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СЦЕПЛЕНИЕ МЕЖДУ АРМИРОВКА И БЕТОН, В КОЙТО Е ВЛОЖЕН ЛАТЕРИТ

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BOND CHARACTERISTICS OF LATERIZED CONCRETE

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Abstract:
The research investigation was carried out to determine the bond characteristics of Laterized Concrete. Sixty RILEM test specimens with 16 mm and 20 mm diameter high yield bars were cast, cured and tested. Thirty specimens were cast with each bar diameter, with ten samples each with 0 %, 15 % and 25 % of sand substituted with laterite. Eighteen 150 mm cubes were also cast to monitor the strength of concrete with six samples for each percentage, 0 %, 15 % and 25 % of sharp sand replaced with laterite. The samples were cured for 28 days and tested for compressive strength and bond by push-in respectively. The cube strength was found to reduce by 6.94 % and increased by 14.36 % at 15 % and 25 % of sand replacement with laterite respectively. Bond resistance of laterized concrete was found to decrease by 4.76 %, 0.43 % and 33.52 %, 14.71 % at 15 % and 25 % of sand replacement with laterite for 16 mm and 20 mm diameter bars respectively.

Keywords:
RILEM, High Yield Bars, Sand, Cube Strength.

1. INTRODUCTION

A major factor affecting the construction industry in developing countries is the cost of building materials. As prices increase sharply, there is a growing need to relate research to local materials as alternatives for the construction of functional but low-cost dwellings in the urban and rural areas of Nigeria. One of such local material that is being researched into is laterized concrete. Burnt brick made with lateritic soil has been one of the major building materials in villages and rural areas of Nigeria for a long time. The main reason is because it is readily available and the cost of production is low.

Lateritic soil has other advantages which make it a very good and appropriate material for construction, especially for the construction of rural structures. These advantages include the non- requirement of specialised or skilled labour to produce laterized concrete and its use in the construction of structures.

This study is part of the continuing effort to investigate the properties of laterized concrete with a view to generating data, improving kNowledge and engineering practice on bond strength

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of laterized concrete. A lot of research investigations had been carried out on the properties of laterized concrete but the bond properties are yet to be comprehensively investigated. Attempt to do so is desirable and worthwhile.

1.1. Significance

Bond behaviour and resistance of laterized concrete with varying percentage substitution of sharp sand with laterite were identified.

1.2. Brief Review of Previous work on Laterized Concrete

The shear resistance of laterized concrete beams without shear reinforcement was investigated in [1]. The results show that the ultimate shearing stress of laterized concrete increased with the increase in the amount of longitudinal reinforcement. The presence of laterite in concrete improved its post cracking ability, stiffness and superior crack control and serviceability condition due to high ductility.

The effect of mix proportion and reinforcement size on the anchorage bond stress of larerized concrete was investigated in [2]. The result showed that both the mix proportion and the size of reinforcement have a significant effect on the anchorage bond stress of laterized concrete specimen. The richer in terms of cement content of the mix proportion, the higher the anchorage bond stress of laterized concrete.

A result on comparative study of long term deformation of laterized and normal concrete short columns under sustained loading was reported in [3]. The results showed there was not much variation between the creep deformation of laterized and normal concrete short columns. However, the laterized concrete specimen, either sealed or unsealed show more creep and shrinkage deformation when compared to corresponding normal concrete.

Some characteristics of concrete as partial or full replacement of sand aggregate were investigated in [4]. It was opined that concrete with up to 40 % replacement level of sand with laterite could attain design strength of 20 N/mm^2. Hence it was concluded that it is possible to use laterite as a replacement for sand in concrete up to 40 % replacement level.

A comparative study of the strength properties of unreinforced and fibre reinforced normal and laterized concretes was reported in [5]. The results showed a consistent trend of increase in values of strength with age in the specimens. A proportion of 45 % laterite content as replacement of sharp sand in concrete produced the highest compressive strength.

