

Flexural Strength Behaviour of Apa (*Afzeliabipindensis*) Reinforced Stabilized Lateritic Soil Beam

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Abstract: This paper reports on the flexural strength behaviour of Apa reinforced stabilized lateritic soil beams. The potential of using timber as a reinforcement material is because timber is abundant, cheap and locally available compared to conventional steel. Apa timber possess a tensile strength of 68.34 N/mm². Experimental and Finite Element Analysis using ANSYS 15 were carried out to determine the flexural strength of Apa reinforced lateritic soil beams. The results showed an increase in the load-bearing capacity with increase in the percentage area of Apa reinforcement used in Lateritic soil beams. BS 8110-1:1997 requires that area of reinforcement for beams should not exceed 4%. At 4 percent area, the flexural strength of the Apa reinforced lateritic soil beams (ALB) was 0.763 N/mm² with corresponding load capacity of 3.435 kN which is slightly higher than the steel reinforced lateritic soil beams (SLB) of 0.740 N/mm² with corresponding load capacity of 3.329 kN obtained in the report.

Keywords: Lateritic soil; Apa (*Afzeliabipindensis*) reinforced soil beam; flexural strength.

Introduction

Laterite is a group of highly weathered soil formed by the concentration of hydrated oxides of iron, and aluminium [1]. Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow fine-grained residual soils of light texture as well as nodular gravels and cemented soils indicating the presence of iron oxide which makes laterite chemically written as $\text{Fe}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ [2,3]. The term Laterite is derived from the Latin word 'later' meaning brick. It was first used in 1807 by Buchanan to describe a red iron-rich material found in the southern part of India. Laterites are widely distributed throughout the world in the regions with high rainfall, especially in the inter-tropical areas of Africa, Australia, India, South-East Asia, and South America where they are generally present just below the surface of grasslands or forest clearings. The utilization of laterites enables the provision of low-cost houses and other rural infrastructures. However, laterites have not been extensively used in constructing medium to large-size building structures. This is probably due to lack of adequate data needed in the analysis and design of structures built of lateritic soils.

Apa is grown in Ajase Ipo, in Kwara State, within North Central zone of Nigeria. It is readily available and extensively used in this area and other places in Nigeria. According to Nigerian Standard Code of Practice, NCP 2 [4], Apa a very durable hardwood, has an excellent resistance capacity to attack by termite. The timber is readily available in the Savannahs and high forests. Environmental condition, weather condition, and the soil affect the growth of trees as well as their strength properties [5]. Apa timber has good machining qualities, it is sandy in texture. Its uses include flooring, furniture, decking, stair rails, and other conventional construction [6]. The strength properties of Apa timber perpendicular to the grain is much lower than its strength properties when parallel to the grain. Apa timber belongs to strength class of D30 – D70 as stated in BS 5268:2002 which indicates that Apa timber is a hardwood and can be used for structural applications like decking, roof constructions, reinforcements in earth and concrete matrix, timber bridges, beams, rafters, and railway sleepers. Due to its relatively high tensile property, it can be used to reinforce the soil for construction of stable structures [7].

Research conducted by Richard [8], on the use of sugarcane bagasse fiber as a reinforcement material in cement-lateritic beam revealed a decrease in the peak load required to cause maximum deflection, as the replacement levels increased. The average maximum peak load-deflection of sugarcane bagasse fiber-cement-lateritic beam was lower than the conventional beam by 17.5%. They also observed that the control beam specimens exhibited a higher stiffness than sugarcane bagasse fiber-cement-lateritic beam,

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and a similar behaviour pattern up to 20 KN. Based on the research conducted, they concluded that sugarcane bagasses laterised concrete beam can be designed for a grade of 20 MPa using the requirements contained in BS 8110 Part 1-1997 for design of structures.

Graeme [9] stated that most parts of Africa have laterite deposits due to the possible factors that encourage its formation. Traditional houses seen in rural part of Africa are usually made using laterite. Openings in mud building such as windows and doors are usually framed and supported by exposed timber which may fail due to exposure to termites and other environmental conditions. There is a need for a suitable structural member like reinforced stabilized lateritic beams to replace the exposed timber. Also, considering the high cost of steel reinforcement, timber such as Apa timber can be used in place of the steel bars to provide the necessary strength.

