Effect of Different Coarse Aggregate Sizes on the Strength Characteristics of Laterized Concrete

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Abstract. The high cost of conventional concrete materials is a major factor affecting housing delivery in developing countries such as Nigeria. Since Nigeria is blessed with abundant locally available materials like laterite, researchers have conducted comprehensive studies on the use of laterite to replace river sand partially or fully in the concrete. However, the works did not consider the optimum use of coarse aggregate to possibly improve the strength of the laterized concrete, since it is normally lower than that of normal concrete. The results of the tests showed that workability, density and compressive strength at constant water-cement ratio increase with the increase in the coarse aggregate particle size and also with curing age. As the percentage of laterite increases, there was a reduction in all these characteristics even with the particle size of coarse aggregate reduction due to loss from the aggregate-paste interface zone. Also, when sand was replaced by 25% of laterite, the 19.5mm and 12.5mm coarse aggregate particle sizes gave satisfactory results in terms of workability and compressive strength respectively at 28 days of curing age, compared to normal concrete. However, in case of 50% up to 100% laterite contents, the workability and compressive strength values were very low.

1. Introduction

Due to increasing cost of producing concrete using conventional materials such as cement, river sand as fine aggregate and granite as coarse aggregate in Nigeria, researchers have been working on alternative, cheap and readily available materials that would serve perfect substitutes for such materials while still meeting the set requirements for concrete in the industry, see Udoeyo [1].

Abdullahi [2] established that aggregate type has effect on the compressive strength of normal concrete and concluded that concrete made from crushed quartzite demonstrates higher compressive strength at all ages compared to the concrete with granite as a coarse aggregate. However, Aginam et al [3] gave a contrary view with the higher compressive strength of the normal concrete with granite as a coarse aggregate when compared with the concrete made with washed and unwashed gravel as a coarse aggregate component.
Muhit et al [4] investigated the effects of “impact crushed” and “vertically shafted” coarse aggregates on the concrete blocks. They concluded that the slump values for the two types of crushed aggregates decreased moderately with water-cement ratio and concrete samples made with “vertically shafted” coarse aggregate having higher slump value than those with “impact crushed”. However, the compressive strength of “impact crushed” aggregate concrete is higher compared to the “vertically shafted” aggregate with the decrease of water-cement ratio.

Jimoh and Awe [5] also investigated the size of aggregate that will improve the properties of the structural normal concrete and concluded that the use of quarry dust and 20mm granite improved the concrete strength by 34% over the strength produced by concrete with sand and gravel of 28mm maximum size. Also, as coarse aggregates’ size increases, normal concrete strength decreases. The rate of fall in strength is highest with the concrete containing quarry dust as a fine aggregate. However, the case of laterized concrete was not studied. Xie et al [6] confirmed these earlier finding that the compressive strength decreases with the increase in the maximum coarse aggregates size. Bhiskshma and Florence [7] assessed the effect of size in higher grade concrete using high volume fly ash and found out that maximum size of coarse aggregates of 12.5mm gave the highest compressive, splitting and flexural strengths; hence the aggregate sizes influence strength.

Laterite has been used for wall construction around the world; it is a cheap, environmentally friendly and abundantly available building material in the tropical region. Lateritic soils, according to Osadebe and Nwakonobi [8], are widely used as construction material in Nigeria, other under-developed and developing countries of the world. However, they argue that laterite has not been extensively used as constructing medium in large-size building structures, probably because of the lack of adequate data needed in the analysis and design of structures built of lateritic soils. Joseph et al [9] investigated the structural characteristics of concrete using various combinations of lateritic sand and quarry dust as complete replacement for conventional river sand fine aggregate. The quantity of laterite was varied from 0% to 100% against quarry dust at intervals of 25%. Specifically compressive strength ranged from 17-34.2N/mm$^2$ for the mixes considered. These results compare favourably with those of conventional concrete. The concrete was found to be suitable for use as structural members for buildings and related structures, where laterite content did not exceed 50%.

Olubisi [10] ascertained the suitability of laterite as aggregate substitutes at 0, 10, 20, 30 and 40% of fine aggregate used in the construction industry. The results showed that the compressive strength of laterized concrete with laterite-fine aggregate ratio variation decreases when subjected to alternate wetting and drying and increases when subjected to magnesium sulphate ($\text{Mg}_2\text{SO}_4$). It was also observed that a laterized concrete with a laterite-fine aggregate ratio of 20% conditioned to a temperature range of 100°C attained optimum compressive strength of 12.9N/mm$^2$.

