab (SRS) with a mix ratio of 0.5:1:2:4 denoting water-cement ratio, cement, fine and coarse aggregate respectively. Longitudinal bars were varied in 1% to 4% slab cross-sectional area in different TRCS samples while the transverse bar was restricted to be 3% by standard and made constant in all the slab samples specimen. A 10 mm diameter steel bar is used as reinforcement in the SRS. Findings revealed that the mean failure stress for Tensile strength parallel to grain was 41.80 N/mm2, Bending strength parallel to grain was 37.05 N/mm2, Compression parallel to grain was 13.48 N/mm2, Compression perpendicular to grain was 8.88 N/mm2, Local Modulus of Elasticity (MOE) was 3800.17 N/mm2, Apparent MOE was 59.42 N/mm2. Also, with regards to TRCS, the flexural strength test at 28 days for 1% to 4% reinforcement in concrete slabs is 3.61, 5.29, 5.49 and 7.22 N/mm2 respectively. The SRS has a flexural strength of 11.54 N/mm2 at 87.5% composition in slabs. These findings indicate enhancement in the strength properties of the concrete slabs with the incorporation of the African Copalwood reinforcement.*

Keywords*: African Copal Wood, Timber-reinforced Concrete Slab (TRCS), Longitudinal Bar, Transverse Bar, Modulus of Elasticity (MOE).*

1. INTRODUCTION

In the realm of construction engineering, the quest for sustainable and eco-friendly building materials has become paramount due to environmental concerns and the depletion of traditional resources. Wood, a renewable and widely available material, is being researched as a replacement for steel reinforcement in concrete structures. African Copalwood, derived from various tree species indigenous to Africa, presents a promising candidate for reinforcing concrete attributable to its inherent mechanical properties and abundance in certain regions. The reinforcement of concrete with wood has gained attention over the past few years to reduce the carbon footprint of construction projects and mitigate the environmental impact related to the production and use of steel reinforcement [1]. Yet, regardless of its prospective advantages, the lack of comprehensive research and data on the structural performance of Copalwood-reinforced concrete slabs hinders its widespread adoption in construction projects. The assessment of the strength performance of TRCS is justified by its potential to promote sustainability, support local economies, reduce cost, ensure structural safety, and enhance durability and foster innovation in the infrastructure industry.

Several studies have centred on the use of fibre-reinforced concrete structures [2, 3, 4, 5]. Nonetheless, few studies have focused on the use of timber as reinforcement in concrete structures [6, 7, 8, 9, 10].

Bello [8] conducted research work on the investigation of flexural and crack behaviours of African Birch Reinforced Concrete. Experimental load results of the four-point flexural test on the reinforced African birch concrete slabs subjected to special treatments such as pre-load, repeated cyclic load, and alternate wet and dry cycles were conducted. African birch-reinforced concrete one-way slab can be expected to develop from 1.38 to 2.37 times the ultimate load of the unreinforced concrete slab of equal dimension for about 1.28 to 4.05 per cent African birch timber reinforcement. The excess the African birch reinforcement percentage, the higher the load-carrying capacity of the slabs. Also, the first crack load reduces with an increase in the percentage of reinforcement for the slabs. Subjecting Africa birch RCS to preload, repeated cyclic loading, and alternate wet and dry conditions does not affect the eventual flexural strength of the slab omitting the case of alternate wet and dry, which increased the strength of the concrete slab due to further curing.

Mankuza [10] conducted research work on the Application of Mangrove Timber in Reinforcing Concrete. Mangrove timber specimens were sampled from Zanzibar, and assessed in the laboratory for their strengths in tension, compression and shear. The experimental findings show that mangrove is a hardwood timber of strength class D70, the superior timber classification. Also, concrete beam samples reinforced with mangrove timber rods, and others reinforced with structural steel were studied. The obtained test results show that beams reinforced with mangrove timber rods with enlarged ends performed better than those reinforced with uniform mangrove rods. The strength of the beams strengthened with mangrove timber was observed to be 50% of the beams strengthened with steel bars, implying that mangrove timber can be used to strengthen concrete beams. It was observed that the weaknesses of all beams were moderately distinct from each other. Beam samples reinforced with mangrove (uniform shape) showed deep cracks in contrast with the control beam and beams strengthened with mangrove rods of enlarged ends.

