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# Determining the Properties of Green Laterized Concrete with Fly Ash for Sustainable Solid Waste Management

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Fly ash is an industrial solid waste that has found application in concrete production for minimization of $CO_2$ emission. The introduction of fly ash into concrete and the replacement of the conventional fine aggregate with laterite can be viewed as an attempt to convert industrial waste material cum locally available fine aggregate to a purposeful use. This paper presents the results of a comprehensive experimental investigation on the strength characteristics of green laterized concrete with fly ash. The physical and chemical properties of fly ash and laterite were studied to evaluate its possible influence on both fresh and hardened state of cement and laterized concrete. A total of 120 cubes of 100 mm dimensions were cast and cured in water for 7, 14, 21, 28 and 56 d of hydration. The results show that the 28 d density dropped from 2467 kg/m$^3$ to 2300 kg/m$^3$ and the compressive strength from 21.94 N/mm$^2$ to 15.02 N/mm$^2$ for 20 % of fly ash content with 0 % - 30 % laterite introduced. The compressive strength decrease with increase in laterite content; the strength of the laterized concrete increases as the curing age progresses.

## 1. Introduction

The continuous search for alternative binders (cement), fine, and coarse aggregate replacement materials had driven interest to utilize industrial and agricultural by-product (waste) as an alternative construction material in the last decades. The investigation of the use of solid waste materials in concrete production have been receiving enormous research attention in the recent past. They include the usage of Fly Ash (FA), volcanic ash (Hossain, 2003), rice husk ash, ceramic powder (Hussein et al, 2017), corncob ash, pulverized burnt clay ash (Al-Ani and Hughes, 1989), Blast Furnace Slag (BFS), core fibre (Ogunbode et al., 2017), Silica Fume (SF) and laterite (Osunade, 2002). Others are coconut shell, oil palm shell (Mohammadhosseini and Awal, 2015), polypropylene carpet fibres (Mohammadhosseini et al., 2017), sawdust ash, acha (wheat) dust ash, sugarcane fibre (bagasse) ash, groundnut husk ash and mining tailings. The industrial and agricultural waste ash is pozzolanic materials because of their reaction with lime (calcium hydroxide) liberated during the hydration of cement. Amorphous silica present in the pozzolanic materials combines with lime and forms cementitious materials. Ordinary Portland Cement (OPC) containing FA and silica fume have gained increasing acceptance while Portland cements containing agricultural waste pozzolans like millet husk ash, rice husk ash, corncob ash and burnt oil shale are dominantly used in areas that these materials are available. FA typically replaces 10 – 30 % of the Portland cement although levels of 50 – 60 % have been advocated (Bilodeau and Malhotra, 2000). When silica fume is added, it commonly comprises 5 – 10 % of the binder. According to Varghese (2006), FA obtained from lignite is superior to that obtained from coals. Up to 20 % FA replacement of cement and 30 % replacement of fine aggregates can be used to replace cement and fine aggregate. In addition to economic and ecological benefits, the use of FA in concrete improves its workability,

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reduces segregation, bleeding, heat evolution and permeability, inhibits the alkali-aggregate reaction, and enhances sulphate resistance.

Laterite has been identified as a possible material for partial replacement of sand in concrete to produce what has been called laterized concrete. Olusola (2005) said that laterite as a term used to describe all the reddish residual and non-residual tropically weathered soils, which form a chain of materials ranging from decomposed rock through clay to sesquioxide ($Al_2O_3$ + $Fe_2O_3$) - rich crusts, generally known as the carapace. Laterized concrete is defined as concrete in which stable laterite fines replace sand wholly or partly. It is called terracrete when the sand is replaced with laterite wholly (Olusola, 2005). Neville (2006) reported that laterite, when used to replace sand in concrete wholly, can rarely produce concrete stronger than 10 N/mm$^2$, but Osunade (2002) has proved that laterite can be used to produce concrete of much higher grades. Studies have been carried out on effects of laterite incorporation in strength and serviceability properties of fresh and hardened concrete (Ata, 2007). This paper presents the results of a comprehensive experimental investigation on the strength characteristics of FA/OPC laterized concrete having 28 d target strength of 25 N/mm$^2$. The introduction of FA into concrete and now laterized concrete can be viewed as an attempt to convert an industrial waste material cum locally available fine aggregate to a purposeful use.

