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FLEXURAL AND TENSILE STRENGTH PROPERTIES OF CONCRETE USING LATERITIC SAND AND QUARRY DUST AS FINE AGGREGATE

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ABSTRACT

This is part of a research on the structural characteristics of concrete using lateritic sand and quarry dust as fine aggregate. This paper presents the results of an experimental study investigating the flexural and tensile characteristics of concrete using combinations of lateritic sand and quarry dust as complete replacement for conventional river sand fine aggregate. Samples of concrete (eg. cylinders, beams) were made using varying contents of lateritic sand and quarry dust as fine aggregate. The proportion of lateritic sand was varied from 0% to 100% against quarry dust at intervals of 25%, using concrete mix of 1:1.5:3 and water/cement ratio of 0.65. Concrete samples were prepared, cured for 28 days, and tested in the laboratory to destruction in order to determine their flexural and tensile strength properties. The results show that flexural strengths were 3.28N/mm^2 for 50% laterite: 50% quarry dust and 2.88N/mm^2 for 25% laterite: 75% quarry dust. Similarly, tensile strengths were 2.91N/mm^2 for 50% laterite: 50% quarry dust and 1.67N/mm^2 for 25% laterite: 75% quarry dust. These indicate that both flexural and tensile strengths increase with increase in laterite content. The results suggest that concrete containing mixtures of lateritic sand and quarry dust can be reasonably used in structural elements as for normal concrete (concrete with river sand as fine aggregate).

Keywords: concrete, flexural strength, tensile strength, lateritic sand, quarry dust.

1. INTRODUCTION

Concrete is probably the most common material used in the construction industry in Nigeria and most countries of the world. The use of concrete structural elements can be easily found in buildings, highways/bridges, runways, jetties, etc. This has continued to place high demand for concrete materials with the need for research into locally available substitutes for conventional concrete constituent materials like river sand.

In highways construction, it is common practice to use quarry fines to stabilize lateritic materials used in road pavements. However, the advantage of this is yet to be fully taken in the construction of structural elements in buildings and related structures.

Recent developments in the building construction industry in Calabar, Southern Nigeria have witnessed an increasing use of mixtures of lateritic sand and quarry dust to replace river sand in concrete and block productions without any reliable data on the appropriate use of these materials in structural elements of buildings. This is worrisome given the history of building collapses in major cities of Nigeria and elsewhere. Information about strength properties of a material from which a load-bearing component is made is required by an engineer to complete the theoretical stress analysis of the component [1]. Flexural and tensile strengths are among some of the important properties to be considered.

Laterite (Lat) and quarry dust (QD) exist in abundance in most parts of Nigeria, and their incorporation in structural concrete elements will likely reduce the cost of construction of buildings significantly. On the other hand, the use of these materials has some tendencies to reduce environmental problems. These include: the environmental problems posed by the excessive mining of river sand [2] - the conventional fine aggregate for concrete works in Nigeria and most parts of the world; and the environmental problems in quarry sites due to large heaps of quarry dust - the waste product of aggregate crushing process.

Saghafi and Al Nageim [3] have studied the possibility of reducing the demand for primary aggregate in the United Kingdom highways construction industry by incorporating limestone waste dust to replace some of the coarse and fine aggregate in road base materials. This tends to have significant impact on the demand for primary aggregate. Similarly, Eze-Uzomaka and Agbo [4] have investigated the suitability of quarry dust as improvement to cement-stabilized laterite for road bases in Nigeria.

However, the use of quarry dust in road construction has not fully addressed the environmental problems in quarry sites, hence the need to open more avenues of disposing this waste material from quarry sites. Concrete production has good potential for consuming quarry dust from quarry sites.

According to Elayesh [5] flexural strength provides two useful parameters, namely: “the first crack strength, which is primarily controlled by the matrix”, and “the ultimate flexural strength or modulus of rupture, which is determined by the maximum load that can be attained.” In China the flexural properties of cement-stabilized macadam reinforced with polypropylene fibre has been studied by Zhang *et al*., [6]. Flexural properties of structural materials are generally important to design engineers to guide appropriate selection of materials.