Mohammad and Nurul [7] conducted a study to focus attention on the flexural behaviour of beams reinforced with two types of timber; Balau and Meranti timber. Eurocode 2 is used to compare the behaviour of the two sample specimens. The experimental findings show that the steel reinforcement beam (SRB) has the maximum load-carrying capacity compared to the timber sample beam strengthened with Balau (BRB) and Meranti (MRB) bars. Compared to the flexural strength of SRB, BRB reached about 69 % of the value while MRB reached to 66 % respectively. It was found that the weaknesses of the timber beam corresponded to the load-deflection behaviour the same as the standard steel beam. The larger the load-deflection value, the wider the range of cracking occurred. The study concluded that Balau timber showed the highest resistance in tension load compared to Meranti timber. The tensile strength test is used to assess the tensile strength of timber and the finding points to different values of the two selected timber. Balau timber is classified as hardwood and ranks in the group (SG 1) in the strength group of timber, which is the highest rank of timber classification. Meanwhile, Meranti timber is located in SG 6 and is classified as light hardwood timber. This gives a new revelation in the civil engineering field about the prospective of Balau timber to be used as a structural material construction. The study further shows that timber has a high potential as renewable reinforcement for concrete structures. Conclusively, a beam reinforced with Balau and Meranti can achieve up to 70% in terms of flexural strength compared to a steel reinforcement bar with a diameter of 12 mm, and it also can achieve up to 90% deflection even though with lesser strength. The formation of cracks and weaknesses showed that the Balau reinforcement bar was a better material for concrete beams, which supported a high imposed load compared to Meranti timber.

Ezeagu et al. [9] conducted research work on the assessment of the suitability of timber products as concrete reinforcement bars in green buildings. The study considered using three locally available Nigeria timbers mainly Melina, Opepe and Bamboo as a replacement for carbon steel reinforced bars in reinforced concrete. The structural test was conducted using Hounsfield structural tests. The findings show that Melina had the maximum compressive strength of 16.25 N/mm^2, which is 6.5% (approx.) that of carbon steel. The maximum flexural strength was 77.097 N/mm^2 which is 4.406% (approx.) that of carbon steel while the highest hardness strength was 78.733 N/mm^2 which is 65.611% (approx.) that of carbon steel.

Grazide et al. [4] conducted research work on the rehabilitation of reinforced concrete structures using fibre-reinforced polymer and wood. He describes concrete and wood as an association that is usable for reinforced concrete strengthening. They experimented to analyze the mechanical properties of several combinations of wood-concrete composite beams with and without fibre-reinforce polymer (FRP) bars. The findings exhibit a greater reaction to the reinforcement, essentially provided by the wood material [5]. The existence of FRP bars seems to increase the stiffness of the reinforced beams without influencing the ultimate load in contrast to a reinforcement using only wood. Verily, the thickness of the wood element can modify the failure mode and the ultimate load. This study underlines the possibility of using wood in the field of RC structure rehabilitation.

The incorporation of sustainable and cost-effective materials in construction practices has become imperative in the quest for environmentally friendly and economically viable solutions. African copalwood, known for its strength and durability, present itself as a potential reinforcement material for concrete structure. However, its efficacy in enhancing flexural strength of concrete slabs remains largely unexplored. Thus, the primary problem addressed in this study is to investigate the flexural strength of African copalwood as reinforcement in concrete slabs.

The study is justified by its potential to offer sustainable, cost-effective, and locally sourced alternative to traditional reinforcement materials. This research can pave the way for innovative construction practices that prioritize environmental sustainability, economic viability and structural resilence.

The motive of the research work is to evaluate the physical and mechanical properties of the selected materials using structural size of the sample specimen and to investigate the strength of TRC slab samples to examine the load-deformation response of timber-reinforced concrete slabs under flexural loading. The purview of the research work focuses on understanding how timber reinforcement affects the behaviour of TRC slabs. It explores various timber configurations (1 to 4%) to provide insights into the structural integrity of timber-reinforced concrete systems and the modulus of rupture (flexural strength) of timber-reinforced slab will be determined.

2. METHODOLOGY

2.1 Materials

The materials for the study are (i) Ordinary Portland Cement (ii) African Copalwood (iii) Sharp river sand and coarse aggregates (iv) Water (v) Nails for holding reinforcement at right angle (vi) steel circular bars. To carry out this work, random samples of African Copalwood free from any wood defects were sourced from several wood processing markets in Ilorin metropolis, Kwara State, Nigeria. The selection was done randomly because there is no specific request from the wood purchasers to pick samplings from specific wood positioning be it at the top, middle or bottom of the tree trunk. The material was sawn and processed at the civil engineering workshop at, the University of Ilorin. 200 sample specimens were put to laboratory findings on physical and mechanical properties using a Universal Testometric Machine at the National Centre for Agricultural Mechanization (N.C.A.M), Kwara State.

2.2 Methods

The methods of this work involve physical tests of selected materials which include timber, granite, sand and cement. It also involves mechanical properties tests of African copal wood and TRCS.

