A study on the properties of fibre reinforced laterized concretes

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Abstract
This paper reports on a study of strength properties of fibre reinforced laterized concretes. The variables in this experimental work are: laterite content in the concrete mix, which was varied from 0% to 100% at 10% interval; curing ages - 7, 14, 21 and 28 days. The concrete mix of 1:2:4 (Cement: Laterite/Sand: Granite) was used with a constant water/cement ratio of 0.65. The fibre content was kept at 2% at all replacement levels with 0% fibre content as control experiment. Three (3) 150mm cube specimens were cast and tested for each mix of concrete with laterite content varied at 10% at the curing ages of 7, 14, 21 and 28 days. The specimens were cured in water at temperature of $21^o \pm 1^oC$. The average load at which a set of three specimens failed was determined and used to compute the strength of each group of cubes. A consistent trend of increase in values of strength with age was observed in the specimens. A proportion of 45% laterite content as replacement of sharp sand in concrete produced the highest compressive strength. At 45% laterite content, a reduction of 18% in cost of fine aggregate in concrete was obtained. Although the strength characteristic of laterized concrete was found to be generally lower than that of normal concrete, notwithstanding, the strength is sufficient for use in normal concrete works.

Key words:
Compressive strength, normal, fibre and laterized concretes. Water /cement ratio.

INTRODUCTION
Laterized concrete is concrete in which the fine aggregate has been partially or wholly replaced with lateritic soils in its natural form [1,2]. These soils are readily available in Nigeria at building construction sites. They are easy to procure and do not require washing before use.

This is because they contain little or no organic material that can harmfully and chemically react with cement during the hydration of cement in the concrete.

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Investigations by Adepegba and Balogun [3] have shown that laterite fines can be used to produce dense concrete as sand in normal concrete. They experimented on part-replacement of sand with laterite. Laterized concrete of improved properties as compared with those of total replacement was obtained. Comparing laterized concrete with normal concrete, they observed that laterized concrete has optimum water/cement ratio, which if exceeded could cause segregation of the constituent materials or lead to non-uniform compaction. Furthermore, Adepegba, D. A., Gidigasu, M. D., Hassan T.C. and Nelson K.E. [4,5,6] conducted investigations on the structural properties of lateritic soils as well as short-term strength and deformation characteristics of laterized concrete elements. Salau and Balogun [7] investigated the shear resistance of laterized concrete without shear reinforcement and concluded that the presence of laterite in concrete improved its cracking ability and serviceability condition due to high ductility and stiffness of the laterite in the mixes.

With a water/cement ratio of 0.65, Balaguru and Foden [8] reported that the properties of lateritic soil that influence its rate and ease of mixing includes its degree of fineness, density, relative density, particle shape, chemical stability and chemical composition. In his study of the mineralogical properties of some Nigerian soils in relation to building problems, Ola [9] concluded that mineralogical contents and climatic conditions jointly influence the geo-technical behaviour of soils. He also reported that engineering properties of lateritic soil could be improved by stabilizing with mineral binders such as cement, bitumen, gypsum plaster and tar. Furthermore, it was also reported that lateritic soil found in Okitipupa area of Ondo state could be made suitable for construction if stabilized with 10-20% cement. Lasisi and Osunade [10] investigated the effects of grain sizes on the cube strength of lateritic soil and concluded that the finer the grain size of the lateritic soil the higher the compressive strength.

Osunade and Ogundeko [11] also accepted the views of earlier researchers on the subject that the addition of randomly distributed steel fibres to concrete increased the resistance to crack from 5.85N/mm^2 to 6.9N/mm^2. Since then, research into development of fibre reinforced cementitious composites has expanded rapidly to include the use of other materials such as plastic and carbon. They further investigated the effects of different types of fibre reinforcement on the shear and tensile strength of laterized concrete. Three types of fibres – steel, sisal rope and elephant grass were used. The results showed that of the three types of reinforcement, steel reinforced laterized concrete gave the highest values of shear and tensile strength followed by rope reinforced laterized concretes while elephant grass reinforced specimens gave the least values. Hansen [12] reported that researchers at the Columbia and Rolla campuses of the University of Missouri are combining different types of fibre-reinforced polymers on bridges in an effort to develop strong and economical decks.