It has been argued that the flexural strength property of concrete is important particularly when the concrete structure has no steel reinforcement. For example, unreinforced concrete roads and runways rely on their flexural strengths to safely distribute concentrated loads over wide areas [7]. This appears to be also true for tensile strength property of concrete. Hence, findings from this research will have great significance in providing relevant data for the analysis and design of structures by consultants and practitioners in the construction industry. It will also open many questions that will trigger further research on the appropriate use of these abundant resources to reduce construction costs and tendencies for building failures.

2. MATERIALS AND METHODS

Lateritic sand was obtained from a borrow pit site at Akim-Akim in Odukpani local government area of Cross River state. On the other hand, quarry dust was taken from the abundant deposits at Akamkpa Quarry site in Akamkpa local government area of Cross River state. Both sites are within few minutes' drive from Calabar city centre. The coarse aggregate used was crushed granite chippings of 20mm nominal size also produced at Akamkpa quarry site. There are many lateritic sand borrow pits within and around Calabar metropolis.

The UNICEM brand of ordinary Portland cement conforming to BS12 [8] was used for producing the samples for this research. The cement supplied in 50Kg bags was well protected from dampness to avoid lumps. Portable pipe borne water supplied by the Cross River State Water Board in Calabar for domestic consumption was used for the experiments. Water is important in starting the reaction between cement and other constituent materials.

The materials were air dried in the laboratory. The coarse aggregate (granite chippings) was passed through sets of sieves, the portion passing through sieve (20mm) and retained on sieve (5mm) was used. The laterite and quarry dust used in the experiments were those passing sieve (2mm) and retained on sieve (150μm). All tests were conducted according to the relevant British Standard (BS) (eg. BS 1881 [9-13]). The materials were specified according to BS 882 [14], BS 5328 [15], and BS 8110 [16].

2.1 Concrete batching and production

The batching of concrete was done by weighing the different constituent materials based on the adopted mix ratio of 1:1.5:3 (Figures 3 and 4). The fine aggregate portion of the mix was achieved by combining lateritic sand and quarry dust in ratios such as 25% Lat: 75% QD and 50% Lat: 50% QD. The materials were then manually mixed thoroughly before adding the prescribed quantity of water and then mixed further to produce fresh concrete. Water/Cement ratio of 0.65 was adopted for this research based on findings from previous research on laterized concrete eg. [17, 18].

Three samples (Figure-3) were used for each test and the average results adopted as the flexural and tensile strength respectively. The tests were conducted in the materials laboratory of the University of Nigeria, Nsukka.

Mix proportion based on 1:1.5:3 mix and 0.65 water/cement ratio:

Weight of cement
= 10.9Kg
Weight of fine aggregate required (lat. + QD)
= 16.4Kg
Weight of coarse aggregate
= 32.7Kg
Weight of water
= 7.09Kg

Based on variations between laterite and quarry dust the following quantities (in Kg) below were obtained for different combinations of laterite and quarry dust, while the weights of cement, coarse aggregate and water remained constant as stated above.

a) 0% laterite : 100% quarry dust
Weight of quarry dust = 16.4 kg
b) 25% laterite : 75% quarry dust
Weight of laterite = 4.1 kg
Weight of quarry dust = 12.3 kg
c) 50% laterite : 50% quarry dust
Weight of laterite = 8.2 kg
Weight of quarry dust = 8.2 kg
d) 75% laterite : 25% quarry dust
Weight of laterite = 12.3 kg
Weight of quarry dust = 4.1 kg
e) 100% laterite : 0% quarry dust
Weight of laterite = 16.4 kg

