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Load carrying capacity of stabilized lateritic soil beam reinforced with Ayin timber

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ABSTRACT

This paper presents the laboratory tests' results to investigate the load-carrying capacity of stabilized lateritic soil beams reinforced with Ayin timber. Twelve (12) specimens incorporating 10% cement as a stabilizer were prepared. For each specimen class, reinforcement was varied using three classes each of 8mm Ayin timber, 12mm Ayin timber, 16mm Ayin timber, and three classes of unreinforced lateritic beams. The result of this analysis was compared to see if there is a difference in properties of tension, compression, strength, applied load, deflection, and crack width.

KEYWORDS

Lateritic soil, Cement, Ayin timber, Applied load, Crack width, Strength.

1. INTRODUCTION

Openings in mud buildings such as window and door lintels are usually framed and supported by exposed timber as shown in Figure 1, which may fail due to environmental effects like exposure of timber to water, fire, weather conditions, attack of borers, and termites. The exposed timber is prone to early distortion and experiences a significant loss of strength over some time. Lateritic soil stabilized with cement and reinforced with Ayin timbers is now seen as a possible replacement for the initial design.

Figure 1: Lintel supported with an exposed timber

The Nigerian Industrial Standard (NIS: 87: 2004) recommends a minimum of 2.5 N/mm^2 and 1.8 N/mm^2 for load-bearing and non-load-bearing blocks respectively. According to (Osunade and Lasisi, 1990), the use of laterite to replace the sand component of concrete either wholly or partially, is becoming widespread among the low-income earners for building construction. 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 the lack of adequate data needed in the analysis and design of structures built of lateritic soils.

Bawa (1957) has stated: "The suitability of any type of laterite soil deposit can usually be judged by a systematic study of the different engineering characteristics of the soil, relevant to a given structure." Based on this statement it can be generally said that the performance of any soil type under given traffic and environmental conditions depends on many factors. Much of the literature discussing the performance of lateritic soils as materials of construction fails to make any reference to:

1. The engineering characteristics of the soils, their selection and method of placement under pavements;
2. The nature, pattern, weight, and intensity of existing and predicted traffic;
3. Climatic and drainage conditions.

Laterite is a reddish, clayey material that significantly expands when wet and contracts when dry. It forms topsoil in some tropical and subtropical regions and is often used in construction (Sabat, 2012). In another report (Kasthurba, Krishna, & Venkat, 2014), laterite was characterized as a type of soil found in hot, humid tropical regions, formed from weathered rocks under conditions of high temperature and rainfall, with alternating wet and dry periods. However, lateritic soils typically have low bearing capacity and strength due to their high clay content (Amu, Ogunniyi, & Oladeji, 2016). When lateritic soil contains a substantial amount of clay, its stability and strength under load are compromised in the presence of moisture (Alhassan, 2008). This plasticity can lead to fractures and damage to pavements, roadways, and building foundations, causing frequent pavement failures on Nigerian highways (Jegeda, 2000). To address these issues, researchers have sought locally sourced, cost-effective materials to enhance soil properties (Bello, Ige, & Ayodele, 2015; Jegeda, 2000). Soil stabilization, a process that enhances soil strength and durability for construction, is one such method (Bello et al., 2015). The use of waste materials in construction has been extensively studied to reduce costs and conserve biodiversity (Awoyera, Akinmusuru, & Ndambuki, 2016). The growing trend of using ceramic waste as an aggregate material in construction has shown that ceramic-based lateritic concrete performs well compared to conventional concrete, offering the added benefit of waste reduction (Awoyera et al., 2016). A significant drawback of these mud houses is their vulnerability to destruction from recurrent floods that accompany the annual rainy seasons. For instance, in Kano, North West Nigeria, a few hours of rain on August 8, 2016, led to the collapse of 5300 mud houses due to the resulting floods (Odogwu, 2016). This study investigates the optimal engineering properties of stabilized lateritic soil with varying ratios of cassava peel ash for lintel members.