OBJECTIVES

The objectives of this study are:

i. To determine the tensile and compressive strengths of different mixes of concretes containing lateritic fines as partial/whole replacement for normal fine aggregate (sharp sand)
ii. To determine the optimum level (%) of partial replacement of fine (sand) with laterite.
iii. To determine the economic importance of use of laterized concrete in place of normal concrete in construction

MATERIALS AND METHODS

The constituents of concrete are coarse aggregate from crushed rock (granite chips); fine aggregates of sand from Ogun riverbed, laterite and Ordinary Portland Cement as binding agent. The dry density tests of the constituent materials were determined in the laboratory. Particle size distribution analysis was also carried out. The acidity level (pH value) as well as the chemical analysis of the laterite were also determined. In this experiment, steel fibres were used. The fibres are waste product from lathe machine operated in workshop. They are blinking short and thin irregular shaped pieces of metal of average length 12.5mm and mean thickness of 2mm.

Concrete of 1:2:4 mix (Cement: Fine aggregate: Coarse aggregate) was used throughout the experiment; with the fine aggregate being a mixture of laterite soil and/or sharp riverbed sand. The percentage of laterite was varied between 0% and 100% laterite, while all other constituents of the concrete were kept constant, including fibre contents at 2% in all mixes. The normal concrete specimens served as control for the experiment. The percentage of fibre was chosen to ensure uniform distribution as well as prevent balling of fibres in the concrete matrix. The water/cement ratio was kept constant at 0.65. The specimens were cast, cured and tested in accordance with B.S. 1881 [12, 13]. They were then demoulded after 24 ± 0.5 hours after casting and stored in a curing tank containing clean water until the age of test. The cubes were removed from the curing tank and tested for compression using 600 KN Avery Denison Universal Testing Machine at a loading rate of 120 KN/min. The maximum crushing load was recorded and the compressive strength of each cube calculated by dividing the maximum load with its cross-sectional area;

$$f_{cs} = P/A \qquad \text{..................} \qquad (1)$$

where:

f_{cs} = Crushing Strength;
P = Crushing Load; and
A = Cross-Sectional Area

RESULTS AND DISCUSSION

The results of experiments on the concrete constituents show the following trends. The particle sizes of coarse aggregates ranged from 3.125 to 16.0 mm maximum size with dry density value of 2840 kg/m^3 while the particle sizes of the sand are those passing sieve with aperture 2.36mm but retained on sieve of 63 μm apertures and having dry density of 2770 kg/m^3. The laterite fines have grain sizes passing through sieve of aperture 2.36mm but retained on sieve of 63 μm apertures with a density of 2480 kg/m^3. In this experiment, it was observed that the average density of the plain concrete specimens was 2538.27 kg/m^3 For the laterized concrete, the average density varied between 2567.01 kg/m^3 and 2469.13 kg/m^3 as the laterite content increased from 10% to 100%. Notwithstanding the decrease in density as laterite content increased in concrete, these results indicate that the laterized concrete can be regarded as normal weight concrete. The results of sieve analysis and grading curves are shown in Fig.1

The moisture content of the laterite soil was 7.4%, the value for the sharp sand was 5.3% while granite was found to have 0.70%. The liquid limit of the laterite was 44.70%, plastic limit 19.80% and linear shrinkage 9.10%. The pH value of the laterite was found to be 5.1, reddish in colour, well-formed crystallized kaolin with organic content of 0.08%, exchangeable sodium percentage (ESP) at 1.45%. From chemical analysis carried out on the sample of laterite, $Si0_2$ was 65%, Al_20_3 was 18.1%, $Ti0_2$ was 2%.