This study is aimed at investigating the flexural strength of stabilized lateritic soil beam reinforced with Apa timber in accordance with the BS EN 12390-5 (Testing hardened concrete-Flexural strength of test specimens) [10]. Comparative performance study will be carried to examine the flexural strength behaviour of Apa, steel, and unreinforced lateritic soil beam.

Materials and Methodology

Materials

The materials used for this experiment were Apa timber, steel bars, timber Stirrups, laterite, ordinary portland cement (OPC), and water. The Apa timbers were obtained from saw mill marketers at Tanke, in Ilorin area of Kwara state, Nigeria. The various steel bars and OPC were also gotten from marketer at Tanke, Ilorin. The lateritic material was dogged from a borrowed pit within the university of Ilorin campus.

Tests for Physical Properties of Laterite

Particle size distribution, specific gravity, moisture content, atterberg limit, and compaction test were carried out on the laterite sample in accordance with BS 1377: Part 2 [11]

Tension Parallel to the Grain of Apa timbers

The specimen shape and the test procedure for this experiment was carried out in accordance with the BS 373 [12]. Twenty (20) specimens of Apa timber obtained from the sawmill were formed and dimensioned as illustrated in Figure 1 to determine the tensile strength parallel to the grain. Figures 2 and 3 showed the tensile test set up and failure mode respectively.

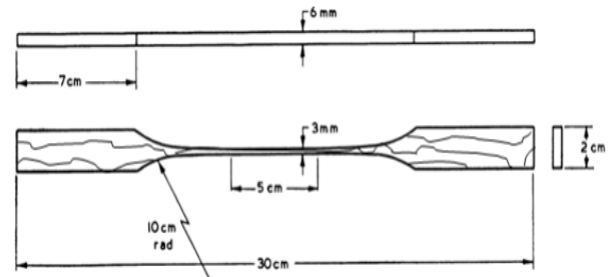


Figure 1. Test Piece for Tension Parallel to the Grain Test



Figure 2. Tensile Strength Set Up



Figure 3. Tensile Failure Mode

Test for Compressive Strength of Stabilized Lateritic Cubes

Test for compressive strength of stabilized lateritic cubes was carried out in accordance with BS 1881 Part 116 [13]. Five (5) stabilized laterite cubes of size 150 mm × 150 mm × 150 mm were moulded according to the mix proportions in Table 1 using absolute volume method [14]. National building and road research institute (NBRRI) proposed the following specifications as requirements for laterite bricks: bulk density of 1810 kg/m³, water absorption of 12.5%, compressive strength of 1.65 N/mm², and durability of 6.9% with maximum cement content fixed at 5%. The cubes were cured by covering using polythene sheets for 28 days before testing.

Table 1. Mix Proportions for Stabilized Lateritic Cubes

S/N	No. of samples	Cement content (%)	Mass of cement (kg)	Mass of laterite (kg)	Mass of water (kg)	water/cement ratio
1	5	5	1.101	22.02	3.096	2.812

Reinforcement Preparation for Flexural Strength Test

Four longitudinal square Apa timber rods each 460 mm long of square cross-sections (12 mm, 16 mm, and 20 mm) and 8 mm link bars were tied together with binding wires as shown in Figure 4. Cover of 20 mm is provided. Steel reinforcement rods for control beams were also prepared similarly as shown in Figure 5.



Figure 4. Apa Reinforcement

Table 2. Description of Test Beams

Label	h (mm)	d (mm)	As (mm ²)	$\frac{100A_s}{bh}$ (%)	Barsize (mm)	No.	Stirrups ϕ (mm)	s (mm)
ALB1	150	116	225	1	12	4	8	90
ALB2	150	114	450	2	16	4	8	88.5
ALB3	150	112	675	3	20	4	8	87
ALB4	150	112	900	4	20	5	8	87
SLB	150	116	180	0.8	12	4	8	90
ULB	150	-	-	-	-	-	-	-

Note: ALB is the Apa Timber Reinforced Lateritic Beam, ULB is the Unreinforced Lateritic Beam SLB is the Steel Reinforced Lateritic Beam, h is the thickness of beam (mm) d is the effective depth (mm), As is the area of reinforcement (mm²), ϕ is the bar size [square] (mm), s is the spacing of stirrups (mm).