2.2 Flexural strength test

The arrangement for flexural strength test is shown in Figure-1. Automatic universal testing machine was used for this test according to BS1881-118 [12]. Beam samples measuring 500×100×100mm were moulded and stored in water for 28days before test for flexural strength. Three similar samples were prepared for each mix proportion. The casting was made by filling each mould with freshly mixed concrete in three layers. Each layer was compacted manually using a 25mm diameter steel tamping rod to give 150 strokes on a layer. The hardened beam was placed on the universal testing machine simply supported over a span 3times the beam depth on a pair of supporting rollers. Two additional loading rollers were placed on top the beam as shown in Figure-1. The load was applied without shock at a rate of 200m/s. The flexural strength was then calculated using the formula below:

$$f_{cf} = \frac{Pl}{d_1 d_2^2} \quad (1)$$

Where,

P = breaking load (in N);

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d_1 and d_2 = lateral dimensions of the cross sections (in mm);

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

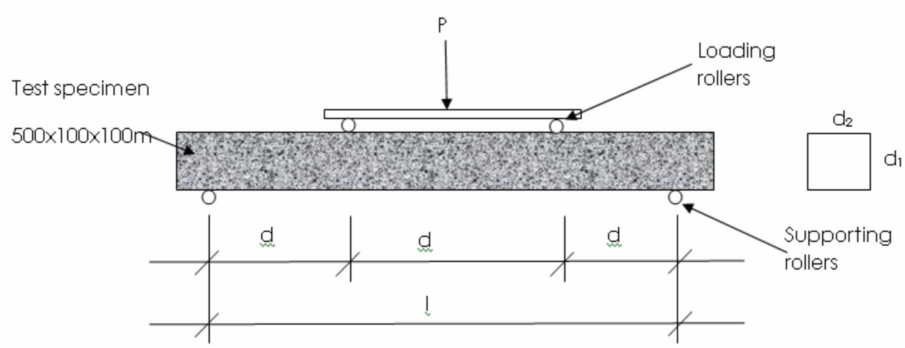

Figure-1. Arrangement of loading (2-point loading) for flexural strength.

2.3 Tensile splitting strength test

This test was carried out as specified in BS1881-117 [11]. Cylindrical concrete specimens of size 100mm diameter × 200mm long were moulded and stored in water for 28 days before testing for tensile splitting strength. The automatic universal testing machine was used for the test. Three similar samples were prepared for each mix proportion used. A total of six cylinders were cast and tested. The casting was made by filling each mould with freshly mixed concrete in two layers of approximately 100mm thickness. Each layer was compacted manually using a 25mm diameter steel rod to give 35 strokes of the tamping rod on each layer.

The hardened concrete specimen was then placed on the universal testing machine and supported longitudinally with hardboard packing strips carefully positioned along the top and bottom of the plane of loading of the specimen. The specimen was positioned centrally before application of load without shock at a rate of 400N/s. The tensile splitting strength was calculated as shown below from BS 1881-117 [11].

Horizontal tensile stress = $\frac{2P}{qLD}$ (2)

Where p = the maximum load (N)
L = length of the specimen (mm)
D = cross sectional dimensions or diameter (mm).
Neville [19] presented the formula for calculating the horizontal tensile stress as shown below. This was used in this work.

$f_t = \frac{2P}{\pi LD}$ (3)

Also, the vertical stress in the cylinder can be calculated from:

Vertical compression stress = $\frac{2P}{\pi LD}\left[\frac{D^2}{r(D-r)} - 1\right]$ (4)

Where r and (d-r) are distances of the element from the two loads, respectively (Figure-2).

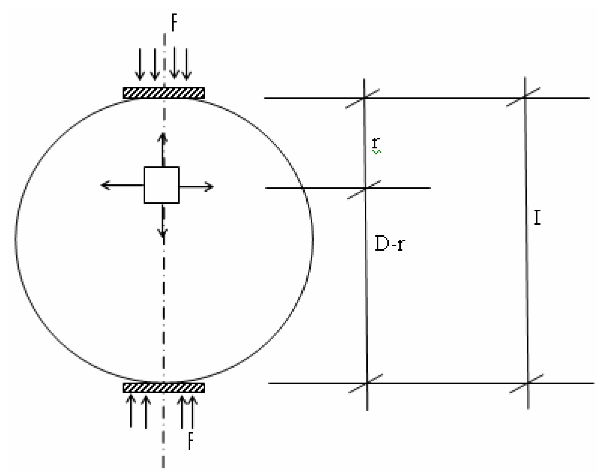

Figure-2. Arrangement of loading for splitting test [19].