2.2.1 Test on physical properties of timbers

The physical properties of timber: moisture content, Specific gravity, density, and water absorption tests were investigated by BS 373 [11].

2.2.2 Tests on physical properties of granite

Specific gravity, Particle Size Analysis and Aggregate Impact Value were investigated by BS 812:1990, BS 812:1995, and BS 812:1985 [12, 13, 14] respectively.

2.2.3 Mechanical properties of timber

The mechanical properties tests which include bending strength parallel to grain, local modulus of elasticity, apparent modulus of elasticity, compression parallel to grain, compression perpendicular to grain and tension parallel to grain were investigated on African Copalwood using the universal testing machine. The tests were:

i. Evaluation of the Bending strength parallel to the grain: For the bending strength, the size of the test pieces was 25 x 25 mm in cross-section and the tests were carried out by BS 408:2003 [15]. A total of 20 sample specimens were used for the test. Figure 1 shows the bending strength arrangement and the failure mode.

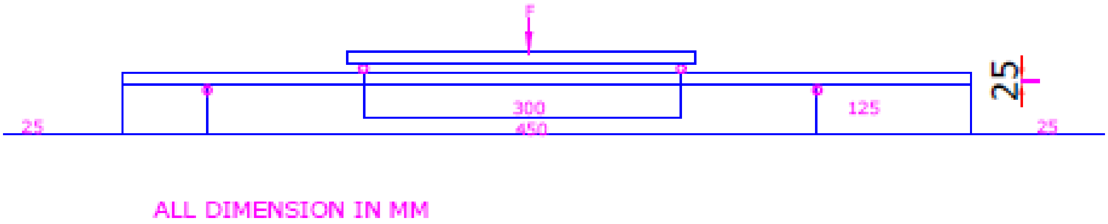

Figure 1: Dimensions of bending strength test piece and arrangement

ii. Evaluation of Local modulus of elasticity in bending: The dimension of the test specimen for local modulus of elasticity was a 25x 25 mm cross-section with a full length of 500mm in consonance with clause 9.1 of BS 408:2003 [15] specifications and the same arrangement as the bending strength test.

iii. Evaluation of Apparent modulus of elasticity: The approach is the same as bending strength, according to BS 408:2003 [15], the specimens were simply supported beams made of 25 x 25 mm cross-section and 500 mm span gauge length and loaded in a central bending point. A total of 20 sample specimens were used for the test. Figure 2 below shows the dimensions of the apparent modulus of the elasticity test piece.

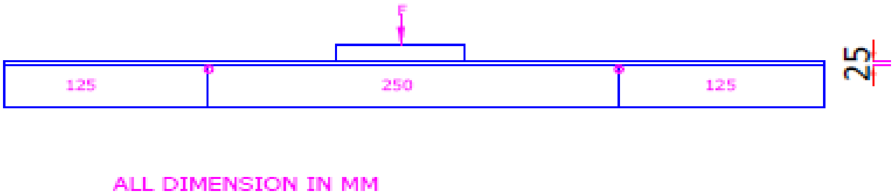

Figure 2: Dimensions of apparent modulus of elasticity test piece and arrangement

1. **Calculation of the shear modulus G**

The shear modulus (G) is computed using Equation (1)

$$G = \frac{k_G h^2}{{l_1}^2\left[\frac{1}{E_{m,app}} - \frac{1}{E_{m,l}}\right]} \tag{1}$$

Where k_G 1.2 for is rectangular or square sections; h is the Depth of the cross-section (mm).

l_1 is centre to centre-to-centre span between supports for the apparent modulus of elasticity setup. $E_{m,app}$ is the mean apparent modulus of elasticity; and $E_{m,l}$ is the local modulus of elasticity.

iv. Evaluation of Compressive parallel to the grain: The dimensions of the test piece adopted were by BS 408:2003 [15] and were 25 x 25 x 150 mm with the end surface particularly prepared to ensure they are plane and parallel to one another and at a right angle to the axis of the piece as well as similar to the loading plates. A total of 20 sample specimens were used for the test. Figure 3 and 4 shows Compression parallel to grain sample geometry and test arrangement.

Figure 3: Compressive strength test

Figure 4: Arrangement and failure mode parallel to grain specimens of compression parallel to grain

v. Evaluation of Compressive strength perpendicular to the grain: The cross-sectional dimensions of the test piece according to BS 408:2003 [15] was 30mm x 55mm x 75mm with the loaded surfaces particularly prepared to ensure they are plane and parallel to one another and perpendicular to the axis of the piece and also parallel to the loading plates. A total of 20 specimens were used for this test. Figure 5 shows arrangement and failure mode of the test pieces.

