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AN INVESTIGATION INTO STRUCTURAL STRENGTHS OF LATERIZED CONCRETE

Introduction

Concrete is one of the commonly used construction materials but there is a need to develop new and sustainable technologies to make concrete more affordable in a developing country like Nigeria. The use of abundantly available materials, like laterite, to replace normal aggregates in concrete for structural purposes could make the use of concrete technology in developing countries more economical if some reliable design data base on concrete produced with such materials was established. Laterites naturally occur widely in the tropics and subtropics. Laterite soils are common types of soils in Nigeria and are spread all over the country. This material has been satisfactorily used as a filling agent for foundation and as a base course for highway construction as well as a primary fine aggregate in the manufacture of the building blocks commonly referred to as "iatentic blocks" [1-3].

In ordinary structural concrete the aggregate occupies 70÷75% of the volume of hardened mass and in similar vein it occupies 90% or more in asphalt cement concrete [4-6]. It is inevitable that a constituent occupying such a large percentage of mass should have an important effect on the properties of both the fresh and hardened product. Their impact on various characteristics and properties of concrete is undoubtedly considerable.

Aggregate can be classified as fine or coarse aggregate. Fine aggregate is generally natural sand and is graded from particles size of 5 mm down to the finest particles size but excluding dust. Coarse aggregate is natural gravel or crushed stone usually larger than 5 and usually less than 16 mm size in ordinary structure [6, 7]. In this research, the emphasis will be on laterite as fine aggregate. Lateritic soils, being locally available, have been one of the major building materials in Nigeria, and in most tropical countries in general [1, 3, 8].

Laterite is a weathered material composed principally of iron oxides, aluminum, titanium and manganese, and is classified as a soft porous earthy soil; often found 15 cm below the top soil [3, 7, 9].

The performance of laterite as fine aggregate replacement in concrete has been found to produce good results [10, 11]. This was confirmed that laterite can be used as cheap, environment-friendly and readily available fine aggregate for concrete production, where it is available in substantial quantities, leading to major reductions in the cost of concrete manufacture [1, 12, 13].

The compressive strength of concrete is commonly considered in structural design but for some special purposes the tensile strength is necessary (e.g. shear and crack resistance in the design of highway and airfield slabs). There is no linear relationship between concrete compressive and tensile strength as the ratio of the two strengths depends on the strength of concrete, in other words, as the compressive strength (f_{cu}) increases the tensile strength (f_t) increases but in a decreasing rate. A number of empirical formulae connecting f_t and f_{cu} have been suggested, many of them are of the type:

$$f_t = k(f_{cu})^n$$

where: k and n are coefficients.

Values of n and k have been suggested which n varies between 0.5÷0.75 and k between 0.12÷0.3 [14-18].

Studies on the compressive and tensile strengths of laterized concrete have shown encouraging results, but the lack of sufficient technical data has limited its wider application in construction work. The inadequacies of research data call for the need for more research work to evaluate the relevant characteristics of laterized concrete necessary to enable the development of standards and codes for safe, economical and functional application of the proposed laterized concrete (LATCON).

The criterion for concrete strength requirement is always based on the characteristic compressive strength obtained after 28-day curing [19-21], but there is need to check concrete strength of other curing periods below the 28-day one.

1. Materials and methods

Physical and mechanical properties such as grading, specific gravity, water absorption, aggregate impact and crushing values, slump and compaction factor, and compressive strength were determined for the sand, laterite and concrete produced.

1.1. Materials

All the materials used for this work confirmed with the British Standards and American Society for Testing Materials (ASTM). Fine aggregate (sand), laterite, coarse aggregate, cement, and water were the materials used for the purpose of this study. They were selected and tested in accordance with British Standard (BS) Codes of practice or specifications and American Society for Testing Materials (ASTM), recommended standards. Both aggregates used complied with the requirements of BS 882.