Figure-3. Weighing of constituent materials.

Figure-4. Constituent materials: cement, laterite, quarry dust and granite chippings (coarse aggregate).

Figure-5. Concrete cubes, beams and cylinder samples.

3. RESULTS AND DISCUSSIONS

This section presents the results and discussions of laboratory tests conducted on the lateritic sand and combination with quarry dust as well as the concrete derived from them in their fresh and hardened states. The analysis is carried out in tables and graphs, while the results are discussed in comparison with properties of normal concrete including works of previous researchers. Table-1 presents a summary of results in comparison with properties of normal concrete provided by Adoga [20].

3.1 Physical properties of materials

The results of physical properties of laterite and quarry dust are first presented followed by those of both fresh and hardened concrete produced using lateritic sand and quarry dust as fine aggregate.

The specific gravity of materials namely: laterite, quarry dust and coarse aggregate were found to be 2.56, 2.67 and 2.71, respectively. The values are in agreement with the results of Udoeyo *et al*., [21] and Ilangovana *et al*., [22]. Similarly, bulk densities of laterite, quarry dust and coarse aggregates were found to be 1460, 1230 and 1830Kg/m^3, respectively. The densities of hardened concrete cube samples were found to be within the range of 2391 - 2591Kg/m^3. This is within the range for normal weight concrete, and results from previous studies on laterized concrete [7, 23, etc].

The results of particle size distribution for laterite, quarry dust and coarse aggregate are shown in figure 6. From the particle size distribution, laterite is uniformly graded with a uniformity coefficient (CU) of 3.25, while quarry dust has a uniformity coefficient of 11.25. The particle sizes of coarse aggregate range from 5mm to 20mm with a CU value of 1.82.

The curves for different combinations of the fine aggregates are superimposed and compared with the overall limits given in Table-4, BS 882 [14] for grading of sand aggregate for concrete works as presented in figure-6 below. The fine aggregates were found to be within the overall limits given in BS 882 [14]. The laterite used by Efe and Salau [24] which had over 80% of the particle size less than 1mm were found to be finer than the lateritic