Figure 5: Arrangement and failure mode of compression perpendicular

vi. Evaluation of Tensile strength parallel to the grain: The test specimen for the tensile strength test parallel to grain was a full structural cross-section according to EN 408: 2003 which was a full length of 650 mm divided into two edges of 100 mm length and 50 mm width each and the gage length of 450 mm and 5 mm width, A total of 20 specimens were used for this test. Figure 6 shows the dimensions of the tensile strength test piece.

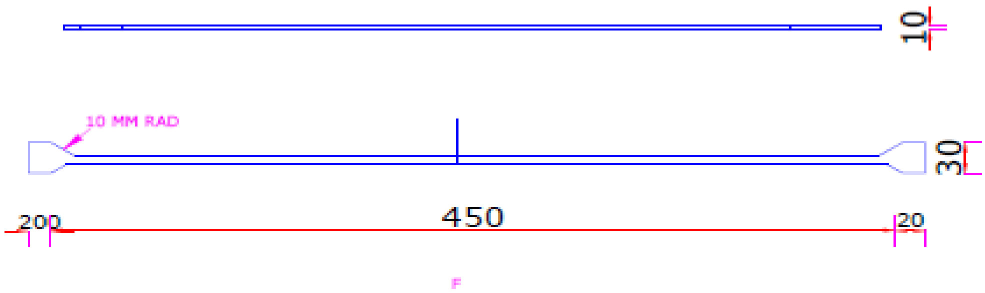

Figure 6: Dimensions of tensile strength test piece

2. Basic stresses

This is the stress which can securely be durably sustained by timber of certain strength and characteristics.

i. Basic bending stress parallel to the grain: The basic bending stress parallel to grain for the African Copalwood species was determined using the failure stresses from tests. It is computed using Equation (2)

$$f_{b,par} = \frac{f_m - 2.33\sigma}{2.25} \tag{2}$$

Where $f_{b,par}$ is basic bending stress parallel to the grain, f_m is the mean value of the failure stresses at 18%, and σ is the standard deviation of the failure stresses

ii. Basic modulus of elasticity and apparent stresses: The formula below gives the relationship between the E_{mean} and the statistical minimum value of E appropriate to the number of species acting together using Equation (3)

$$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \tag{3}$$

Where E_N is the statistical minimum value of E appropriate to the number of pieces N acting together (where N=1, E_N becomes the value for E_{min}) and σ is the standard deviation.

iii. Basic compression stress parallel to the grain: The basic compressive stresses parallel to grain for the three species were determined using the failure stresses from tests and computed using Equation (4)

$$c_{b,par} = \frac{f_m - 2.33\sigma}{1.4} \tag{4}$$

iv. Basic compression stress perpendicular to the grain: The basic Compression stress perpendicular to the grain for African Copalwood species was investigated using the failure stresses from tests using equation (5)

$$c_{b,perp} = \frac{f_m - 1.96\sigma}{1.2} \tag{5}$$

v. Basic tensile stress parallel to the grain: The basic tensile stress parallel to grain for African Copalwood species was determined using the failure stresses from tests and computed using Equation (6)

$$t_{b,par} = \frac{f_m - 2.33\sigma}{2.25} \tag{6}$$

3. Statistical analysis

It is the science of collecting, exploring and presenting large amounts of data to discover underlying patterns and trends.

i. Confidence limit: The Confidence Limit for 95% and 99% mean failure stresses at 12% moisture content were calculated using statistical Equation (7) (upper and lower limit).

$$f_m \pm t^{\alpha}/_{2}\, n - 1\, {}^{S}/_{\sqrt{n}} \tag{7}$$

Where f_m the sample is mean, α is the level of significance, S is the standard deviation, n is several samples, and $t^{\alpha}/_{2}\, n - 1$ is obtained in the distribution table.

4. Flexural strength

The flexural strength test was conducted to determine the flexural strength of the African Copalwood reinforced concrete slab. The tests were carried out by [16]. The flexural strength (f_{cf}) in N/mm^2 is given in Equation (8).

$$f_{cf} = \frac{3FL}{2bd^2} \tag{8}$$

Where f_{cf} is the failure load, L is the length of the slab, b is the width and d is the depth of the sample slab.

5. Slab reinforcement preparation

Design parameters were formulated based on BS 8110 [17]. Longitudinal reinforcement was varied by section of slab (area) in 1% to 4% in different timber-reinforced concrete slab samples while transverse bars were selected to be 3%

given the maximum reinforcement in slab is restricted to 3% [17]. Longitudinal square timber of 670 mm long and square transverse timber of 270 mm long was nailed together at right angles. Also, Steel reinforcement for control slabs was prepared similarly. The information on the arrangement for both timber and steel is shown in Tables 1 and 2.