1.1. Modulus of rupture

Beam specimens of size 300x100x100 mm were moulded and tested for modulus of rupture. A total of twelve beam specimens were cast and tested. Each specimen was made by filling each mould in three layers. Each layer was compacted manually by using a 25 mm diameter rod to deliver 150 strokes on the layer. For the flexural strength of the beam specimens, the "third-point" loading method was used (Fig. 2).

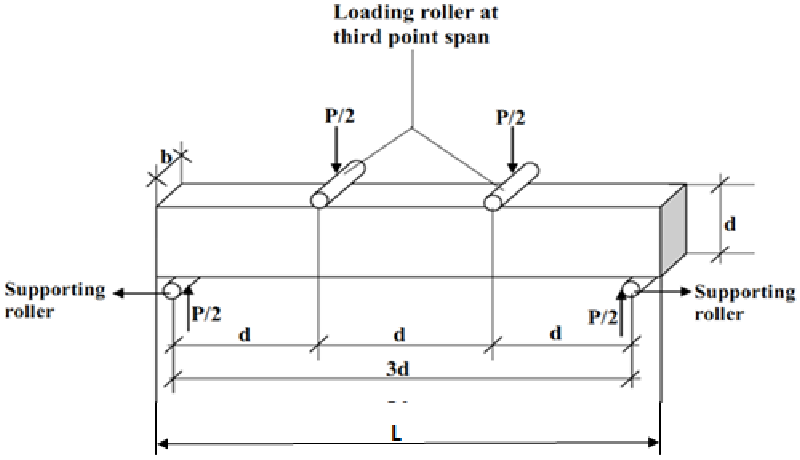

Figure 2: Third - point loading arrangement

If a fracture occurs within the central one–third of the beam, the modulus of rupture is calculated based on ordinary elastic theory, and therefore equal to PL/bd^2 (Neville A.M, 1981).

$$f_r = \frac{PL}{bd^2} \tag{1}$$

Where, F_r – modulus of rupture [N/mm^2], ρ – maximum total load on the beam [N], L – length of the beam specimen [mm], d – depth of the beam [mm], b – width of the beam [mm].

If, however, fracture occurs outside the load points, say at a distance "a" from the near support, "a" is measured along the center line of the tension surface of the beam, then the modulus of rupture is given by 3Pa/bd^2

$$f_r = \frac{3Pa}{bd^2} \tag{2}$$

1.2. Ultimate loading capacity for Ayin timber

To accomplish the ultimate loading capacity for the Ayin beam (Jimoh A.A, 2008) the axial stress-strain equations of tension and compression were applied,

$$\sigma_T = 1.00\times10^6\,\varepsilon_T^3 - 1.54\times10^5\,\varepsilon_T^2 + 7.56\times10^3\,\varepsilon_T \tag{3}$$

$$\sigma_C = -3.00\times10^6\,\varepsilon_C^3 + 1.01\times10^5\,\varepsilon_C^2 + 1.18\times10^3\,\varepsilon_C \tag{4}$$

where σ_T, σ_c, ε_T and ε_C denote axial tensile stress, axial compressive stress and corresponding strains. The experimental values of ultimate tensile stress (σ_{ET}=128 N/mm^2) and ultimate compressive stress (σ_{EC}=54.35 N/mm^2) were used to validate the theoretical parameters calculated by the design equations.

2. RESEARCH METHODOLOGY

2.1. Collection of materials

The laterite samples were collected at a depth of 0.6 to 1.0 m within the campus, University of Ilorin, Ilorin, Kwara state, using the method of disturbed sampling. The materials needed for this research work include:

- Laterites
- Stabilizer in the form of Portland cement
- Reinforcement in form of Ayin timber of size 8, 12, and 16mm
- Water for mixing and workability
- Stirrup in the form of a flexible wooden rod
- Planks for shuttering/form works

2.2. Testing of materials

2.2.1. Compressive strength test of stabilized laterite

Compressive strength remains the most important property of structural concrete, from an engineering point of view. In most structural applications concrete is employed primarily to resist compressive stresses. In cases where strength in tension or shear is of primary importance, compressive strength is frequently used as a measure of these properties.