With all these research works on laterized concrete, no known attempt has been made to evaluate the effect of different coarse aggregate particle sizes on workability and compressive strength of laterized concrete, as in the case of normal concrete. However, it is well known that coarse aggregate of particular size is sometimes supplied and used on site. The aim of this study, therefore, is to determine the extent to which different sizes of coarse aggregate used for production would influence the workability and strength characteristics of laterized concrete.

2. Materials of experimental procedure
The coarse aggregates of different particle sizes viz; 19.5mm, 12.5mm, 9.5mm, 5.0mm and 2.36mm were obtained from Ojodu-Berger in Lagos State while the sharp river sand, used as a fine aggregate,
was collected from Ogun River bed in Ogun state of Nigeria; the reddish-brown laterite, obtained from Sagamu in Ogun State, has maximum size 2.36mm sieve, just as the sharp sand; Ordinary Portland Cement with fineness value of 320m$^2$/kg, initial and final setting times of 85 and 218 minutes respectively was used. Portable water, free from any visible impurities was used for the experiments.

The mix proportion of the concrete used in this study is 1:2:4 (cement: sand/laterite: granite) with a constant water-cement ratio of 0.60. The sand was replaced at 25% and 50% with laterite while 0% was used for normal concrete with all the particle sizes of granite inclusive in the coarse aggregate.

Slump and Compacting Factor tests were carried out on the fresh concrete using granite (all particle sizes inclusive) at 0%, 25%, and 50% laterite contents, as well as for each of the coarse aggregate sizes (19.5mm, 12.5mm, 9.5mm, 5.0mm and 2.36mm) at 25% and 50% laterite contents to determine their workability according to ASTM C 143. Density and compressive strength tests were carried out on 150mm x 150mm x150mm cubes in a 2000kN capacity strength machine after curing for the relevant number of days in line with BS EN 12390 series. A total of 156 Nos. 150mm concrete cubes with different laterite contents were tested at different curing ages of 7, 14, 21 and 28 days.

3. Results and discussions

3.1. Preliminary tests on aggregates

The results of particle size distribution for the aggregates are shown in figure 1 while table 1 gives the physical properties of the materials used in the laterized concrete. Table 1 shows that the coefficients of uniformity of the laterite, sand and granite are respectively, 2.35, 2.25 and 2.45 while those of curvature are 1.35, 1.38 and 1.24. In view of these, the aggregates are well graded and suitable for concrete production according to ASTM C33. The fineness moduli are within the specified limit of ASTM 125.

3.2. Tests on fresh concrete

The results of the slump test, indicating the workability of the concrete at 25% and 50% laterite contents with granite (all particle sizes inclusive) as controls, and using different coarse aggregate sizes (retained on 19.5mm, 12.5mm, 9.5mm, 5.0mm and 2.36mm sieve sizes) at 25% and 50% replacement of sand with laterite are shown in table 2.

![Particle size distribution curves for laterite, sand and granite.](image.jpg)
For controls at 25% and 50% laterite contents using all granite particle sizes inclusive, the results show true slump all through but the degree of workability ranges from medium at 25% to a very low degree at 50% laterite contents due to high water absorption ability of laterite. In view of this, more water is needed as the percentage of laterite increases to achieve workable concrete. Moreover, the concrete slump decreases as coarse aggregate particle size decreases in the mixes from 80mm slump value for 19.5mm coarse aggregate particle size to zero for 2.36mm particle size at 25% laterite content. This is due to large surface area from the small particle sizes of coarse aggregate in the mix that requires more water to improve workability.