Influence of weather on the performance of laterized concrete was studied in [6]. The weathering characteristics of laterized concrete with the laterite – granite fine ratio as a factor. The simulation of weathering condition (wet and dry) was carried out by conditioning laterized concrete cubes to varying temperature and alternate wetting and drying. The results of the investigation showed that the compressive strength of laterized concrete with laterite-granite fine ratio variation decreases when subjected to alternate wetting and drying. It was concluded that laterized concrete with a laterite-granite fine ratio of between 40 % and 60 % conditioned to a temperature range of 75-125^{o}C attained a compressive strength up to 22.52 N/mm^2.

The residual compressive strength of laterized concrete subjected elevated temperature was investigated in [7]. The investigation analysis of variance test showed that exposure to temperature, cooling regime and their interaction have a significant influence on the compressive strength of laterized concrete samples. When subjected to the investigated temperature specimens experienced strength losses that increased with the temperature. The study further revealed that air cooled concrete specimens maintained higher residual strength values than water-cooled specimens.

The effect of short steel fibre reinforcement on laterized concrete was studied in [8]. It was found that the density and cube strength of fibre reinforced laterized concrete increases as the fibre content of the concrete is increased. 1.5 % fibre content by volume was considered as optimum value of fibre in laterized concrete. For non-critical construction, the inclusion of 1 %

fibre by volume of concrete can effectively be used as replacement for normal shear reinforcement in laterized concrete columns. The ductility of fibre reinforced laterized concrete increases as the percentage of fibre content was increased and the ductility reaches its maximum at about 1 % fibre content. Samples with 0.0 % fibre showed little or no deflection capacity.

A lot of research investigations have been carried out on laterized concrete but the bond characteristics of laterized concrete are yet to be comprehensively investigated. Attempt to investigate the bond resistance of laterized concrete is worthwhile and desirable.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

The concrete used for this investigation was mixed in ratio 1:2:4 (cement, sand and granite). In the fine aggregate (sand), there was 0 %, 15 % and 25 % content of laterite for each of the percentages while the water - cement ratio was 0.45, all the constituents were batched by weight. The mixing machine was powered on while the constituents were poured in the order of water, sand and granite. After thorough mixing of the constituents, the concrete was poured into the RILEM moulds.

2.1. Reinforcement

The reinforcements were wire brushed and cut into lengths determined by the diameter of each steel reinforcing bar. For 16 mm diameter bars, the total length of reinforcement was meant to be 480 mm (i.e.160 mm within the cube, 50 mm for the shorter end that resist push and 270 mm for the longer end where push was applied) while for 20 mm diameter bars, the total length was meant to be 600 mm but due to the type of available machine “Technotest Compressive Machine”, for 16 mm diameter bars, the total length of reinforcement was 380 mm long, while for 20 mm diameter bars the total length of reinforcement was 500 mm long. The encased region of the reinforcement as reco mmended by RILEM is 10D where D is the diameter of the bar. Half of this length (5D) was wrapped up with polythene while the other half was left bare (unwrapped) in order to provide adhension between the concrete and the reinforcement.

2.2. Aggregates

Three types of aggregates were used in the work, crush granite, fine and laterite aggregates with the nominal granite size of 10 mm. The fine aggregate (sand) was air dry to ensure the water -cement ratio was not affected. The sieve analysis was carried out to determine the aggregate passing 600 mm sieve. The coarse aggregate was air dried to ensure that the water – cement ratio was not affected. The crushed granite is grey in colour, irregular shape with sharp edges and rough surface while the laterite is dark red in colour, irregular shape but with round edges and relatively smooth surface. The lateritic soil was brought from Ikenne in Ogun State, Nigeria. The lateritic soil was added in various percentages (15 % and 25 %) to the fine aggregate (sharp sand) to determine the compressive strength and bond resistance of laterized concrete. Table 1, 2 and 3.