Figure 3: Compressive testing machine

2.2.2. Moisture content of Ayin timber

1. Cut the sample into smaller pieces and measure their original weight;
2. Dry the sample in the oven for 24 hours at 110°C;
3. Allow the sample to cool for five minutes then weigh;
4. Oven drying of the sample is repeated daily until a constant weight is finally obtained;
5. The difference between the original weight and the final weight is the weight of water.

The moisture content of the sample is calculated using the following equation:

$$W[\%] = \frac{A-B}{B} \times 100\% \tag{5}$$

Where, W – Percentage of moisture in the sample, A – Weight of wet sample [g], and B – Weight of dry sample [g]

2.2.3. Compressive strength of Ayin timber

A total of 5 specimens with dimensions 100x25x25 mm were prepared for testing of Ayin wood in compression parallel to the grain (Fig. 3). A test speed of 1.3 mm/min was used for compression test according to (BS 373, 1957).

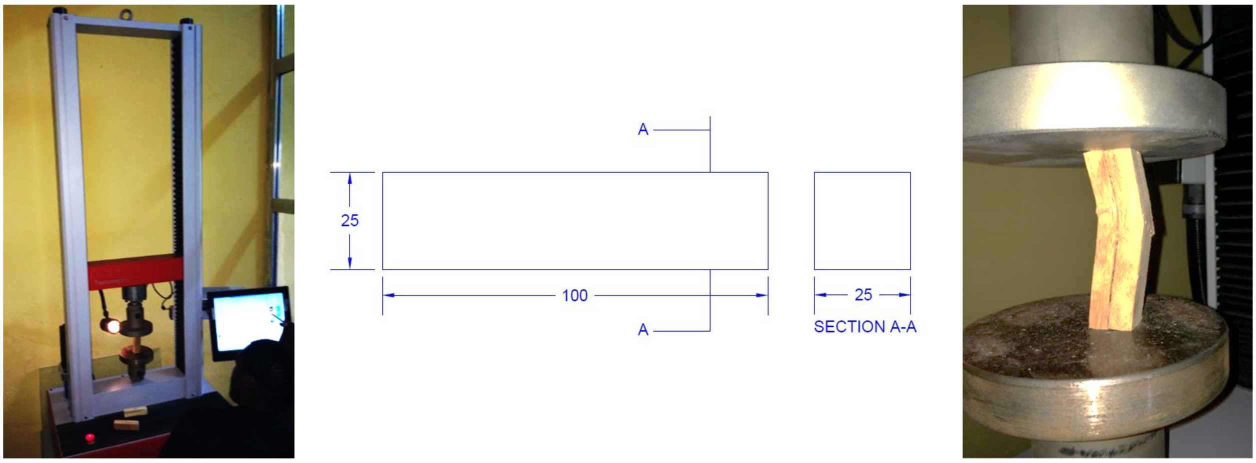

Figure 4: Universal testing machine under compressive strength test with specimen for Ayin timber

2.2.4. Tensile strength of Ayin timber

A total of 5 specimens with gauge lengths of 55mm and an overall length of 200mm were tested for Ayin wood in tension. (Fig.2.3). A test speed of 10mm/min was used for the tensile test.