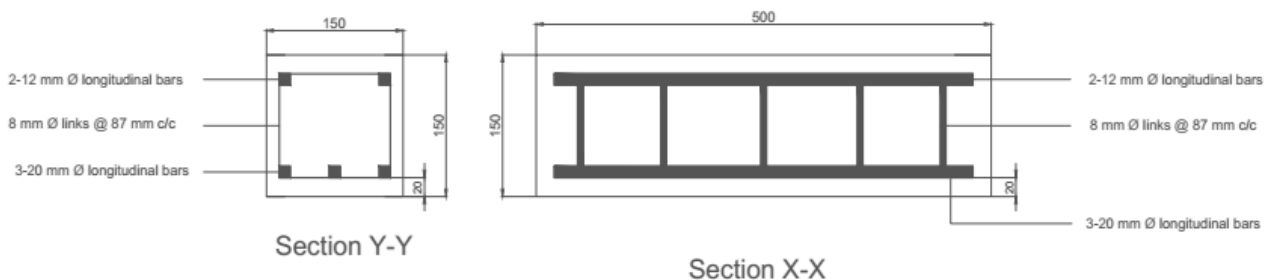


Figure 6. Apa Reinforced Lateritic Beams



Figure 5. Steel Reinforcement

Beam Detailing

Figure 6 shows a typical reinforcement detail of the stabilized lateritic beams.

Stabilized Lateritic Soil Preparation

The preparation of Stabilized lateritic soil was carried out after reinforcements were arranged. The materials used were ordinary Portland cement (Dangote brand) and laterite.

Casting of Lateritic Soil Beam

Forty-five (45) stabilized laterite beams of length 500 mm and size 150 mm × 150 mm were moulded according to the mix proportions in Table 3 using absolute volume method [15], by filling the mould in five layers and each layer was given 25 blows of compaction

using a standard rammer of weight 4.5 kg falling from a height of 0.45 m according to BS 1377: Part 2: 1990 [11]. The freshly moulded beams were carefully extruded on a clean and flat surface as shown in Figure 7 and Figure 8, and were cured by covering the samples with polythene sheet for 28 days before testing

Table 3. Mix Proportions for Stabilized Lateritic Beams

S/N	No. of samples	Cement content (%)	Mass of cement (kg)	Mass of laterite (kg)	Mass of water (kg)	water/cement ratio
1	27	5	33.075	661.5	93.015	2.812



Figure 7. Beams in the Mould



Figure 8. Demoulded Beam Sample

Flexural strength test

The test method (centre point loading) was carried out in accordance with the BS EN 12390-5:2000 [10]. It was ensured that the reference direction of the loading is perpendicular to the direction of the casting of the specimen as shown in Figure 9. A constant rate of stress with the range 10 mm/min was applied. The flexural strength is given by the equation:

$$f_d = \frac{3 \times F \times l}{2 \times d_1 \times d_2^2} \quad (1)$$

Where:

f_d = flexural strength in megapascals (Newton per square millimetre (N/mm²));

F = the maximum load, in Newton (N);

l = the distance between the supporting rollers, in millimetres (mm).

d_1 and d_2 = the lateral dimensions of the cross-section, in millimetres.



Figure 9. Flexural Test Arrangement

Validation of Results

Finite element analysis using ANSYS 15.0 was carried out to see the behaviour of Apa reinforced Lateritic beams when subjected to point load at the centre. This was carried out to validate the experimental results. The unreinforced, steel reinforced, and Apa reinforced Lateritic beams were modelled in ANSYS 15.0 using the standard geometry of the specimens. Material behaviour properties such as the modulus of elasticity (Young’s modulus) and Poisson ratio gotten from the experimental results were inputted for computation. Triangular supports were modelled and fixed at 25 mm from the ends to have a clear span of 450 mm same as the laboratory experimental set up was done. Also, centre point load was applied in the middle of the clear span in the negative y-axis.