Table 1. Sharp sand size distribution test

Aperture size (mm)	Weight retained (W_1 in gram)	Percentage (%) retained (W_2 in gram)	Percentage (%) passing (W_3 in gram)
2.360	11.0	5.50	94.75
1.180	20.2	10.10	84.4
0.600	40.3	20.15	64.25
0.425	30.5	15.25	49.00
0.300	20.5	10.25	38.75
0.120	21.5	10.75	28.00
0.150	16.0	8.00	20.00
0.750μm	10.0	5.00	15.00
Dust	-	15.00	0.00

Table 2. Lateritic sand size distribution test

Aperture size (mm)	Weight retained (W_1 in gram)	Percentage (%) retained (W_2 in gram)	Percentage (%) passing (W_3 in gram)
2.360	3.0	1.50	98.5
1.180	8.0	4.00	94.5
0.600	27.80	13.50	81.0
0.425	20.00	10.00	71.0
0.300	14.00	7.00	64.0
0.120	16.00	8.00	56.0
0.150	21.00	10.50	45.5
0.750µm	20.00	10.00	35.5
Dust	-	35.5	0.00

Table 3. Granite size distribution test

Aperture size (mm)	Weight retained (W_1 in gram)	Percentage (%) retained (W_2 in gram)	Percentage (%) passing (W_3 in gram)
25.40	0.00	0.00	100.00
19.05	100.00	10.00	90.00
9.52	400.00	40.00	50.00
6.35	350.00	35.00	15.00
4.76	150.00	15.00	0.00