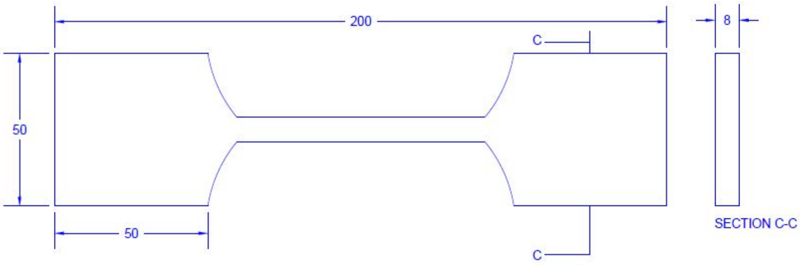

Figure 5: Tensile strength test specimen for Ayin timber

Figure 6: Universal testing machine under tensile test and data

2.3. Preparation of testing specimens (LATB)

Three samples each of plane, 8mm, 12mm, and 16mm reinforced Ayin timber rod beam specimens were cast in a mould of 300 x 100 x 100mm. The Ayin timber rod was placed in the mold first before placing the already mixed materials.

a) b) c)

Figure 7: a) Binder, b) Ayin rod, c) Formwork

a) b) c)

Figure 8: a) Planks for shuttering/form works, b) Stirrup in the form of a flexible wooden rod, c) Specimen samples

2.4. Testing of LATB

Beam specimens of size 300 x 100 X 100 mm were molded and tested for modulus of rupture. The making, curing, and testing methods were followed (BS 1881-118:1983). Twelve (12) beam specimens, varying in the Ayin timber rod were cast and tested. Each specimen was made by filling each mold in three layers. Each layer was compacted manually by using a 25mm diameter rod to deliver 150 strokes on the layer. For the modulus of rupture of the beam specimens, the "third-point" loading method was used and the specimens were air-cured to standard curing age of 28 days. The flexural strength formula is given as:

$$F_r = \frac{PL}{bd^2} \tag{6}$$

Figure 9: Modulus rupture test and ruptured samples

3. RESULTS AND DISCUSSION

3.1. Compressive strength test

The compressive strength of concrete is the most common performance measure used by the engineer in designing and other structures. The compressive strength is measured by breaking concrete cubes or cylindrical concrete specimens in a **Compression Testing Machine**.

$$Compressive\,Strength = \frac{Crushing\,Load}{Effective\,Area}\left[N/mm^2\right] \tag{3}$$

Where the effective area is 150mm x 150mm = 22 500mm^2

Table 1: Results of compressive strength test

0% cement stabilizer

Sample label	A_1	A_2	A_3
Age	7 days	14 days	28 days
Crushing load [N]	13 050	16 200	23 175
Compressive strength [N/mm^2]	0.58	0.72	1.03

5% cement stabilizer

Sample label	B_1	B_2	B_3
Age	7 days	14 days	28 days
Crushing load [N]	13 725	17 550	51 750
Compressive strength [N/mm^2]	0.61	0.78	2.3

10% cement stabilizer

Sample label	C_1	C_2	C_3
Age	7 days	14 days	28 days
Crushing load [N]	18 450	40 950	78 525
Compressive strength [N/mm^2]	0.82	1.82	3.49

20% cement stabilizer

Sample label	D_1	D_2	D_3
Age	7 days	14 days	28 days
Crushing load [N]	25 200	49 725	87 300
Compressive strength [N/mm^2]	1.12	2.21	3.88

40% cement stabilizer

Sample label	E_1	E_2	E_3
Age	7 days	14 days	28 days
Crushing load [N]	26 325	45 675	80 775
Compressive strength [N/mm^2]	1.17	2.03	3.59