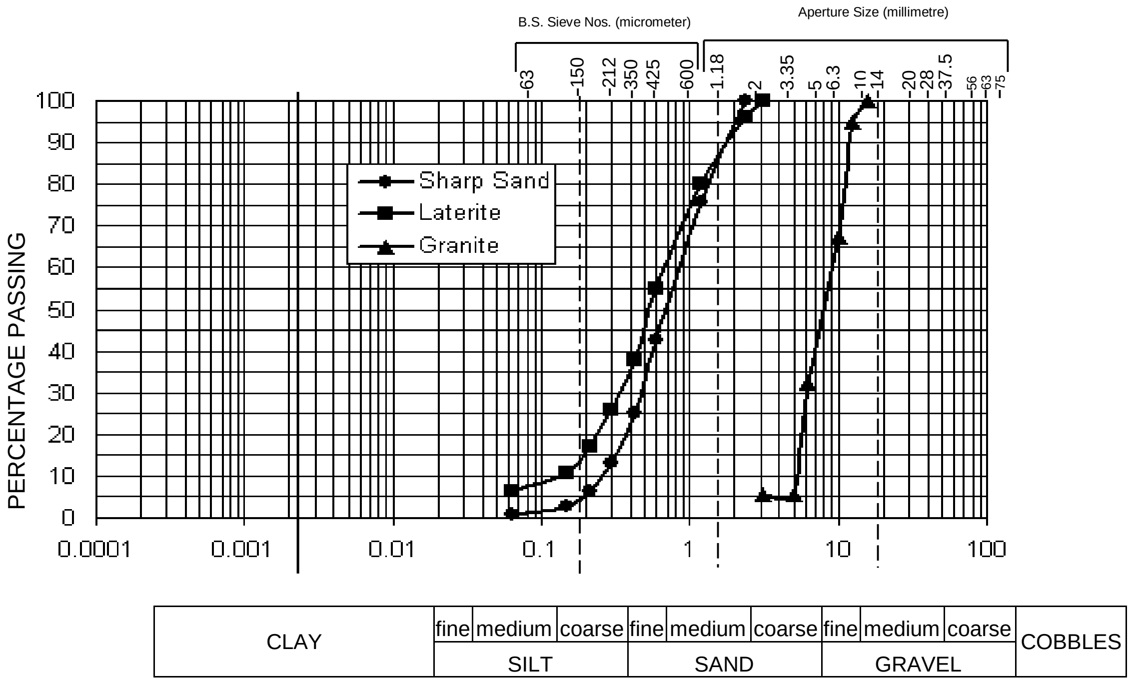

Fig.1 **Particle Size Distribution of The Aggregates (Sieve Analysis)**

The Fe_2O_3 was found to be 5.6%, MgO stood at 0.1% and SO_3 was 0.3%. The results further showed that the laterite had kaolin structure, slightly acidic and ferolitic with the silica alumuna ratio of 65/18.1 = 3.59. Accordingly, this ratio is greater than 2, it means the origin of the soil is non-lateritic tropically weathered soil.

Slump Test:
The results of slump test showed that the mix with zero percent laterite content has the highest workability value of 55mm. With the introduction of laterite fines into the mix, the slump values decreased. This may be due to finer grain sizes associated with laterite fines. The specific gravity of laterite was 2.48 while that of sand was 2.77, and batching was by weight. It means that for a given weight reduction of sand in a mix, greater quantity (volume) of laterite would be required for replacement. As the water/cement ratio was kept constant, the workability of the mix reduced (Fig. 2).

Compressive Test:
The summary of the compressive strength results of the tests on cubes produced from different proportions of laterite/sand in the mixes is shown in Appendix 1.

Figure 3 shows the strength values of concretes having different proportions of sand to laterite content in concrete. Fig.3 shows that there was increase in strength at 7-day curing for mixes with 10%, 30% up to 50% laterite/sand content. For these percentages, the strength values are 16.02, 17.16 and 19.97N/mm^2, respectively. Between 50 and 70%, there was a relatively sharp reduction in strength at all ages while after 70% and up to 100% there was a more gentle reduction in strength. The reduction in strength at this interval of replacement level (≥ 50% laterite content) may be attributed to low workability of the mix as a result of insufficient water for the hydration process.