Table 1: Description of steel reinforcement arrangement for slab

Label	**h (mm)**	**D (mm)**	**Distribution Steel bar**					**Main Steel Bar**				
			As mm^2	$\frac{100A_s}{bh}$ **(%)**	ϕ **(mm)**	**No**	**S (mm)**	**As (mm^2)**	$\frac{100A_s}{Lh}$ **(%)**	ϕ **(mm)**	**No**	**S (mm)**
1SRS	75	54	124	0.55	10	2	135	315	0.60	10	5	168

Table 2: Description of timber reinforcement arrangement for slab test

Label	**h (mm)**	**d (mm)**	**Longitudinal Timber bar**					**Transverse Timber Bar**				
			As (mm^2)	$\frac{100A_s}{bh}$ **(%)**	ϕ **(mm)**	**No**	**S (mm)**	**As (mm^2)**	$\frac{100A_s}{Lh}$ **(%)**	ϕ **(mm)**	**No**	**S (mm)**
1%S	75	54	225	2	12	2	27 0	1575	3	20	6	134
2%S	75	54	450	3	12	3	13 5	1575	3	20	6	134
3%S	75	52	675	4	16	4	90	1575	3	20	6	134
4%S	75	52	900	5	16	5	68	1575	3	20	6	134

6. Preparation and Casting of Concrete Slab

The mixing method used for the production of timber-reinforced concrete slab was the manual method. The mix ratios for batching were 0.5:1:2:4 denoting the water-cement ratio, cement, sand and granite respectively. Sample slabs of 75 mm depth by 300 mm width by 700 mm length (Figure 7) were cased inside a prepared wooden formwork. The sample slabs were cured for 28 days by total immersion of the slab in water. A total of thirty (30) slabs of five (5) sets each were cast on different days. Figure 8 below shows the failure mode of TRCS.

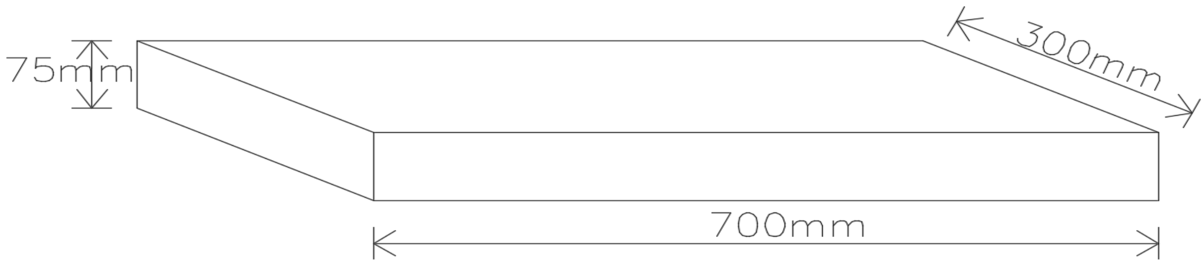

Figure 7: Concrete slab section

Figure 8: Failure mode of timber reinforced concrete slab

3. RESULTS AND DISCUSSIONS

3.1 Physical Properties Results of African Copal Wood

i. Moisture Content Result: Moisture content for each property of African Copalwood is revealed in Table 3. The MC of the sample specimens for bending strength, local MOE, compression parallel to the grain, compression perpendicular to grain and tensile parallel to grain have a mean value of 14.63%, 12.81%, 12.13%, 12.33% and 11.46% respectively. It was established that African Copalwood has a mean M.C of 12.67%

Table 3: Moisture content results for African copal wood specimen

	Bending Strength	Local M.O.E	Comp. Par. To Grain	Comp. Per.	Tens.Par.	Mean M.C (%)
African Copalwood	12.35	15.39	11.7	10.23	11.36	**12.67**
	15.33	10.97	11.04	14.14	16.92	
	19.18	11.38	13.57	17.61	7.12	
	11.64	13.51	12.19	7.32	10.45	
Mean	**14.63**	**12.81**	**12.13**	**12.33**	**11.46**	

ii. Density Results: The density for each property of African copalwood is revealed in Table 4. The density values of test specimens for bending strength, local MOE, compression parallel to grain, compression perpendicular to grain and tensile parallel to grain are 388.69 kg/m^3, 428.88 kg/m^3, 446.16 kg/m^3, 371.23 kg/m^3 and 454.30 kg/m^{3}respectively. It was revealed African Copal wood has a mean value of density, ρ of 417.85kg/m^3.