Table 1. Summary of the physical properties of the materials used.

| Physical Properties | Cement | Laterite | Sand | Granite |
|---------------------|--------|----------|------|---------|
| Moisture Content (%)| -      | 0.72     | 3.56 | 1.21    |
| Specific Gravity    | 3.15   | 2.54     | 2.62 | 2.65    |
| Bulk Density (kg/m³)| 2298   | 2642     | 2668 | 2750    |
| Dry Density (kg/m³) | -      | 2638     | 2610 | 2729    |
| Coefficient of Uniformity (cu) | - | 2.35     | 2.25 | 2.45    |
| Coefficient of Curvature (cc) | - | 1.35     | 1.38 | 1.24    |
| Fineness Modulus    | -      | 1.75     | 1.98 | 4.50    |

Table 2. Slump value for laterized concrete with different coarse aggregate sizes at 25% and 50% laterite contents.

| Particle Size (mm) | 25% Replacement of Sand with Laterite | 50% Replacement of Sand with Laterite |
|-------------------|--------------------------------------|--------------------------------------|
|                   | Slump Value (mm) | Type of Slump | Degree of Workability | Slump Value (mm) | Type of Slump | Degree of Workability |
| 19.5              | 80            | True Slump    | Medium                | 35              | True Slump    | Low                  |
| 12.5              | 65            | True Slump    | Medium                | 20              | True Slump    | Low                  |
| 9.5               | 45            | True Slump    | Low                   | 10              | True Slump    | Low                  |
| 5.0               | 15            | True Slump    | Low                   | 0               | True Slump    | Low                  |
| 2.36              | 0             | True Slump    | Low                   | 0               | True Slump    | Low                  |
| All Sizes of Coarse Aggregate | 25            | True Slump    | Low                   | 10              | True Slump    | Low                  |

With 25% laterite content in the mix, using coarse aggregate sizes of 19.5mm and 12.5mm, medium workability (with slump of 80mm and 65mm) was achieved but its values were low for other remaining coarse aggregate sizes. This also implies that more water is needed for smaller coarse aggregate particle sizes to achieve medium workability because of large surface area. However, for 2.36mm coarse aggregate particle size at 25% laterite content and for both 5.0mm and 2.36mm coarse aggregate sizes at 50% laterite content values of slump were zero, showing a stiff consistency. This may be due to affinity of laterite for water and also large surface area caused by the small particle sizes of coarse aggregates.

The compaction factor test results for controls (all granite particle sizes inclusive) and with different coarse aggregate sizes (19.5mm, 12.5mm, 9.5mm, 5.0mm and 2.36mm sieve sizes) at 25% and 50% laterite contents show that the degree of workability ranges from medium at 25% laterite content to a very low degree at 50% laterite content for controls (all granite particle sizes inclusive)
due to high water absorption ability of laterite. However, it was observed that the workability of the laterized concrete decreases as the coarse aggregate particle size decreases from 19.5mm particle size (0.938 to 0.804) to 2.36mm particle size (0.73 and 0.70) for both 25% and 50% laterite contents. This is in agreement with slump test results.

3.3. Tests on hardened concrete

3.3.1. Density.

The relationship between density of the laterized concrete for controls (all granite particle sizes inclusive) as well as with different coarse aggregate particle sizes at 25% and 50% laterite contents and curing age are shown in table 3.

Table 3. Variation of Density of Laterized Concrete with Different Coarse Aggregate Particle Sizes and Curing Age.

| Curing Age (Days) | Coarse Aggregate Particle Sizes (mm) at 25% Laterite Content | Density (kg/m³) | Coarse Aggregate Particle Sizes (mm) at 50% Laterite Content |
|-------------------|---------------------------------------------------------------|-----------------|---------------------------------------------------------------|
|                   | 2.36              | 5.00             | 9.50             | 12.50            | 19.50          | 2.36              | 5.00             | 9.50             | 12.50            | 19.50          |
| Control (All Granite Sizes) | 2565              | 2325             | 2391             | 2400             | 2435             | 2488             | 2477             | 2281             | 2311             | 2358             | 2468             | 2551             |
| 14                 | 2577              | 2340             | 2400             | 2429             | 2506             | 2545             | 2500             | 2290             | 2325             | 2429             | 2497             | 2557             |
| 21                 | 2651              | 2367             | 2414             | 2462             | 2518             | 2577             | 2610             | 2340             | 2370             | 2515             | 2533             | 2577             |
| 28                 | 2740              | 2400             | 2429             | 2503             | 2548             | 2640             | 2651             | 2355             | 2456             | 2533             | 2595             | 2592             |

It was observed that the density of concrete produced using all granite particle sizes inclusive and different coarse aggregate particle sizes at 25% and 50% laterite contents generally increases with curing age and the increase in coarse aggregate particle size from the smallest to the biggest, (2400kg/m³ for 2.36mm and 2640kg/m³ for 19.5mm at 25% laterite content and 28 days curing age), but reduces insignificantly with the increase in percentage of laterite content. All the laterized concrete studied can be considered as normal weight and suitable for structural purposes.