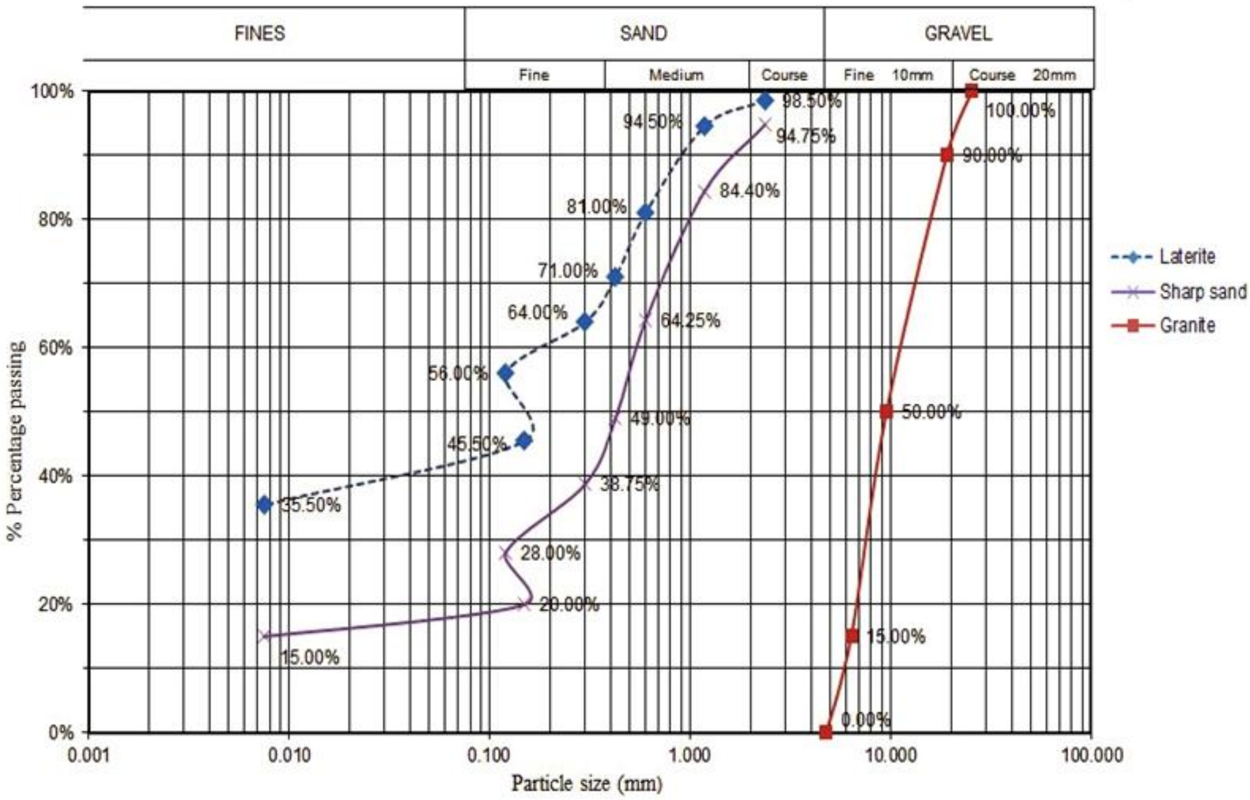

Figure 1. Grain size analysis for fine (lateritic and sharp sand) and coarse aggregate.

2.3. Tensile Strength Test of Reinforcement

Tensile test was carried out on steel reinforcement used in the investigation. The aim was to determine the physical properties of the steel rods used. The high yield steel bars were procured in the open market. Three (3) samples of each diameter from different lengths were cut to 600 mm length. Each of the samples was carefully centred and clamped in the Amsler Testing machine and gradually loaded first to the yield and later to failure. The loads were noted and analysed, the results are in Table 4. The average yield stress for the 16 mm and 20 mm diameter bars were 571.48 N/mm^2 and 549.64 N/mm^2 respectively.

Table 4. Tensile test results

Bar	Yield		Ultimate		Elongation (%)
Size (mm)	Load (Tons)	Stress (N/mm^2)	Load (Tons)	Stress (N/mm^2)	
Y16	11.4	564.87	13.4	663.97	13.0
Y16	11.5	569.83	13.6	673.88	12.5
Y16	11.7	579.74	13.5	668.93	12.0
Average	11.53	571.48	13.5	668.93	12.5
Y20	17.6	558.1	22.4	710.3	12.5
Y20	17.3	548.58	22.3	707.13	13.0
Y20	17.1	542.24	21.3	675.42	15.0
Average	17.33	549.64	22.00	697.62	13.5

2.4. Preparation of the moulds

The sizes of the moulds used were a function of the bar diameters. The moulds for 16 mm and 20 mm diameter bars were 160×160×160 mm and 200×200×200 mm the mould to allow the passage of the reinforcement bars along the axis of the mould. The inner part of the formwork was made smooth, lubricated with oil to prevent adhesion of concrete to the mould and for easy de-moulding and smooth surface finish.

2.5. Compressive strength of concrete cubes

Eighteen (18) cubes of 150×150×150 mm concrete were cast to monitor the strength of the concrete used in casting the RILEM specimens. The bond resistance/behaviour of laterized concrete were established with varying percentages of laterite to sharp sand which showed different modes of failure after testing for compressive strength. Table 5.

2.6. Test procedure on the RILEM samples

Push in test was carried out on all samples to determine the force required to push in the reinforcement in the concrete. The samples were carefully placed centrally between the upper and lower plates. The lower cylinder gradually moved until the bar in the sample touched the fixed upper plate. At this point, the computer attached to the Technotest machine began to record the applied load. The push-in force was applied to the longer side of the reinforcement in the specimen in order to push in the reinforcement until it fails (in adhesion). The failure load was recorded and the bond stress was calculated from the value of the failure load.

3. ANALYSIS

With the failure load, the bond stress was determined using the following relationship in [11].

$$\tau_P = (0.00637\, F \times 25) 10^3 / \phi^2 \times f_{cu} \,. \quad (1)$$

where: τ_P – bond strength, (N⁄mm²); F – failure load, (kN); ϕ^2 – bar diameter, (mm^2);
f_{cu} – compressive strength of concrete, (N⁄mm²).