Table 4: Density results for African copalwood specimen

	Bending Strength	Local M.O.E	Comp. Par. To Grain	Comp. Per. To Grain	Tens.Par.to Grain	Mean Density (kg/m^3)
African Copalwood	421.77	493.21	456.16	307.69	312.74	**417.85**
	439.67	415.48	435.62	442.38	453.83	
	300.00	325.00	442.86	311.77	492.31	
	393.33	481.82	450.00	423.08	558.33	
Mean	**388.69**	**428.88**	**446.16**	**371.23**	**454.30**	

3.2 Physical Properties Results of Granite

The specific gravity test results on the coarse aggregate (granite) are presented in Table 5. The average specific gravity, apparent specific gravity and water absorption capacity results were 2.65, 2.69 and 0.61% respectively. The aggregate impact value test on the coarse aggregate (granite) is presented in Table 5. It is noticed that the coarse aggregate had an aggregate impact value of 16.63% which is less than 25%. The results of the aggregate water content of the coarse aggregate (granite) are presented in Table 5. A value of 0.3% was obtained, which is in a basic state of saturated and surfaced dried condition.

Table 5: Physical properties results of granite and sand

S/N	Test	Value	
		Sand	Granite
1	Specific Gravity	2.63 [indicates the aggregate used is Sand]	2.65 [indicates the aggregate used is normal weight aggregates]
2	Apparent Specific Gravity	2.67	2.69
3	Water Absorption	-	0.61
4	Aggregate Impact Value	-	16.63% [< 25% , Therefore, aggregate is regarded as a suitable material]
5	Moisture Content	-	0.3% [This indicates a basic state of saturated and surfaced dried condition.]
6	coefficient of uniformity (C_u)	2.18 < 4 [the fine aggregate is regarded as a Well Graded Sand (SW)]	-
7	coefficient of curvature (Cc)	1.18 >1<3	-
8	fineness modulus values	2.8 [Lies between 2.3 and 3, the aggregate is a fine aggregate]	-

3.3 Physical Properties Results of Sand

The specific gravity results of the fine aggregate (sand) are presented in Table 5. The average specific gravity result, apparent specific gravity result and water abortion result of the fine aggregate (sand) used for this experiment were 2.64, 2.67 and 0.54% respectively. The sieve analysis results conducted on the fine aggregate (sand) are presented in Table 6. Since the coefficient of uniformity (C_u) value of 2.18 is < 4 and the coefficient of curvature (C_c) value of 1.14 lies between 1 and 3, the aggregate is regarded as a Well Graded Sand (SW). Also, the fineness modulus value of 2.8 lies between 2.3 and 3.0, this shows that the material is a fine aggregate. Sand correlates with grading Zone II.

3.4 Mechanical Properties Results of African Copal Wood

i. Bending strength parallel to the grain: The bending strength parallel to grain test results of African Copalwood species were presented in Table 6. The MOR was obtained at 14.63% M.C. The characteristic experimental values were adjusted from 14.63% M.C to 12% MC and 18% MC at 48.83 N/mm^2 and 39.94 N/mm^2. The basic and 80% grade stresses established from the test are 6.07 N/mm^2 and 4.86 N/mm^2 respectively.

ii. Local modulus of elasticity: The local MOE results of the African Copalwood species are presented in Table 6. The characteristic experimental values were adjusted from 14.63% M.C to 12% MC and 18% MC at 4404.40 N/mm^2 and 3948.38 N/mm^2. The basic and 80% grade stresses obtained from the test are 3276.16 N/mm^2 and 2620.93 N/mm^2 respectively.

iii. Apparent modulus of elasticity: The apparent MOE results of the African Copalwood species are presented in Table 6. The characteristic experimental values were adjusted from 12.81% M.C to 12% and 18% moisture content at 4404.40 N/mm^2 and 3948.38 N/mm^2. The basic and 80% grade stress established from the test is 55.40 N/mm^2 and 44.32 N/mm^2 respectively.

iv. Compressive strength parallel to the Grain: The compressive strength parallel to grain results of African Copalwood species are presented in Table 6. The characteristic experimental values were adjusted from 12.13% M.C to 12% MC and 18% MC at 18.84 N/mm^2 and 14.79 N/mm^2. The basic and 80% grade stresses established from the test are 5.89 N/mm^2 and 4.71 N/mm^2 respectively.

v. Compressive strength perpendicular to the grain: The compressive strength is perpendicular to grain results of African Copalwood species presented in Table 6. The characteristic experimental values were adjusted from 12.33% M.C to 12% MC and 18% MC at 12.41 N/mm^2 and 9.75 N/mm^2. The basic and 80% grade stresses established from the test are 7.10 N/mm^2 and 5.68 N/mm^2 respectively.

vi. Tensile strength parallel to the grain: The tensile strength parallel to grain results of African Copalwood species are presented in Table 6. The characteristic experimental values were adjusted from 19.22% M.C to 12% MC and 18% MC at 58.42 N/mm^2 and 45.88 N/mm^2. The basic and 80% grade stresses established from the test are 17.23 N/mm^2 and 13.79 N/mm^2 respectively.