Results and Discussion

Physical Properties of Steel and Laterite

Y12, Y16 and Y20 steel rods had a yield strength value of 410 MPa while the Y10 and Y8 steel rods had a yield strength value of 250 MPa. The index properties of the laterite used in the study are summarized in Table 4, while Figure 10 shows the particle size distribution curve of the laterite. The relationship between the dry density and moisture content is presented in Figure 11. The soil is classified in A-2-7 Subgroup of A-2 group according to AASHTO [15] classification which gives the usual types of significant constituent materials as silty or clayey gravel and sand, and the soil can be rated as good. The normal compaction curve for most laterite is depicted, indicating a maximum dry density (MDD) of 4.24 g/cm³ and an optimum moisture content (OMC) of 14.06%.

Table 4. Properties of the Laterite Used

Characteristic	Laterite
Natural moisture content (%)	3.36
Percentage passing BS No 200 sieve (%)	2.6
Liquid limit (%)	51
Plastic limit (%)	30.6
Plasticity index (%)	20.4
AASHTO classification	A-2-7
Maximum dry density (g/cm ³)	4.24
Optimum moisture content (%)	14.06
Specific gravity	2.69
Condition of sample	Air-dried

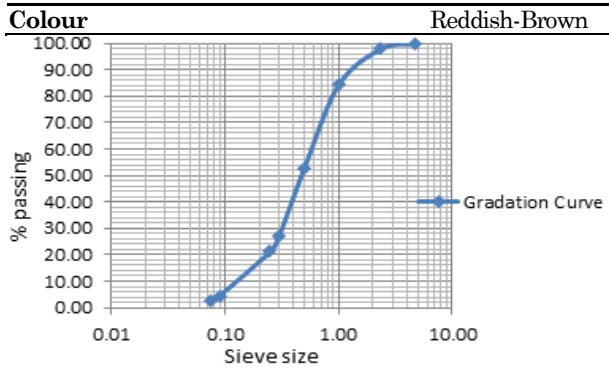


Figure 10. Particle Size Distribution Curve of the Laterite Used

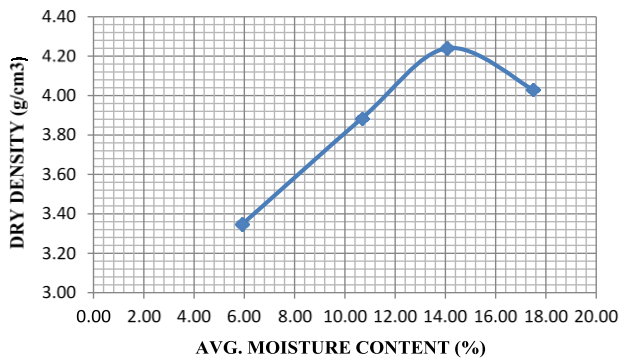


Figure 11. Dry Density Against Average Moisture Content

Test Result of Tension Parallel to the Grain of Apa Timber

Results of Tensile strength parallel to grain of Apa timber are presented in Table 5. The result of mean tensile strength at yield is 68.339 N/mm²

Table 5. Tensile Strength Test Result for Apa Timber

S/N	Stress (σ) at Yield (N/mm ²)	Strain (ε) at Yield (%)	Young's Modulus (N/mm ²)	Energy to Yield (N.m)
Mean	68.339	1.887	4321.217	1.005

Results of Compressive Strength for Stabilized Lateritic Soil Cubes

The results of compressive for stabilized lateritic soil cubes are presented in Table 6, and Figure 12 shows the stress-strain curve. A linear increase in stress with corresponding increase in strain was observed. The mean compressive strength at yield point was 2.013 N/mm². The ultimate strain was 0.047. Beyond the peak point, there was a rapid drop in stress-strain. However, further research should be carried out to better understand fracture mechanics of the lateritic specimens.