Table 5. Compressive strength of various percentages of laterized concrete

S/N	Cube Name	Dimension (mm)	Maximum Load (kN)	Strength f_{cu} (N/mm^2)
0 %				
1	A01	150×150×150	427.4	19.00
2	A02		694.3	30.86
3	A03		576.5	25.62
4	A04		451.6	20.07
5	A05		651.3	28.95
6	A06		655.3	29.12
	Average		576.1	25.60
15 %				
1	A15.1	150×150×150	653.3	29.04
2	A15.2		569.6	25.32
3	A15.3		538.9	23.95
4	A15.4		574.2	25.52
5	A15.5		428.5	19.04
6	A15.6		450.6	20.03
	Average		535.9	23.82
25 %				
1	A25.1	150×150×150	617.1	27.43
2	A25.2		694.4	30.86
3	A25.3		656.2	29.16
4	A25.4		658.0	29.24
5	A25.5		693.5	30.82
6	A25.6		685.0	30.44
	Average		667.4	29.66

4. RESULTS AND DISCUSSION

For this investigation, some tests were carried out on the cement, aggregates (fine and coarse) including laterite and concrete to determine their physical properties. The tests are the Sieve Analysis, Slump Test on fresh concrete and the Compressive Strength of Concrete Cubes. The results are given in Tables 1, 2, 3, 4, 5.

Bond resistance of laterized concrete was investigated with 16 mm and 20 mm diameter high -yield reinforcing bars, sixty samples of RILEM (push-in) cubes made up of thirty cubes each of 160 mm and 200 mm cubes were cast with varying percentages (0 %, 15 % and 25 %) of sharp sand replacement with laterite.

Eighteen cubes of 150×150×150 mm compressive cubes were cast to monitor the strength of concrete used in casting the RILEM specimen. The laterized concrete, which was made with varying percentages of laterite to sharp sand, shows different modes of failure after testing for compressive strength.

The result obtained from the tests carried out to determine the bond strength of laterized concrete with steel reinforcement bars 16 mm diameter and 160×160×160 mm cube moulds gave the value of average failure load 96.08 kN and bond stress of 2.34 N/mm^2 at 0 % with a few specimen failing by slipping while majority of them have diagonal cracks and average failure load of 91.52 kN and bond stress of 2.30 N/mm^2 at 15 % laterite inclusion, with a few samples failing by slipping and majority of them with diagonal cracks, the average failure load 95.77 kN and bond stress of 2.01 N/mm^2 at 25 % laterite inclusion.

The results of samples cast with 20 mm diameter bars gave the value of average failure load as 106.0 kN and bond stress of 1.65 N/mm^2 at 0 % with diagonal, lateral and right angle cracks. The value of average failure load was 70.73 kN and bond stress of 1.23 N/mm^2 at 15 % laterite inclusion with diagonal crack and majority slipped and the average failure load was 90.33 kN and bond stress of 1.21 N/mm^2 at 25 % laterite substitution with majority of the samples in this category slipped. The test results are shown in Table 7.

It is also seen from the test results that the bigger the size of the specimen, the lesser the bond strength. Samples with 20 mm diameter bars have bond resistance lesser by 14.8 %, 87 % and 66.1 % at 0 %, 15 % and 25 % respectively for samples with 16 mm diameter bars. This effect may be due to air pockets below the steel bar. The graph of the bond stress for different percentages (0 %, 15 % and 25 %) of laterite substitution is shown in Figure 2.

In the push in test, there was no possibility of measuring the slip of reinforcement from the specimens (cubes), because the compression machine used to test samples was adapted; it was not possible to measure the slip as the other short end of the bar was enclosed.

The bond strength of laterized concrete reduces as the percentage of laterite substitution of sand increases. This may be due the level of impurity in the laterite.