## 2. Methodology

### 2.1 Sample collection

The FA used was obtained as an ash (fine particles) from the waste dump at Thermal Electric Power Station in Oji River, Enugu State, Nigeria. The granite size used was of 10 – 20 mm obtained from Tri- Acta quarry in Minna, Nigeria. The fine aggregate used were sand and laterite. The laterite was obtained from Pogo near Shelter Clay Brick Company, while sand used was river sand, free from deleterious substances obtained from Sarkin pawa area all in Niger State, Nigeria, the coarse aggregate used was granite obtained from quarry in Dikko, Niger State, Nigeria with maximum size 20 mm. The cement used was Dangote Portland cement produced in Obajana factory, Kogi State, Nigeria and conformed to BS EN 197 (2000). Portable drinking water, which was obtained from borehole water supply, was used for the concrete mixes and curing.

### 2.2 Chemical analysis of the sample

The Chemical Analysis of laterite and FA samples was carried out in the Chemistry laboratory of West African Portland Cement Company (WAPCO) - Shagamu Works Department via an X-ray Fluorescent Analysis using a Total Cement Analyser model ARL 9900 XP.

### 2.3 Concrete mix proportions

The laterized concrete mixtures made up of two levels of FA replacements at 0 and 20 % and four levels of laterite replacement ranging from 0 to 30 % (i.e. a total of 8 levels of samples produced in triplicates) were tested. The control mixture was proportioned for a target concrete strength of 25 N/mm$^2$ and had a cementitious material content of 292 kg/m$^3$, fine aggregate content of 680 kg/m$^3$, coarse aggregate content of 1158 kg/m$^3$, and water-cementitious materials ratio of 0.65 giving a free water content of 190 kg/m$^3$. The cement and sand replacement by FA and laterite respectively were thereby computed by weight as required. The range of laterite and sand used were those that passed through 5mm British Standard (BS) sieve, while the FA was 75 μm sieve. The work entailed laboratory test conducted on normal and laterized concrete mix of 25 N/mm$^2$, for 28 d strength.

### 2.4 Details of specimen and testing of samples

Tests to determine slump, density and compressive strength were carried out in this study. For the comprehensive strength tests, 100 mm cube specimens were used. A total of 120 specimens were cast and cured in water at room temperature in the laboratory for 7, 14, 21, 28 and 56 d. At the end of each curing period, three specimens of each mixture were tested for compressive strength and the average was recorded.

## 3. Analysis and results

Table 1 shows that the total content of Silicon Dioxide ($SiO_2$), Aluminium Oxide ($Al_2O_3$) and Iron Oxide ($Fe_2O_3$) was 73.04 % which is a little above the minimum of 70 % specified in ASTM C 618 (2017), which made it fit as a good pozzolan. Cassava Peels Ash (CPA) has cementitious compounds like calcium oxide, alumina and iron oxide (total about 30 %). The amount of oxides of sodium and potassium known as ‘alkalis’ in FA is found to be 0.35 % which is within the range (0.2 - 1.3) given by Neville (2006) and 0.6 % maximum specified in ASTM C 150 (2017) for OPC and also a maximum of 1.5 % specified in ASTM C 618 (2017) for FA in Cement and concrete. Higher alkali presence in the FA may have deleterious effects leading to disintegration of concrete due to reaction with some aggregate and affect the rate of gain in strength of cement. Table 2 shows the specific gravity of the FA sample as 2.25, a value less than that of cement (3.15) as provided by Neville (2006).