Table 6. Compressive Test Results for Stabilized Lateritic Soil Cubes

S/N	Stress (σ) at Yield (N/mm ²)	Strain (ε) at Yield (%)	Young's Modulus (N/mm ²)	Energy to Yield (N.m)
Mean	2.013	4.663	94.733	106.181

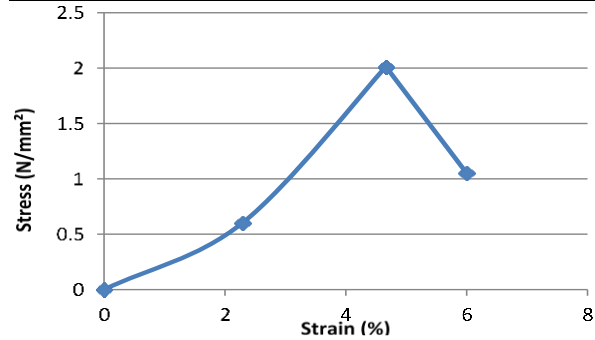


Figure 12. Stress-strain Curve for Stabilized Lateritic Soil Cubes

Results of Flexural Strength for Unreinforced, Steel, and Apa Reinforced Lateritic Soil Beams

The experimental load results of the three-point flexural test on the unreinforced and steel reinforced lateritic soil beams are presented in Table 7. The failure load for the unreinforced lateritic beam was 873.6N, while for the steel reinforced lateritic beam; the failure load was 3329.4 N. The flexural strength for the unreinforced lateritic beam was 0.194N/mm², while for the steel reinforced lateritic beam; the flexural strength was 0.740 N/mm². The crack pattern of the steel reinforced lateritic soil beam started from both supports up to the point of application of load in a diagonal direction, while the unreinforced lateritic beam failed utterly. This showed that steel improved the flexural strength of the beams. The value of the flexural strength (0.194 N/mm²) for the unreinforced lateritic beam was less than 0.79 N/mm² obtained for un reinforced lateritic beam with 10% cement content as reported by Sackey [16].

The experimental load results of the three-point flexural test on the Apa reinforced lateritic soil beams are presented in Table 8. From the failure loads, it was observed that the higher the percentage of Apa timber, the higher the load required to rupture the beams. While the flexural strength also increased from 0.364 N/mm² to 0.763 N/mm² with an increase in percentage area of Apa reinforcement. The flexural strength of lateritic soil beam with 4% area of Apa reinforcement (0.763 N/mm²) was a little bit higher than the steel reinforced lateritic soil beam (0.740 N/mm²), and was less than 0.85 N/mm² obtained for polypropylene reinforced lateritic beams with 10% cement content as reported by Sackey [16]. The failure pattern is the same as the steel reinforced specimen. From the failure mode, it was observed that the number of cracks and deflection of the steel reinforced lateritic soil beam increased as a result of

steel having a higher modulus of elasticity compared to timber. The flexural load-deflection curve of control beams and Apa reinforced lateritic soil beams are presented in Figure 13. As presented in Figure 13, the Mode of failure of the lateritic soil beam (ALB2) containing 2 % area of Apa differed from the others specimens in terms of its failure rate; the failure rate results obtained for this particular specimen (ALB2) may have being faulty due to an experimental or sampling error during batching process.

Table 7. Flexural Test Result for Unreinforced and Steel Reinforced Lateritic Soil Beams

Label	Specimen S/N	Density (kg/m ³)	Failure load (N)	Deflection at peak (mm)	Flexural Strength (N/mm ²)
ULB	Mean	1806.039	873.600	3.754	0.194
SLB	Mean	1942.454	3329.400	12.205	0.740

Table 8. Flexural Test Result for Apa (*Afzeliabipindensis*) Reinforced Lateritic Soil Beam

Label	Specimen S/N	Density (kg/m ³)	Failure load (N)	Deflection at peak (mm)	Flexural Strength (N/mm ²)
ALB1	Mean	1817.086	1636.200	12.189	0.364
ALB2	Mean	1884.907	2181.400	5.999	0.485
ALB3	Mean	1943.218	2479.400	9.803	0.551
ALB4	Mean	1866.112	3435.000	11.822	0.763