The fine (sand) aggregate used was river-bed sand type which was obtained locally from river Bako at Kpankungu along Federal University of Technology, Gidan Kwano main campus, Minna. The laterite soil used was also obtained locally from burrow pits located around Tsohon-Gada village along Minna - Kataeregi road, Niger State, Nigeria. The coarse aggregate used was crushed gravel of 25 mm maximum size obtained from Yarmuk Nigeria Limited quarry site along Paiko - Lapai road, Niger State, Nigeria. It has a unit weight of 1363.75 kg/m^3 and specific gravity of 2.65, bulk density of 1413 kg/m^3 water absorption and moisture content of 0.46 and 0.70%, void ratio and porosity of 0.48 and 11.24%, average impact and crushing values of 12.75 and 20.28% respectively. Ordinary Portland cement of Burham brand used as main binder for all the concrete mixes was purchased in bags of 50 kg from local distributors in Minna and of recent supply, free of adulteration. The brand of cement used conformed to BS 12:1991. The unit weight, specific gravity, fineness, consistency, soundness, initial and final setting times of cement are 1440 kg/m^3, 3.15%, 0.75%, 32%, 0.58 mm, 148 and 215 minutes, respectively. Potable clean tap water, free from impure substances such as alkaline salt, acid and organic matter was used for the concrete production. The materials were transported and stored in laboratory premises before use.

1.2. Methods

Physical and mechanical properties of laterized concrete were conducted in accordance with BS and other related codes of practice and specifications. The sieve, specific gravity, impact and crushing values test analysis were carried out in accordance with [22-26] respectively.

Concrete of mix proportion 1:2:4:0.6 and 1:2:2:0.6 (cement: sand: coarse aggregate: water/cement ratio) containing varying percentages of laterite as a substitute for sand was used for this research. The replacement levels of sand by laterite considered were 0, 20, 40, 60, 80 and 100%. Control concrete (concrete with sand only) was also produced for reference purpose. Batching of all the concrete constituents was by weight. The concrete ingredients were manually mixed thoroughly with a pre-calculated amount of water. The fresh concrete was then placed in cubical moulds of size 150 mm lightly oiled before casting of test specimens. This was conducted in accordance with [27].

Six cubes and six cylinder specimens for each replacement level were cast from a single batch of concrete in moulds. The specimens were demoulded after 24 hours and immersed in water in a curing tank maintained at room temperature for 7-, 14-, and 28-day period before testing for the respective strength characteristics. Six cubes for each replacement level were produced for the water absorption test. The cubes were weighed in a balance before and after immersion in water for

24 hours. The difference in the weight before and after immersion in water expressed as a percentage of the weight before immersion was taken as the water absorption.

For water absorption test, specimens were weighed before and after immersion in water for 24 hours. Water absorption was then determined as the difference in the weight of specimen before and after immersion in water relative to the weight of specimen before immersion in water, expressed in percentage. This was carried out in accordance with [28]. Curing was done by immersion of hardened concrete in water tank situated in the laboratory, and this was in compliance with [29].

Workability of the specimen was determined through slump and compacting factor tests which were conducted in compliance of [30, 31] respectively.

The procedure for the compressive strength tests was conducted in accordance with [32] and the machine used for this purposed complied with [33] specifications. The concrete strength was confined to characteristic concrete strength grade of 20 and 25 N/mm^2 (C20 and C25).

2. Results and discussion

After sieve and specific gravity analysis fine aggregate was found to be under standard F-classification and falls under the grading limit of Zone 2 conforming to the requirements of [34], with sand and laterite having a specific gravity of 2.60 and 2.50 respectively. The particle size distribution of the sand and laterite are shown in Figure 1.