3.3.2. Compressive Strength.

The variation of compressive strength of concrete with curing age for controls (using all granite particle sizes inclusive) at 0%, 25% and 50% replacement of sand with laterite is shown in figure 2.
Figure 2. Variation of compressive strength with curing age for controls (all granite particle sizes) at 0%, 25% and 50% laterite contents.

Figure 2 shows that normal concrete with all granite particle sizes inclusive at 0% laterite content gives peak values of compressive strength at 7 days (16N/mm\(^2\)) and 28 days (24.44N/mm\(^2\)), while concrete with maximum laterite content (50%) gives minimum strength at 7 days (14.2N/mm\(^2\)) and 28 days (20.00N/mm\(^2\)). This shows that compressive strength decreases with increase in laterite content in concrete. This is in consonance with Udoeyo [1]. However, the development of strength in normal and laterized concrete is consistent.

The comparison of compressive strength for control (all granite particle sizes inclusive) and with different coarse aggregate particle sizes at 25% laterite content can be seen in figure 3.

Figure 3. Comparison of compressive strengths of laterized concrete for control (all granite sizes) and with different coarse aggregate particle sizes at 25% laterite.
It can be observed from figure 3 that compressive strength for laterized concrete like normal concrete increases with curing age, \{at 25% laterite content with 19.5mm coarse aggregate particle size (16.00N/mm² at 7 days and 22.22N/mm² at 28 days)\}. Also, it increases with the increase in coarse aggregate particle size, (22.22N/mm² for 19.5mm and 12.89N/mm² for 2.36mm at 28 days) but for the two biggest particle sizes 19.5mm and 12.5mm, the values of compressive strength for both 25% and 50% laterite contents are almost the same with that of control at 28 days of curing.

Garrison [11] showed that concrete mixes with larger coarse aggregate at constant water-cement ratio give lower compressive strength due to the presence of a weak zone at the aggregate-paste interface where cracking will first occur. He further explained that with larger aggregates, larger cracks can form at the interface, and they can interact easily with paste cracks as well as other interfacial cracks. In contrast to this, the values of compressive strength at 28 days curing age for laterized concrete (25% laterite content) with the two biggest particle sizes of 19.5mm (22.22N/mm²) and 12.5mm (21.78N/mm²) from figure 3 are very close to that of normal concrete (24.44N/mm²). This might be a result of the presence of laterite in the paste which improved the aggregate-paste interface zone to avoid any form of failure due to crack.

4. Conclusions and recommendations

From this study, the following conclusions can be arrived at:

1. The workability of laterized concrete at constant mix ratio of 1:2:4 and water-cement ratio of 0.6 increases as coarse aggregate particle size increases. However, it decreases with the increase in percentage of laterite content.
2. For the two biggest coarse aggregate particle sizes (19.5mm and 12.5mm), the workability of laterized concrete at 25% laterite content was almost the same (medium) compared to that of normal concrete but was low for 50% laterite content.
3. The density of the hardened concrete (using all granite particle sizes inclusive) increases from 0% (normal concrete) to 25% laterite content but later decreases from 25% to 50%.
4. The mean compressive strength at constant mix ratio of 1:2:4 and water-cement ratio of 0.6 increases with the increase in coarse aggregate particle sizes and curing age but decreases as percentage of laterite content increases. However, the 28th day compressive strengths of concrete for control (using all granite particle sizes inclusive) at 0%, 25% and 50% laterite contents were almost the same. Also, for the two biggest coarse aggregate particle sizes (19.5mm and 12.5mm), the 28th day mean compressive strengths of laterized concrete at 25% laterite content were almost the same with that of control but for 50% laterite content, it was low.

It is recommended that laterized concrete can be used in place of normal concrete provided the percentage of laterite content to replace sand does not exceed 50%, but 25% laterite content gives a good quality concrete in terms of workability and compressive strength even when compared to normal concrete.

Coarse aggregate with maximum particle size of 19.5mm should be used where high strength laterized concrete is required but it is significant to consider the dimensions of such concrete member, the size and spacing of reinforcement. However, when smaller particle sizes of coarse aggregate like 2.36mm, 5.00mm and 9.50mm are required to produce concrete, the cement paste would require high percentage of water to produce a concrete with good degree of workability.
5. References

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