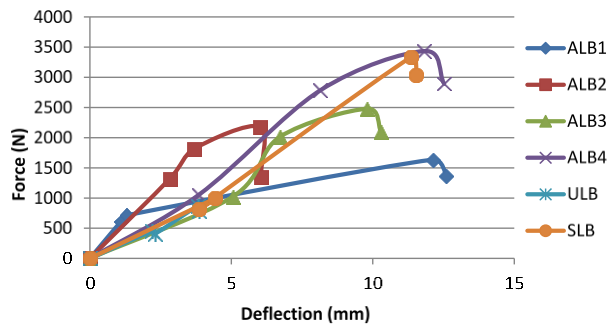


Figure 13. Load-deflection Curve for the Unreinforced, Steel, and Apa Reinforced Soil Beams

Modelling of Test Beams with ANSYS 15.0

A typical representation of the flexural strength of the unreinforced, steel reinforced, and Apa reinforced lateritic soil beams obtained using ANSYS 15.0 software is presented in Figure 14.

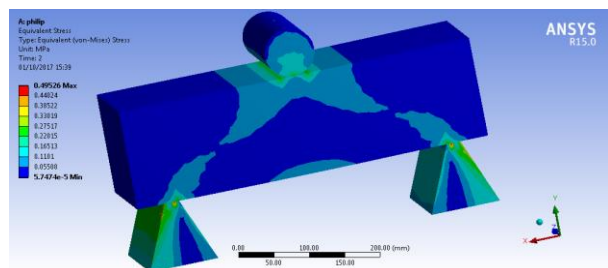


Figure 14. Typical (von - mises) Stress for a Modelled Beam

These results from the analysis performed using ANSYS 15 also followed the same trend with the laboratory results which showed that the higher the percentage area of Apa reinforcements used in Lateritic soil beams, the higher the flexural strength, and at percentage area of 4, the flexural strength of the Apa reinforced lateritic soil beams was slightly higher than the steel reinforced lateritic soil beams at 0.8 %. The ANSYS flexural strengths were compared with experimental flexural strengths in Table 9. The results value obtained from the experimental flexural strength test can be multiplied with the average factor (FA/FE) of 2.63 to obtain ANSYS flexural strength, since the pattern of flexural strength development between the ANSYS results and experimental result are in tandem for all the various specimen samples (ALB1, ALB2, ALB3, ALB4).

Table 9. Comparison between ANSYS Flexural Strengths and Experimental Flexural Strengths

Experiment al Flexural Strength (N/mm ²) (F _E)	ANSYS Flexural Strength (N/mm ²) (F _A)	$\frac{F_A}{F_E}$
0.364	0.931	2.56
0.485	1.248	2.57
0.551	1.463	2.66
0.763	2.094	2.74
Average CONTROL BEAMS		2.63
0.194	0.495	2.55
0.740	2.068	2.79

Conclusion

The following conclusion were deduced from the study:

1. The flexural strength of the Apa reinforced lateritic soil beams (ALB) at 4 % is 0.763 N/mm² with corresponding load capacity of 3.435 kN which is higher than the steel reinforced lateritic soil beams (SLB) of 0.740 N/mm² with corresponding load capacity of 3.329 kN. BS 8110-1 [17] requires that area of reinforcement for beams should not

exceed 4%. This report shows that Apa timber at 4 percent area can be used as a reinforcing material in earth.

2. The higher the percentage area of Apa reinforcements used in Lateritic soil beams, the higher the load-bearing capacity.

Recommendation

Further research should be carried out on:

1. Determining the flexural strength behaviour of Apa timber reinforced lateritic soil beam beyond a beam length of 500 mm.
2. Determining the swelling and shrinkage characteristic of Apa timber and how to improve the bond between the timber and earth.
3. Bond linearity and fatigue analysis of Apa reinforced lateritic soil beam.
4. Study of fire resistance capacity of Apa reinforced lateritic soil beam.

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