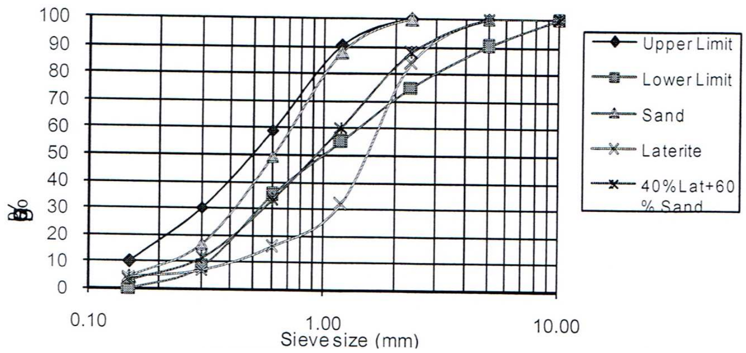


Fig. 1. Particle size distribution of sand and laterite

The percentage silt content in sand and laterite was 2.36 and 8.95 respectively. The laterite had higher percentage of silt and lay below the lower limit of zone boundary.

However, the sieve analysis of 40% percent laterite and 60% sand fell within the upper limit and lower limit suggesting that this composition could be used in the manufacture of laterized concrete.

2.1. Workability

Figures 2a and 2b present the results of the workability of LATCON measured in terms of slump test and compacting factor in accordance with [30, 31] for nominal concrete design strength of grade 20 and 25 N/mm^2 respectively.

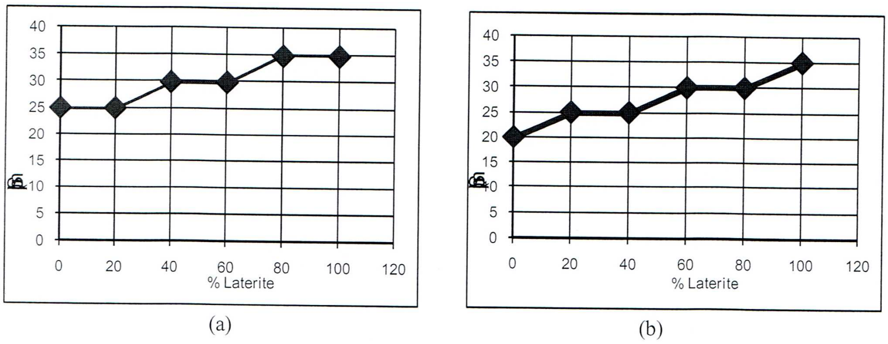


Fig. 2. Slump test versus % of laterite in LATCON for: a) C20, b) C25

Both graph plotted show that the workability of the concrete increases with the replacement level of sand by laterite possibly due to the presence of laterite fines that were greater in size than the particles of the sand replaced in the mix.

Additionally, aggregate size and texture affect workability of concrete.

2.2. Water absorption

The mean of triplicate test results of the water absorption test presented in Figure 3 show that normal concrete (control i.e. 0% laterite) absorbed more water than LATCON for both class C20 and C25. It is observed that the water absorption decreased with increase in the replacement level of sand by laterite. This may be due to the filler effect of the laterite in the concrete. The cement fine plus the laterite fines may have filled more concrete pores in LATCON compared to the plain concrete, thus making LATCON less porous. The water absorption of C25 is lower than that of C20; possibly due to higher percentage of fine in C25 than the latter making the concrete pores more filled than those of C20.

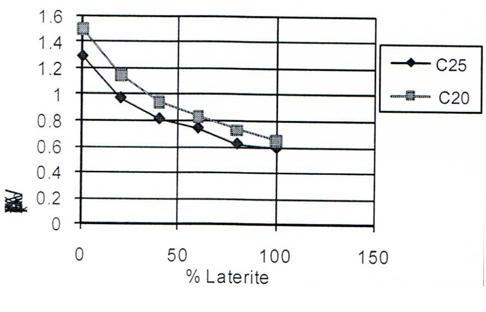


Fig. 3. Water absorption versus percentage of laterite content

2.3. Cube compressive strength

A total of 124 cube specimens of size 150 mm were tested for compression. The test triplicate results averages are summarized in Tables 1 and 2 for nominal design of C20 and C25 respectively.