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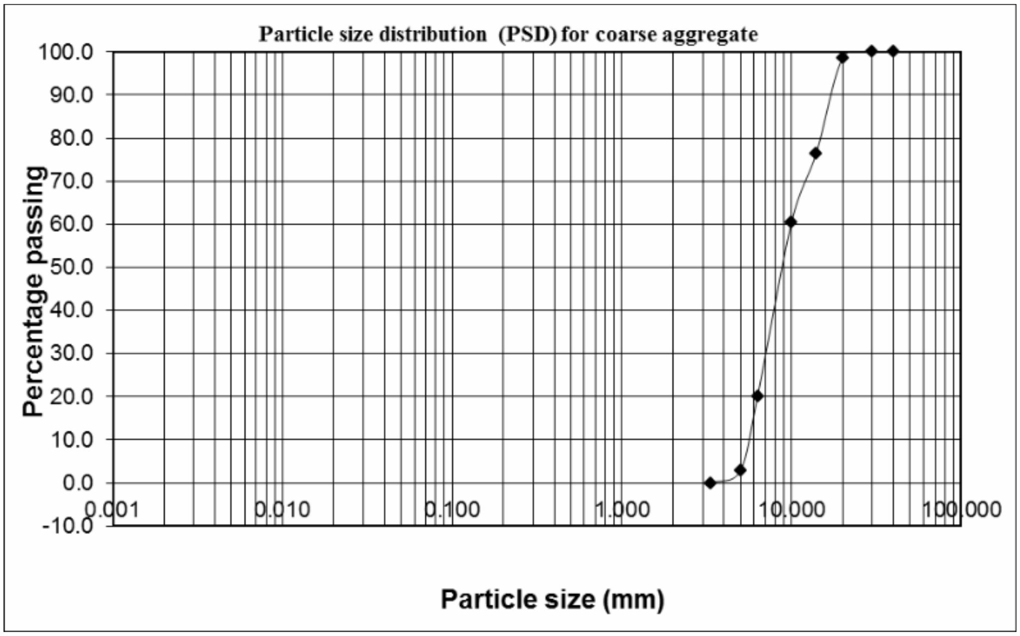
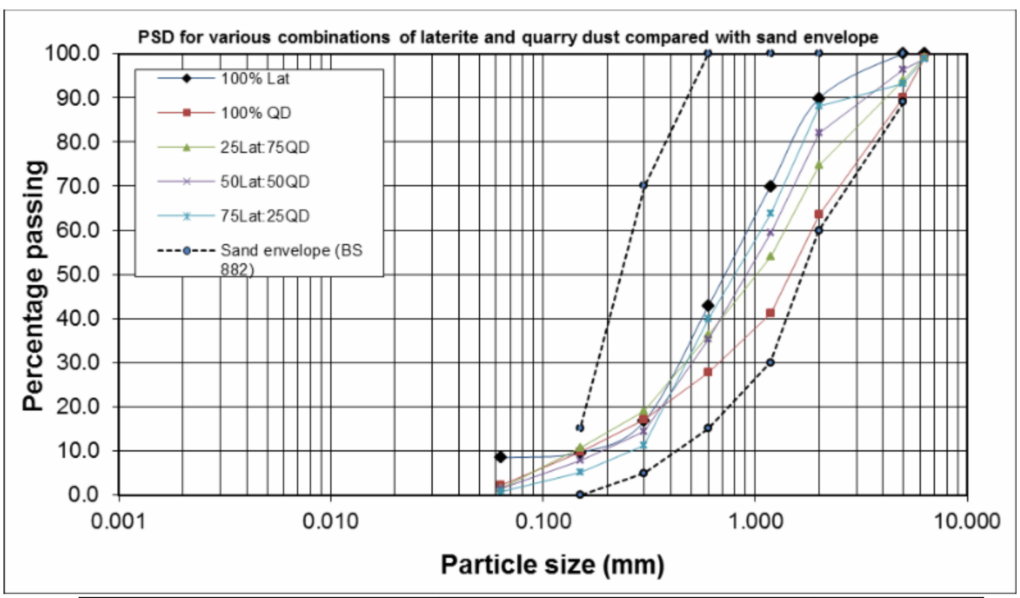
sand used in this study with 60 % of the material more than 1mm in size. This indicates some difference between the Calabar lateritic sand and those used by previous researchers.





CLAY	SILT	SAND	GRAVEL
0.002	0.06	2.0	10.0

0.06 0.20 0.60 2.00 6.00 20.0

COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
SILT	**SAND**			**GRAVEL**		

Figure-6. Particle size distribution curves for coarse aggregate and various combinations of laterite and quarry dust compared with specified sand grading envelope.

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3.2 Flexural strength and tensile strengths

The results for flexural strengths of concrete using lateritic sand and quarry dust were found to be 3.28N/mm^2 for 50% laterite: 50% quarry dust and 2.88N/mm^2 for 25% laterite to 75% quarry dust. The tensile splitting strengths on the other hand were 2.91N/mm^2 for 50% laterite: 50% quarry dust and 1.67N/mm^2 for 25% laterite: 75% quarry dust. The details of calculations are given in appendices A and B. These values compare well with those for conventional concrete as shown in Table-1. It was observed that tensile and flexural strengths reduce with increase in quarry dust content which agrees with the results of Osunade [25]. The tensile strength values are higher than those of laterized concrete by Osunade [26] which ranged from 1.44 - 2.0N/mm^2. Typical failure modes for flexural and tensile tests are shown in Figures 7 and 8, respectively.