Table 6: Mechanical properties results of African copal woodcopal wood

African Copalwood	(MOR) (N/mm^2)	Local MOE (N/mm^2)	App MOE (N/mm^2)	Comp. Par. (N/mm^2)	Comp. Per. (N/mm^2)	Tens. Par. (N/mm^2)
Mean Stress	37.05	3800.17	59.42	13.48	8.88	41.80
Std.Deviation	11.28	1290.24	12.17	2.81	2.81	3.05
C.O.V	30.43	33.95	20.49	20.86	4.51	21.91
Shear Mod.			0.73			
12% M.C	48.83	4404.40	68.87	18.84	12.41	58.42
18% M.C	39.94	3948.38	61.74	14.79	9.75	45.88
Basic Stress	6.07	3276.16	55.40	5.89	7.10	17.23
Grade 80	4.86	2620.93	44.32	4.71	5.68	13.79

3.5 Flexural Strength Test Result of African Copal Wood-Reinforced Concrete Slab

Table 7 shows the experimental load findings of the central point flexural test on the African copalwood-reinforced concrete slabs. The failure load of African Copalwood-reinforced concrete slabs at 28 days strength was from 5800 N to 11600 N i.e. 1% to 4% variation. From the failure load results, it was noticed that the higher the fraction of African Copalwood reinforcement, the higher the load required rupturing the slabs. Also, deflection increased with an increase in the percentage of African Copal wood reinforcement from 5.5 mm to 8.25 mm. The flexural strength of slabs also increased from 3.61 N/mm^2 to 7.22 N/mm^2 with an increase in the percentage of African Copalwood reinforcement. Figure 5 shows the flexural load deflection curve of 1% to 4% African Copalwood-reinforced concrete slab while Figure 6 also shows flexural strength against Percentage (%) Variation for Copalwood-reinforced slab. From Figure 4, steel reinforced concrete slab produces a flexural strength of 62.56% times the ultimate strength of African Copal wood. Table 8 below shows a comparison of flexural strengths of TRS of some Nigerian locally available timbers.

Table 7: Flexural strength (experimental load) result of African copalwood

28 days						
Label		**Density (kg/m^3)**	**Failure load (N)**	**Deflection at Peak (mm)**	**Flexural Strength (N/mm^2)**	**Mode of Failure**
1IRS	Mean	2255.66	5800	5.5	3.61	One visible cracks were seen and failure is in tension.
2IRS	Mean	2380.68	8500	6.15	5.29	One visible cracks were seen and failure is in tension.
3IRS	Mean	2247.26	8825	7.00	5.49	Two visible cracks were seen and failure is in tension.
4IRS	Mean	2380.62	11600	8.25	7.22	Two visible cracks were seen and failure is in tension.

3.6 Compared with other Studies

In comparing the flexural strength of African Copalwood-reinforce concrete slab with existing studies (details in table 8), the composite system exhibits higher carrying capacity when compared with timber like African birch and Palm broom.

Table 8: Flexural strength of TRS of some Nigerian locally available timbers

Timber	Flexural Strength (N/mm^2)	Reference
African birch	6.709	Bello [8]
Oil Palm Broom	5.76	Mohammed [7]
Africa Copal wood	7.22	Current Study