TABLE 1

Compressive Strength of LATCON for C20

Combination [%]		Compressive strength [N/mm^2]			
Sand	Laterite	7 Days	14 Days	28 Days	f_{cu7}/f_{cu28}
100	0	17.53	20.72	20.99	0.835
80	20	16.87	19.98	20.61	0.819
60	40	16.21	16.91	20.48	0.792
40	60	15.81	16.17	19.18	0.824
20	80	14.73	15.82	15.77	0.093
0	100	10.99	12.17	15.03	0.731

TABLE 2

Compressive Strength of LATCON for C25

Combination [%]		Compressive strength [N/mm^2]			
Sand	Laterite	7 Days	14 Days	28 Days	f_{cu}^/f_{ciOS}
100	0	17.41	21.81	25.83	0.674
80	20	15.29	20.94	22.38	0.683
60	40	14.04	19.86	21.16	0.664
40	60	13.88	19.59	20.36	0.682
20	80	13.11	14.48	16.95	0.773
0	100	11.09	18.18	14.49	0.765

The compressive strength of all LATCON specimens increased with age but decreased with increase in the replacement level of sand as shown in Figures 4 and 5.

The designed strength of 20 N/mm^2 for C20 was attained when a maximum of 40% of the sand was replaced by laterite while the target of 25 N/mm^2 for C25 was underachieved by 15.36%.

The laterite which consists of quartz and granular aggregates of kaolinite clay particles weakly cemented by sesquioxide (Fe_2O_3 and Al_2O_3) [3, 7] has less compressive strength than the sand it replaces in the concrete matrix. This may explain the reduction in compressive strength of laterized concrete compared to the plain concrete.

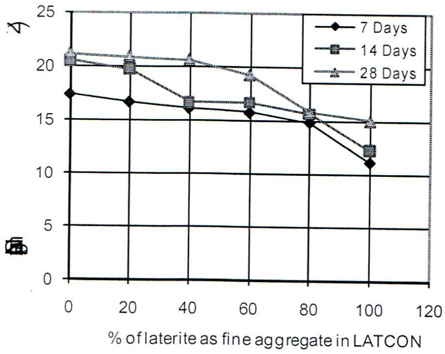


Fig. 4. Compressive strength versus % of laterite in LATCON for C20

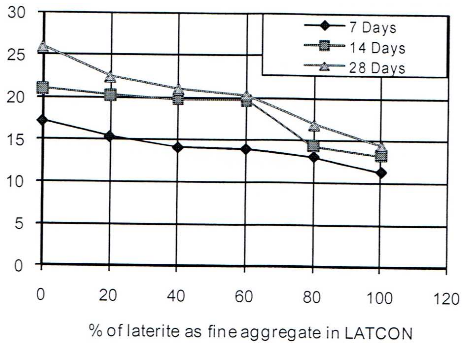


Fig. 5. Compressive strength versus % of laterite in LATCON for C25

Laterite may therefore be used as a partial replacement of sand up to 40%. This then translates for class C20 a mix ratio of 1:0.8:1.2:4 (cement: laterite: sand: coarse aggregate) instead of the usual 1:2:4 (cement: sand: coarse aggregate) and for class C25 a mix ratio of 1:0.8:1.2:2 (cement: laterite: sand: coarse aggregate) instead of the usual 1:2:2 (cement: sand: coarse aggregate).

2.4. Split cylinder tensile strength

A total of 124 standard concrete cylinders of sizes 150 mm diameter and 300 mm height were tested for the indirect tensile strength. The averages of triplicate test results are shown in Tables 3 and 4 for class C20 and C25 LATCON at the various sand replacement levels.

Each value represents the average of three test results. The split tensile strength was calculated accordingly as follows:

$$f_s = \frac{2P}{\pi LD}$$

where: f_s = split tensile strength (N/mm^2), P = peak load on cylinder (N), L = length of specimen (mm), and D = diameter of specimen (mm).