Analysis of results of crushing tests carried out on cubes of different mixes show that the average rate of increase in strength of the plain concrete mix was highest in the first seven days. This stood at 3.09N/mm^2 per day compared to the fibre reinforced mix, which was 2.64N/mm^2 per day during the same period. At the early age of strength development, the bond between the steel fibres and the concrete matrix tends to be weak, resulting in lower compressive strength values. With age, the values increase.

For the mixes with various proportions of laterite content, the average rate of strength development was comparatively lower than in the plain concrete. The value increased from 2.29N/mm^2 per day for 10% sand replacement with laterite to 2.85N/mm^2 per day for 50% sand replacement with laterite. A graphical representation of strength development of the samples tested (Fig.3) showed that 45% of laterite could be considered ideal for structural concrete provided adequate measures are taken to produce quality mixes. Since the water/cement ratio was constant for all mix proportions, the inadequacy of water in the mix containing 60 and 70% laterite resulted in low workability, which might have contributed to low strength. With low workability, from tested specimens, visual inspection showed that high laterite content allows air to be trapped in abundant volume in the mixes. The pores so created tend to reduce the strength of the mixes. Figure 4 shows the strength characteristics of the concrete mixes of varying laterite contents with age.

On the average, with partial replacement of sand with laterite between 10% and 50% there was noticeable increase in the strength of the mix. The strength of the plain concrete mix at seven days stood at 21.63N/mm^2, while at 50% laterite content, the strength was 19.97N/mm^2 (a reduction in strength of 7.63%).

Comparing mixes with 10% laterite content with mixes of 30% and 50% laterite content, the increase in strength at seven days stood at 6.64% and 19.78%, respectively. With age, these characteristics changed as mixes with 10% partial replacement of fines with laterite proved to be superior in strength. After twenty-eight days of curing, mixes with 10% lateritic fines gave a strength indication of 22.68N/mm^2 while that of 50% replacement recorded 21.62N/mm^2. The ability of fibres to marginally increase the strength characteristics of concrete is more apparent with age. The low strength exhibited by laterized concretes with about 70% laterite as fines is traceable to the low workability of the mix, which could have resulted in incomplete hydration process (see Figs. 4 and 5). Figure 5 gives the likely percentage changes in strength characteristics of the concrete mixes of variable laterite contents with age. This is derived from the quantities being measured and is expressed as