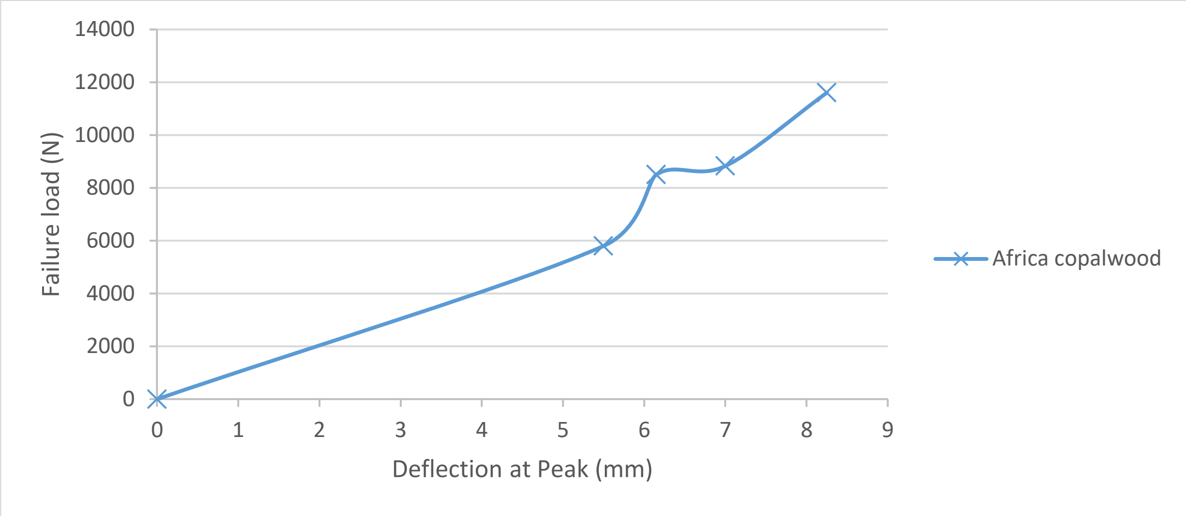

Figure 5: Failure load against deflection at peak

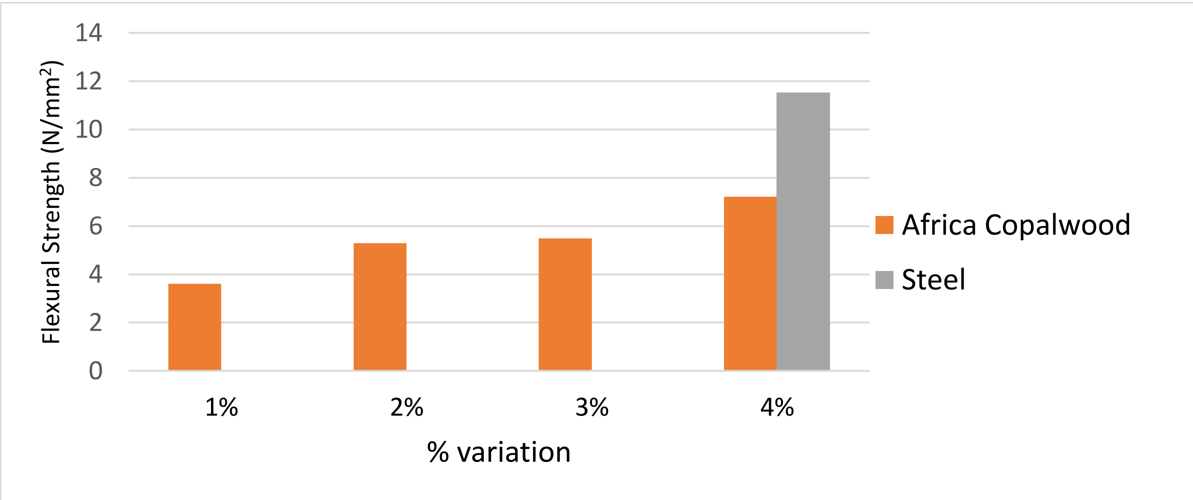

Figure 6: Flexural strength against percentage (%) variation for Copalwood and Steel

4. CONCLUSION AND RECOMMENDATION

African Copalwood offers advantages over traditional reinforcement materials in terms of availability, environmental impact and costs. The mechanical test conducted on sample specimens disclosed that mean failure stress for Tensile strength parallel to grain was 41.80 N/mm^2, bending strength parallel to grain was 37.05 N/mm^2, Compression parallel to grain was 13.48 N/mm^2, Compression perpendicular to grain was 8.88 N/mm^2, Local MOE was 3800.17 N/mm^2 and Apparent MOE was 59.42 N/mm^2. Also, with regards to concrete slabs reinforced with African Copalwood, the flexural strength test at 28 days for 1% to 4% reinforcement in concrete slabs is 3.61, 5.29, 5.49 and 7.22 N/mm^2 respectively. Also, the flexural strength of ACRS obtained is higher than those of African birch and Oil Palm Broom TRS. The steel-reinforced slab has a flexural strength of 11.54 N/mm2 at 87.5% of the crossectional area. The optimum sectional amount of African Copalwood rods that maximise flexural strength is at 4% in this research work. Conclusively, African Copalwood can effectively be used as reinforcement in concrete.

It is recommended that more comprehensive research is needed to explore the potential of African Copalwood as reinforcement in various types of concrete under different loading conditions and environments. This includes investigating its behaviour in terms of shrinkage, creep, and resistance to biological degradation.

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