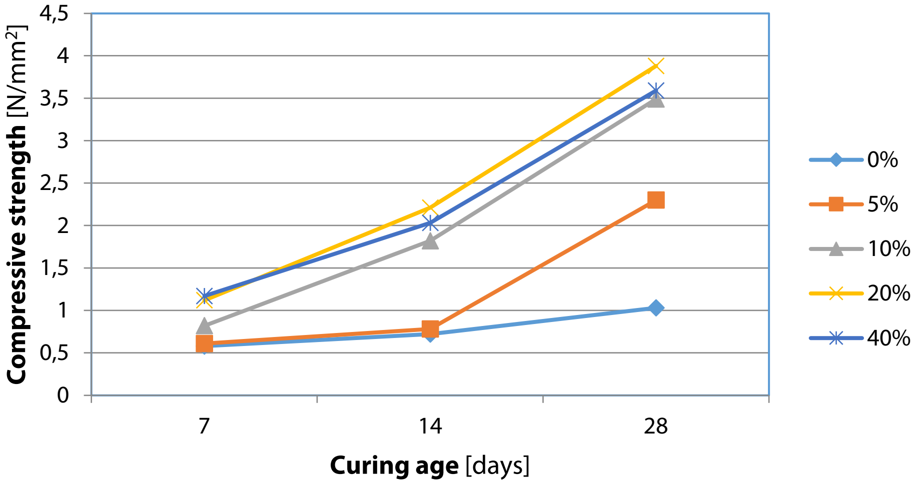

Figure 10: Compressive strength – curing age relationship

3.2. Test on Ayin timber

3.2.1. Moisture content test

The amount of moisture present in wood varies appreciably in different, but the dry weight of wood substance in a given sample is constant. Hence, it is usual to express the variable moisture content as a percentage of the constant dry weight of the sample (Feirer John 2000). The dimension of the sample is 50mm x 25mm x 25mm and was oven-dried at 105^{0}C.

$$moisture\,content\,(\%) = \frac{weight\ of\ water\ present}{dry\,weight\ of\ sample}\,x\,100 \tag{4}$$

$$weight\ of\ water\ present = original\,wt - constant\,wt \tag{5}$$

Table 2: Moisture content of Ayin timber determination

Sample label.	A	B	C	D	E
Original weight [g]	31	30	32	34	33
Weight after 24 hours [g]	26	26	27	29	28
Weight after 48 hours [g]	22	23	23	24	24
Weight after 72 hours [g]	22	22	23	24	23
Weight after 96 hours [g]	22	22	23	24	23
Weight of water, w [g]	9	8	9	10	10
Moisture content, w [%]	40.91	36.36	39.13	41.67	43.48

The moisture content of the Ayin timber $= \dfrac{40.91 + 36.36 + 39.13 + 41.67 + 43.48}{5} = 40.31\%$

3.2.2. Compressive strength test

The compressive and tensile test data were determined by the Testometric material testing machine as seen in Fig. 2.4 above. The data derived are summarized below:

Table 3: Compressive strength results parallel to the grain of Ayin timber (thickness = 25mm and width = 25mm)

Test No.	**Stress @ Peak** [N/mm^2]	**Stress @ Yield** [N/mm^2]	**Force @ Peak** [N]	**Def. @ Peak** [mm]	**Stress @ 0.000 mm** [N/mm^2]	**Time to Failure** [s]	**Young Mod.** [N/mm^2]	**Def. @ Break** [mm]	**Energy to Peak** [N.m]
1	24.018	24.018	15011.000	4.759	0.002	44.206	1073.938	7.371	26.135
2	19.733	19.733	12333.000	3.888	0.002	34.689	875.015	5.785	18.883

Test No.	Stress @ Peak [N/mm^2]	Stress @ Yield [N/mm^2]	Force @ Peak [N]	Def. @ Peak [mm]	Stress @ 0.000 mm [N/mm^2]	Time to Failure [s]	Young Mod. [N/mm^2]	Def. @ Break [mm]	Energy to Peak [N.m]
3	26.880	26.880	16800.000	4.188	0.002	31.023	1357.483	5.174	31.293
4	27.619	27.619	17262.000	3.460	0.002	31.974	1414.213	5.331	23.503
5	26.992	26.992	16870.000	4.111	0.002	39.330	1446.280	6.553	32.228
Min	19.733	19.733	12333.000	3.460	0.002	31.023	875.015	5.174	18.883
Mean	25.048	25.048	15655.200	4.081	0.002	36.244	1233.386	6.043	26.408
Max	27.619	27.619	17262.000	4.759	0.002	44.206	1446.280	7.371	32.228
S.D.	3.281	3.281	2050.617	0.473	0.000	5.496	248.634	0.915	5.543
COV	13.099	13.099	13.099	11.585	0.000	15.165	20.159	15.149	20.988
L. C. L.	20.974	20.974	13109.023	3.494	0.002	29.420	924.666	4.906	19.526
U. C. L.	29.122	29.122	18201.377	4.668	0.002	43.069	1542.106	7.180	33.291