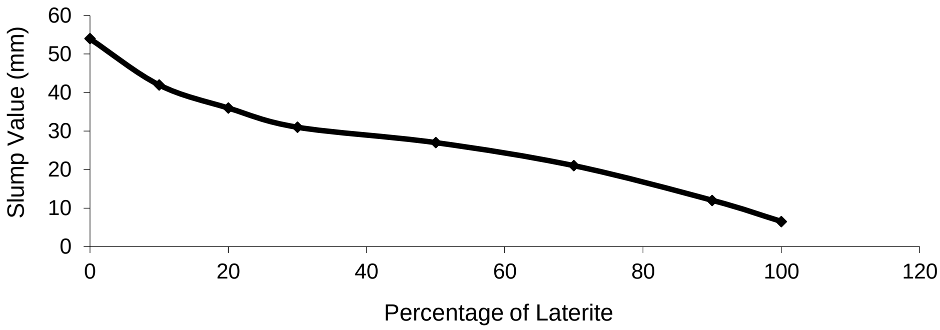

Fig 2. Variation of Slump Values With Increase In Laterite/Sand Ratio

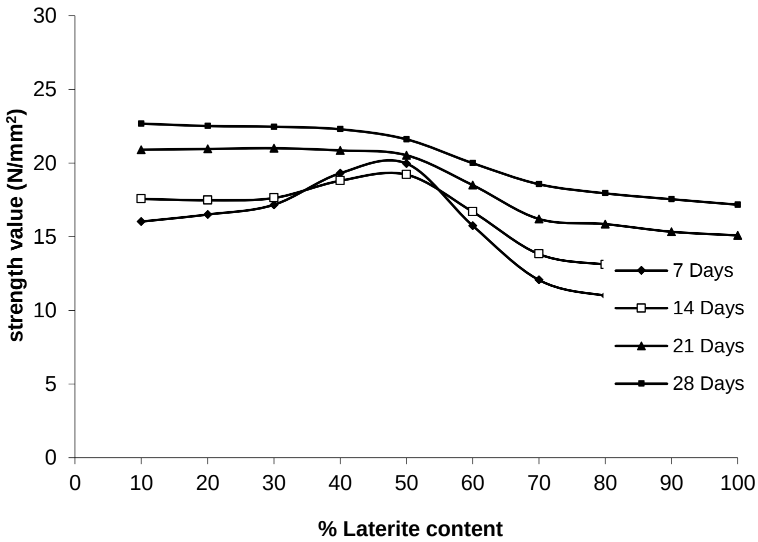

Fig.3 Strength Characteristics relative to laterite content

f_c = compressive strength of plain concrete at each curing age; and

f_{ci} = compressive strength of laterized concrete of a defined proportion of laterite/sand content at each curing age.

At the early stages of strength development, with normal concrete as control the percentage variation in strength of fibre reinforced concrete compared to normal concrete improved considerably. From figure 5, it is seen that normal concrete after seven days curing tends to be stronger than fibre reinforced normal concrete. On 28th day, the reverse was the case. The fibre reinforced normal concrete on 28th day showed better strength characteristics.

During the same period, the percentage variation in strength characteristics of other mixes of laterized concrete compared to the normal concrete decreased with age. With age, the gap between the strength of the normal concrete and that of laterized concrete decreases.

ECONOMY

There would be considerable economic savings if laterized concrete is used in construction. For example, in many areas of Lagos State, the cost of $3.6m^3$ of fine aggregate (sand) as at October 2005 was ₦6500.00 compared to that of laterite which stood at ₦3700.00. This shows a cost ratio of 1:1.724; laterite to sharp sand as fines. If fine aggregate is replaced with 45% laterite, the cost ratio becomes 1:1.412. This shows about 18% reduction in the cost of fine aggregate.

CONCLUSIONS AND RECOMMENDATIONS

From the findings of this investigation, the following conclusions are made:

1. For 1:2:4 mix ratio and at 0.65 water/cement ratio, both normal and laterized concretes can be regarded as normal weight concretes. On average the laterized concrete strength was 10-11% below the normal concrete strength.
2. There exist a consistent pattern of strength development with time curve for both laterized and plain concrete specimens tested at all ages. The compressive strength results show that laterized concrete with 45% laterite content is adequate for structural works.
3. At 45% laterite content in the mix, a reduction of 18% in cost was obtained.
4. Although the strength character-istic of laterized concrete was found to be generally lower than that of normal concrete, notwithstanding, the strength is sufficient for use in normal concrete works.
5. From the above aforementioned conclusions, it is recommended that more research be carried out on the durability and structural deformation characteristics of laterized concrete elements before the use of laterized concrete is fully accepted as an alternative to plain concrete in construction; especially in low cost and medium scale projects.