Different crack patterns occur with different sizes of reinforcement, and percentages of laterite substitution of laterized concrete. The laterized concrete with 16 mm diameter steel reinforcing bars and 160×160×160 mm cube moulds gave the values of few specimens failing by slipping while majority of the specimen have diagonal cracks and at 15 % laterite inclusion with few samples failing by slipping and majority of them with diagonal cracks but at 25 % laterite substitution, it gives diagonal crack, right angle cracks and wider crack width. This is due to higher percentage of laterite substitution in laterized concrete which increases bond resistance, which the size of the cover “72” (for 160 mm cubes) could not restrict from the wider crack of the cover.

While 20 mm diameter bars gave the values of diagonal, lateral and right angle cracking at 0 % but at 15 % laterite inclusion, it gives few diagonal cracks and majority of them slipped, while at 25 % laterite substitution, all the samples in this category slipped with no cracks. This is due to higher concrete cover “90 mm” (for 200 mm cubes) which could withstand the increases in resistance of higher percentage of laterite substitution in laterized concrete. Hence, increase in percentage of laterite substitution in laterized concrete, changes the crack pattern and crack size but increase in concrete cover reduces the crack width.

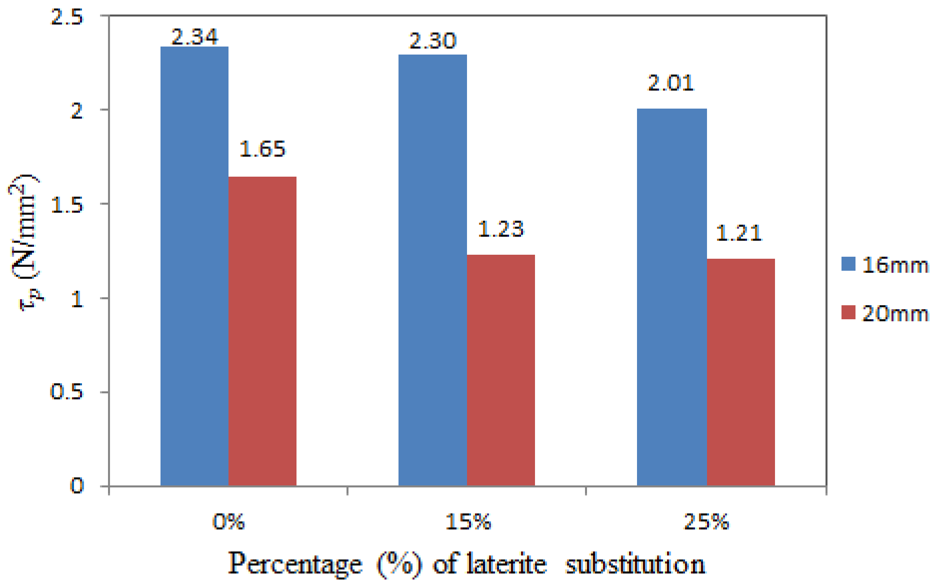

Figure 2. Bond Resistance of Laterite-Concrete.

Table 6a. RILEM Test Results for 0 %, 15 %, 25 % laterite substitution - 160 mm cube.