3.2.3. Tensile strength test

Table 4: Tensile strength test result of Ayin timber

Test No.	Width [mm]	Thick-ness [mm]	Force @ Peak [N]	Stress @ Peak [N/mm^2]	Energy to Peak [N.m]	Elong. @ peak [mm]	Time to Failure [s]	Strain @ break [%]	Youngs Mod. [N/mm^2]
1	10.000	2.000	1621.100	81.055	1.485	1.491	89.937	2.726	4918.697
2	10.900	6.400	6081.000	87.170	9.781	2.817	169.407	5.139	2740.690
3	10.600	7.200	4251.600	55.708	6.788	2.726	163.816	4.970	1885.115
4	9.300	6.600	5488.000	89.410	10.776	3.632	217.880	6.608	1288.665
5	10.900	6.400	9025.000	129.372	35.739	7.370	465.300	14.114	917.718
Min	9.300	2.000	1621.100	55.708	1.485	1.491	89.937	2.726	917.718
Mean	10.340	5.720	5293.340	88.543	12.914	3.607	221.268	6.711	2350.177
Max	10.900	7.200	9025.000	129.372	35.739	7.370	465.300	14.114	4918.697
S.D.	0.688	2.105	2699.729	26.476	13.262	2.238	143.876	4.365	1592.547
COV	6.651	36.805	51.002	29.902	102.696	62.051	65.024	65.033	67.763
L. C. L.	9.486	3.106	1941.238	55.669	-3.553	0.828	42.625	1.292	372.801
U. C. L.	11.194	8.334	8645.442	121.417	29.381	6.386	399.911	12.131	4327.553

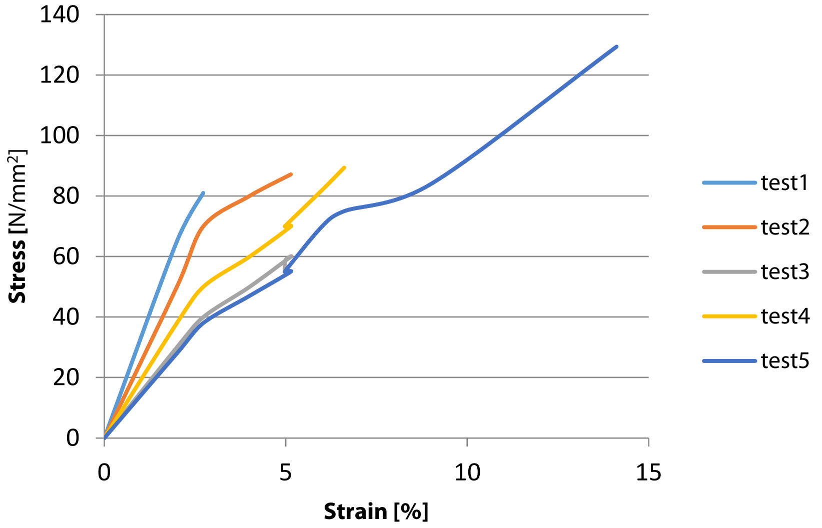

Figure 11: Stress–strain chart of Ayin timber

3.3. Characteristic strength of Ayin timber

The characteristic value is the value below which not more than 5% of all possible results fall, and is given by:

$$f_c = f_m - 1.64S \tag{6}$$

Where, f_c – characteristic strength, f_m – mean strength, S – standard deviation