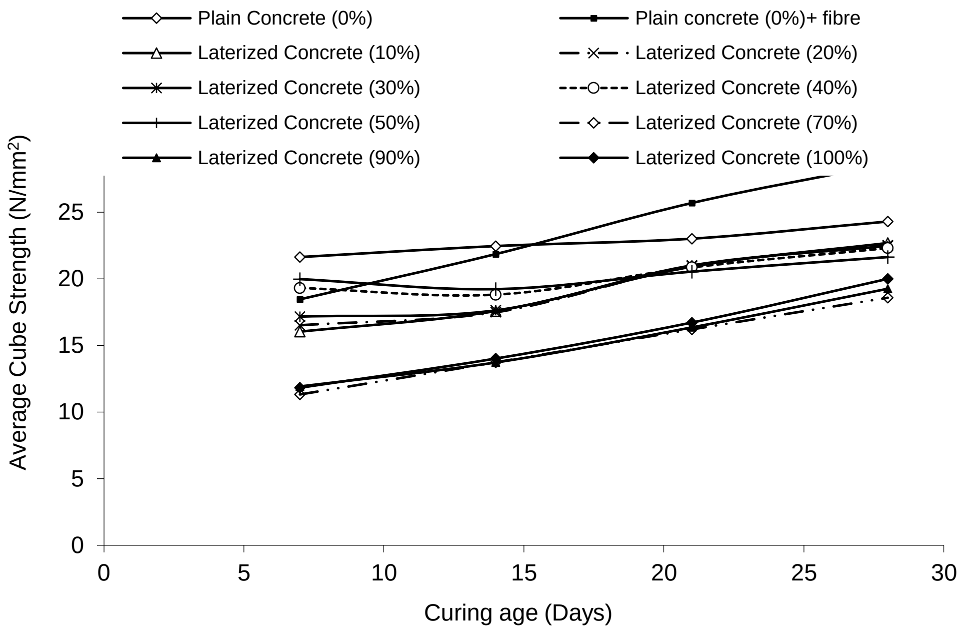

Fig.4 Short-term strength characteristics

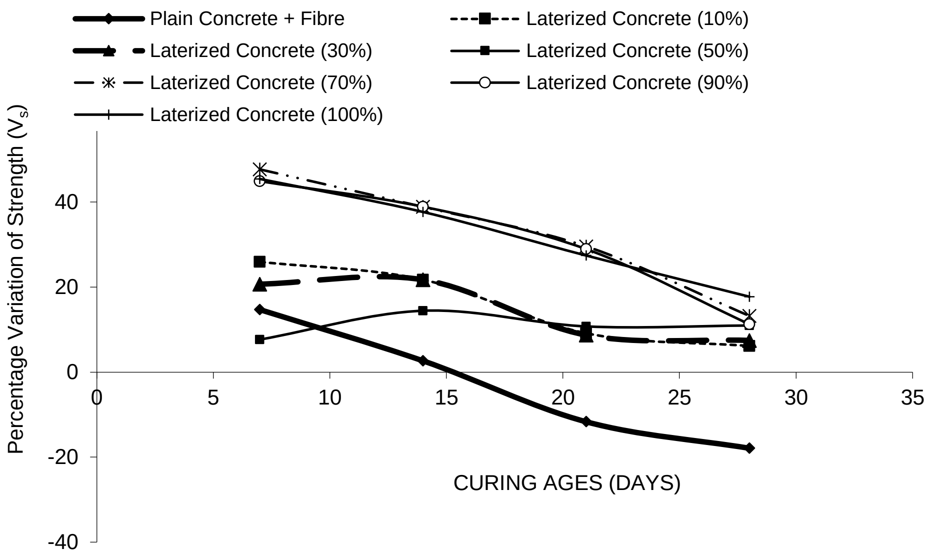

Fig.5 Percentage Variation in Strength with Different Proportions of Lateriste/sand Ratio

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Appendix 1: Summary of Average Cube Strength (N/mm^2)

Age (Days)	7	14	21	28
Average Weight (Kg)	8.70	8.65	8.65	8.70
Average Density (Kg/m^3)	2577.78	2563.00	2563.00	2577.78
Plain Concrete	21.63	22.45	23.00	24.28
Plain Concrete + fibre	18.45	21.85	25.68	28.62
Laterized Concrete (10%)	16.02	17.57	20.90	22.68
Laterized Concrete (20%)	16.50	17.48	20.95	22.52
Laterized Concrete (30%)	17.16	17.63	21.00	22.47
Laterized Concrete (40%)	19.30	18.80	20.85	22.30
Laterized Concrete (50%)	19.97	19.22	20.53	21.62
Laterized Concrete (60%)	15.75	16.70	18.50	20.00
Laterized Concrete (70%)	12.06	13.83	16.20	18.57
Laterized Concrete (80%)	11.00	13.12	15.85	17.95
Laterized Concrete (90%)	10.75	12.83	15.33	17.55
Laterized Concrete (100%)	10.45	12.55	15.08	17.18