Figure-7. Flexural test result.

Figure-8. Tensile splitting test result.

Table-1. Comparison between research findings and conventional concrete.

Parameter	Experimental concrete		Normal concrete 1:2:4 [20]
	$1:1\frac{1}{2}:3:0.65$ (25% lat:75% QD)	$1:1\frac{1}{2}:3:0.65$ (50% lat:50% QD)	
Density (kg/m^3)	2388 - 2434	2293 - 2447	2000 - 3900
Water absorption (%)	0.37 - 1.23	0.48 – 1.31	$\ngtr$ 7%
Compressive strength (N/mm^2)	24.25	22.85	20±2
Flexural strength (N/mm^2)	2.88	3.28	3.82
Tensile strength (N/mm^2)	1.67	2.91	1.85
f_{cf}/f_{cu}	11.9	14.4	8 - 15
f_t/f_{cu}	6.9	12.7	9 - 10
f_t/f_{cf}	58	88.7	45 - 52

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4. CONCLUSIONS

The flexural and tensile strength properties were found to compare closely with those for normal concrete. Hence, concrete with mixtures of lateritic sand and quarry dust can be used for structural construction provided the proportion of lateritic sand content is kept below 50%. Both flexural and tensile strengths were found to increase with increase in laterite content. Further work is required to get data for long-term deformation characteristics and other structural properties of the experimental concrete. These include: shear strength, durability, resistance to impact, creep, etc. Also, it may be necessary to investigate the optimum contents of lateritic sand and quarry dust in relation to the structural properties of the concrete. These will assist engineers, builders and designers when using the materials for construction works.

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Appendices

Appendix A. Flexural strength calculation (Microsoft Excel Output)

	1:1.5:3 mix		Water/cement ratio = 0.65					Flexural strength	Average
% LAT/QD	**F**	**L**	**A=FL**	**d1**	**d2**	**d2^2**	**B=d1*d2^2**	**A/B**	
50/50	7926.5	400	3170600	100	100	10000	1000000	3.1706	3.28
50/50	8473.5	400	3389400	100	100	10000	1000000	3.3894	
25/75	6926.5	400	2770600	100	100	10000	1000000	2.7706	2.88
25/75	7473.5	400	2989400	100	100	10000	1000000	2.9894	

Appendix B. Split tensile strength results (Microsoft Excel Output).

S/N	Splitting tensile test Results 50 % lat/50 % qd Mix = 1: 1$\frac{1}{2}$:3 Water/cement ratio = 0.65						Horizontal
	P	**Π**	**L**	**D**	**2P**	**π LD**	**Tensile** **A=2P/ π LD**
1	4500	3.142	200	100	9000	62840	0.143220878
2	14500	3.142	200	100	29000	62840	0.461489497
3	24500	3.142	200	100	49000	62840	0.779758116
4	34500	3.142	200	100	69000	62840	1.098026735
5	44500	3.142	200	100	89000	62840	1.416295353
6	64500	3.142	200	100	129000	62840	2.052832591
7	84500	3.142	200	100	169000	62840	2.689369828
8	91500	3.142	200	100	183000	62840	2.912157861

S/N	Splitting tensile test Results 25 % lat/75 % qd Mix = 1: 1$\frac{1}{2}$:3 Water/cement ratio = 0.65						Horizontal
	P	**π**	**L**	**D**	**2P**	**π LD**	**Tensile** **A=2P/ π LD**
1	4500	3.142	200	100	9000	62840	0.1432208
2	14500	3.142	200	100	29000	62840	0.4614894
3	24500	3.142	200	100	49000	62840	0.7797581
4	34500	3.142	200	100	69000	62840	1.0980267
5	44500	3.142	200	100	89000	62840	1.4162953
6	52500	3.142	200	100	105000	62840	1.6709102