0 % Laterite Substitution				
S/N	Specimen Name	Maximum Load *F* (kN)	Bond Resistance $\tau_P = 6.37\times F\times 25/\Theta^2\times f_{cu}$	Type of failure
	160×160×160			
1	C01	92.7	2.25	Diagonal cracking
2	C02	80.2	1.95	Diagonal cracking
3	C03	108.1	2.63	Diagonal cracking
4	C04	81.9	1.99	Slip
5	C05	103.7	2.52	Diagonal cracking
6	C06	131.8	3.20	Diagonal cracking
7	C07	101.5	2.47	Diagonal cracking
8	C08	62.6	1.52	Slip
9	C09	95.5	2.32	Diagonal cracking
10	C010	102.8	2.50	Diagonal cracking
	Average	96.08	2.34 N/mm^2	Majority cracked
15 % Laterite Substitution				
	160×160×160			
1	C15.1	104.3	2.72	Right angle cracking
2	C15.2	99.8	2.60	Right angle cracking
3	C15.3	95.5	2.49	Diagonal cracking
4	C15.4	93.0	2.43	Diagonal cracking
5	C15.5	93.5	2.44	Diagonal cracking
6	C15.6	87.5	2.29	Diagonal cracking
7	C15.7	84.1	2.20	Diagonal cracking
8	C15.8	95.9	2.50	Right angle cracking
9	C15.9	79.7	2.08	Slip
10	C15.10	81.9	2.14	Slip
	Average	91.52	2.30 N/mm^2	Majority cracked
25 % Laterite Substitution				
	160×160×160			
1	C25.1	99.6	2.09	Diagonal cracking
2	C25.2	99.6	2.09	Diagonal cracking
3	C25.3	95.9	2.01	Diagonal cracking
4	C25.4	98.8	2.07	Diagonal cracking
5	C25.5	104.5	2.19	Diagonal cracking
6	C25.6	83.8	1.76	Right angle cracking
7	C25.7	104.5	2.19	Right angle cracking
8	C25.8	94.5	1.98	Diagonal cracking
9	C25.9	82.3	1.73	Right angle cracking
10	C25.10	94.2	1.98	Right angle cracking
	Average	95.77	2.01 N/mm^2	Majority cracked

Table 6b: RILEM Test Results for 0 %, 15 %, 25 % laterite substitution - 200 mm cube.

0 % Laterite Substitution				
S/N	Specimen Name	Maximum Load F (kN)	Bond Resistance $\tau_P = 6.37 \times F \times 25/\Theta^2 \times f_{cu}$	Type of failure
	200×200×200			
1	B01	104.6	1.63	Diagonal cracking
2	B02	100.8	1.57	Lateral cracking
3	B03	107.9	1.68	Lateral cracking
4	B04	114.0	1.77	Diagonal cracking
5	B05	99.4	1.55	Diagonal cracking
6	B06	109.1	1.70	Diagonal and right angle cracking
	Average	106.0	1.65 N/mm^2	Majority cracked
15 % Laterite Substitution				
	200×200×200			
1	B15.1	81.0	1.35	Slip
2	B15.2	74.9	1.25	Slip
3	B15.3	70.4	1.18	Slip
4	B15.4	70.4	1.18	Diagonal cracking
5	B15.5	71.9	1.20	Slip
6	B15.6	72.6	1.21	Slip
	Average	70.73	1.23 N/mm^2	Majority slipped
25 % Laterite Substitution				
	200×200×200			
1	B25.1	97.1	1.30	Slip
2	B25.2	90.3	1.21	Slip
3	B25.3	91.4	1.23	Slip
4	B25.4	83.7	1.12	Slip
5	B25.5	87.2	1.17	Slip
6	B25.6	91.3	1.23	Slip
	Average	90.33	1.21 N/mm^2	Majority slipped

5. CONCLUSIONS

Based on the Sixty RILEM push in test samples and the analysis of the test results, the following conclusions can be drawn:

i. Bond resistance of laterized concrete reduces with percentage increase in laterite substitution of sharp sand. The bond resistance at 25 % replacement of sharp sand with laterite is lower than the bond resistance at 0 % sharp sand replacement for 16 mm and 20 mm diameter bars by 16.4 % and 36.4 % respectively.

ii. The bond resistance of 16 mm diameter bars is higher than that of 20 mm diameter high yield bars. Figure 2. The air bubbles that settled under the 20 mm bars are more because of the larger surface area of 20 mm diameter bars, hence the lower bond resistance values.

iii. The mode of failure of the 160×160×160 mm cubes are majorly by diagonal cracks while majority of 200×200×200 mm cubes failed by slip failure. Table 7. The cover is more in 200 mm specimen.

6. RECOMMENDATION

Further work is recommended on bond resistance of higher percentages of laterite substitution in concrete to confirm the bond strength of laterized concrete especially at 25 % of laterite substitution and the optimum percentage substitution of laterite in concrete.

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