Hence, characteristic compressive strength of parallel Ayin timber is equal to

$$f_c = 25.048 - 1.64(3.281) = 19.667 \text{ [N/mm}^2\text{]} \tag{7}$$

Characteristic compressive strength of perpendicular Ayin timber

$$f_c = 7.088 - 1.64(0.856) = 5.684 \text{ [N/mm}^2\text{]} \tag{8}$$

Characteristic tensile strength of Ayin timber

$$f_c = 88.543 - 1.64(26.476) = 45.122 \text{ [N/mm}^2\text{]} \tag{9}$$

3.4. Modulus of rupture for LATB

The modulus of rupture for LATB, 300 x 100 x100mm is noted for twelve 12 different specimens at 28 days air-curing age. The modulus of rupture is calculated based on ordinary elastic theory, and therefore equal to PL/bd^2 (Neville A.M, 1981).

$$f_r = \frac{PL}{bd^2} \tag{10}$$

Where, F_r – modulus of rupture [N/mm^2], ρ - maximum total load on the beam [N], L – length of the beam specimen [mm], d – depth of the beam [mm], b – width of the beam [mm]

Table 5: Modulus of rupture for plane specimen (laterised beam)

Specimen no.	**Failure load** [N]	**Modulus of rupture** [N/mm^2]
A_1	78 500	7.850
A_2	78 000	7.800
A_3	78 550	7.855

Hence, the modulus of rupture for plane specimen = $\frac{7.850 + 7.800 + 7.855}{3} = 7.835$ [N/mm^2]

Table 6: Modulus of rupture for specimen reinforced with 8mm Ayin timber rod

Specimen no.	**Failure load** [N]	**Modulus of rupture** [N/mm^2]
A_1	81 250	8.125
A_2	81 100	8.110
A_3	81 750	8.175

Hence, the modulus of rupture for plane specimen = $\frac{8.125+8.110 + 8.175}{3} = 8.137$ [N/mm^2]

Table 7: Modulus of rupture for specimen reinforced with 12mm Ayin timber rod

Specimen no.	**Failure load** [N]	**Modulus of rupture** [N/mm^2]
A_1	84 300	8.430
A_2	84 250	8.425
A_3	84 750	8.475

Hence, the modulus of rupture for plane specimen = $\frac{8.430+8.425+8.475}{3}=8.443$ [N/mm^2]

Table 8: Modulus of rupture for specimen reinforced with 16mm Ayin timber rod

Specimen no.	Failure load [N]	Modulus of rupture [N/mm^2]
A_1	84 800	8.480
A_2	84 950	8.495
A_3	85 050	8.505

Hence, the modulus of rupture for plane specimen = $\frac{8.480+8.495+8.505}{3}=8.493$ [N/mm^2]

4. CONCLUSION AND RECOMMENDATION

The first noticeable crack width in each of the reinforced beam specimens was rounded up to 1 mm, although a crack width of less than 1 mm is practically possible. The representative maximum crack width was found to be 2 mm. The measured loadings at the initial and final cracks indicated that, generally, as the number of reinforcement bars increases, the beam's maximum bearable load also increases, with some exceptions. This is expected in an ideal situation for a group of beams with the same make and condition. Additionally, the reasonable increase in the beam's maximum bearable load as the proportion of laterite in the mix increases suggested the positive effect of laterite on the ultimate strength of the beam specimens with the same reinforcement. The presence of good-quality laterite and Ayin timber in the making of LATB would not only maintain the ultimate strength of the beam but could also improve some of its mechanical properties. Variation in the reinforcement content of laterised beams will affect their performance, increasing it up to a threshold value. Finally, the laterised-Ayin timber beam specimens compared well with plain beam specimens at 10% cement content, demonstrating the optimum performance of laterised beams as structural members of a building. The timber supporting the lintels should not be exposed.

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