TABLE 3

Split cylinder tensile LATCON for C20

Combination [%]		Split tensile strength [N/mm^2]		
Sand	Laterite	7 Days	14 Days	28 Days
100	0	0.88	0.99	1.12
80	20	0.85	0.96	1.09
60	40	D.85	0.91	1.05
40	60	0.79	0.89	0.99
20	80	0.76	0.87	0.93
0	100	0.70	0.81	0.89

TABLE 4

Split cylinder tensile strength of LATCON for C25

Combination [%]		Split tensile streng th [N/mm^2]		
Sand	Laterite	7 Days	14 Days	28 Days
100	0	1.11	1.15	1.29
80	20	1.09	1.15	1.2-
60	40	0.93	1.13	1.25
40	60	0.88	1.01	1.18
20	80	0.79	0.86	1.00
0	100	0.72	0.79	0.94

The tensile strength for both C20 and C25 LATCON shows increase with age but decreased with increase in sand replacement as it was the case with compression strength. However, the increase of strength with age was comparatively lower in value than the corresponding values of the compressive strength.

Figures 6a and 6b show the 28-day compressive strength of LATCON C20 and LATCON C25 in relation to the split tensile strength of the concrete of corresponding age. Regression analysis of the data in Figures 6a and 6b suggests the following relationships:

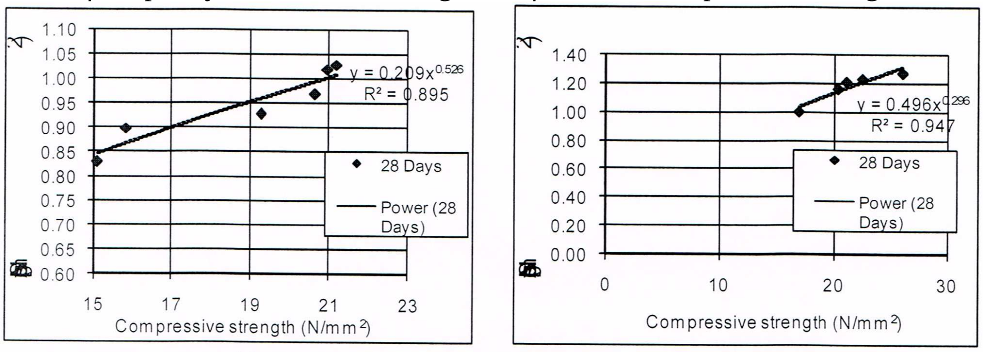
$$R^2 = 0.8946$$

$$f_{t(C20)} = 0.2093(f_{cu})^{0.5259}$$

$$f_{t(C25)} = 0.4961(f_{cu})^{0.2945}$$

$$R^2 = 0.947$$

where: f_t = split cylinder tensile strength and f_{cu} = cube compressive strength



(a) (b)

Fig. 6. Split tensile strength against compressive strength for: a) C20, b) C25 LATCON

Conclusions

Based on the results obtained from the experiment conducted on laterized concrete (LATCON), it can be concluded that: the workability of LATCON increases while the percentage of water absorption by the concrete decreases with increase in replacement level of sand by laterite; 40% of laterite and 60% of sand is classified as falling into Zone 2 region as evidenced of grading (Fig. 1): the strengths of laterite concrete generally increased with age but decreases with increase in the replacement level of sand by laterite; LATCON with maximum of 40% replacement levels of sand by laterite attained the design strength of 20.48 N/mm^2 for C20, but was 15.36% lower than the design of 25 N/mm^2 for C25 at 28-day hydration period; for class C20 it is proposed that the mix proportion be modified to 1:0.8:1.2:4 (cement: daterite: sand: coarse aggregate) instead of the usual 1:2:4 (cement: sand: coarse aggregate) and correspondingly 1:0.8:1.2:2 instead of 1:2:2 for C25: and for C20 and C25 LATCON the following expressions are proposed:

$$f_{t(C20)} = 0.2093(f_{cu})^{0.5259}$$

$$R^2 = 0.8946$$

$$f_{t(C25)} = 0.4961(f_{cu})^{0.2945}$$

$$R^2 = 0.947$$

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Abstract

This paper presents the results of an investigation into the characteristics of concrete containing laterite as a full or partial replacement of sand. Sand in a concrete mix proportion of 1:2:4:0.6 and 1:2:2:0.6 (cement: sand: coarse aggregate: water-cement ratio) was replaced with 0, 20, 40, 60, 80, and 100% laterite. The concrete strength was confined to characteristic concrete strength grade of 20 and 25 N/mm^2. Experimental results based on qualitative and quantitative data shows that, concrete produced at 28-day hydration period with up to 40%> replacement level of sand by laterite attained the designed concrete compressive strength of 20.48 N/mm^2 for concrete strength grade of 20 N/mm^2 but fell slightly below 25 N/mm^2 for concrete strength of grade 25 N/mm^2. This indicates the possibility of using laterite as a partial replacement for sand up to 40%>. It was also observed from the results obtained that the workability - of laterite concrete increased with increase in the replacement level of sand by laterite, while the cube compressive strength, split cylinder tensile strengths and the percentage water absorption of the concrete decreased with increase in the replacement level of sand. Regression models relating the split cylinder tensile strength and cube compressive strength of concrete strength grade of 20 and 25 N/mm^2 of partial sand replacement with laterite in the various percentage, yielded predictive models $f_{t(C20)} = 0.2093\ (f_{cu})^{0.5259}$ and $f_{t(C25)} = 0.4961\ (f_{cu})^{0.2945}$ with correlation coefficients $R^2 = 0.8946$ and $R^2 = 0.947$ respectively.

Badanie wytrzymałości betonu z zastosowanym laterytem

Streszczenie

W artykule przedstawiono wyniki badań w zakresie właściwości betonu zawierającego lateryt jako całkowity lub częściowy substytut piasku. Piasek z mieszanki betonowej o proporcji 1:2:4:0.6

i 1:2:2:0.6 (cement : piasek : kruszywo grube : stosunek cementowo-wodny) zastąpiono układem 0, 20, 40, 60, 80 i 100% laterytu. Wytrzymałość betonu została ograniczona do charakterystycznej wytrzymałości betonu - 20 i 25 N/mm^2. Eksperymentalne wyniki oparte na danych ilościowych i jakościowych pokazują, że beton po 28-dniowym okresie dojrzewania, w którym na poziomie do 40% zastąpiono piasek laterytem, osiągnął wytrzymałość na ściskanie 20,48 N/mm^2 dla zaprojektowanej klasy 20 N/mm^2, ale wartość wytrzymałości na ściskanie dla zaprojektowanej klasy 25 N/mm^2 spadła poniżej 25 N/mm^2. Wskazuje to na możliwość wykorzystania laterytu do częściowego zastąpienia piasku do 40%. Na podstawie otrzymanych wyników stwierdzono również, że urabialność betonu z wykorzystaniem laterytu wzrosła wraz ze wzrostem poziomu zastąpienia piasku przez lateryt, zaś wytrzymałość na ściskanie, wytrzymałość na rozciąganie i procent zużycia wody w betonie zmniejszyły się wraz ze wzrostem poziomu zastąpienia piasku. Modele regresji odnoszące się do wytrzymałości na rozciąganie i wytrzymałości na ściskanie betonu klasy 20 N/mm^2 i 25 N/mm^2, w którym piasek w różnych procentach częściowo zastąpiono laterytem, pozwoliły przyjąć modele analityczne: $f_{t(\mathrm{C20})} = 0.2093(f_{cu})^{0.5259}$ oraz $f_{t(\mathrm{C25})} = 0.4961(f_{cu})^{0.2945}$ ze współczynnikami $R^2 = 0.8946$ i $R^2 = 0.947$.