*Table 1: Result of chemical analysis of fly ash sample*

| Constituent of fly ash | Composition (%) |
|---|---|
| $Si0_2$ | 43.84 |
| $Al_20_3$ | 25.97 |
| $Fe_20_3$ | 3.23 |
| Ca0 | 0.67 |
| $M_g0$ | 0.40 |
| $K_20$ | 0.17 |
| $Na_20$ | 0.18 |
| $P_20_5$ | - |
| L.O.1 | 2.71 |
| Total= $SiO_2$+$Al_2O_3$+$Fe_2O_3$ | 73.04 |

Table 2 also presents the results of the physical properties of the constituent concrete material. The laterite sample has a specific gravity of 2.90, bulk density of 1378 kg/m$^3$, moisture content of 29.00 %, fineness modulus of 2.79, Coefficient of Uniformity (CU) of 9.11 and Coefficient of Curvature (CC) of 1.22. It has Silica: Sesquioxide ($SiO_2/Al_2O_3+Fe_2O_3$) ratio that is also simply referred to as Silica Ratio (SR) as 0.97 as shown in Table 3, which presents the result of chemical analysis, carried out on the laterite sample. The ratio is less than 1.33 indicating a true laterite classification as specified by Fermor (1981). The sand, on the other hand, has a specific gravity of 2.70, the bulk density of 1533 kg/m$^3$, the moisture content of 10.67 %, fineness modulus value of 2.32, CU of 5.90, and CC of 1.06. These results reflect that both the laterite and sand samples are well graded. The granite sample has a specific gravity of 2.71, the bulk density of 1483 kg/m$^3$, CU of 4.16, and CC of 1.11, reflecting a uniform sample. All the aggregates conformed to the British Standard Specification (BS 812:103, 1985).

*Table 2: Summary of physical properties of the concrete constituent*

| Parameter | Fly ash | Sand | Laterite | Granite |
|---|---|---|---|---|
| Bulk density uncompacted (kg/m$^3$) | 1306 | 1417 | 1250 | 1260 |
| Bulk density compacted (kg/m$^3$) | 1414 | 1533 | 1378 | 1483 |
| Void (%) | 17.12 | 9.67 | 8.02 | 25.22 |
| Specific gravity | 2.25 | 2.70 | 2.90 | 2.71 |
| Moisture content (%) | | 10.06 | 29.00 | 21.00 |
| Fineness modulus | | 2.32 | 2.79 | |
| Coefficient of uniformity | | 5.90 | 9.11 | 4.16 |
| Coefficient of curvature | | 1.06 | 1.22 | 1.11 |

*Table 3: Result of chemical analysis of laterite sample*

| Elements | Composition by weight (%) |
|---|---|
| $SiO_2$ | 38.75 |
| $Al_2O_3$ | 20.42 |
| $Fe_2O_3$ | 19.50 |
| SR | 0.97 |
| AR | 1.05 |
| $K_2O$ | 0.14 |
| $Na_2O$ | 0.02 |
| C3A | 14.56 |
| $TiO_2$ | 1.10 |
| C4AF | 33.62 |
| $Al_2O_3$+$Fe_2O_3$ | 39.92 |
| $Mn_2O_3$ | 0.16 |
| Total= $SiO_2$+$Al_2O_3$+$Fe_2O_3$ | 78.67 |

The setting times of all the replacements shown in Figure 1 are within the provision of BS EN 196-3 (2005) limits of not less than 45 min initial setting time and not more than 10 hours of final setting time and also satisfy the requirements of both Portland fly ash and Portland cement (AS 2350.3, 2006). The compressive strength of 20 % / 1 % - 30 % laterite FA/OPC Laterized concrete mix satisfies the requirements of both Type C Portland cement and Type FC of Portland–FA cement. Due to an increase of setting time, the heat of hydration is less in FA/OPC than normal Portland cement. Hence it is possible to manufacture blended FA/OPC equivalent to Type C of Portland cement and Type FC of Portland FA cement using up to 20 % FA content.

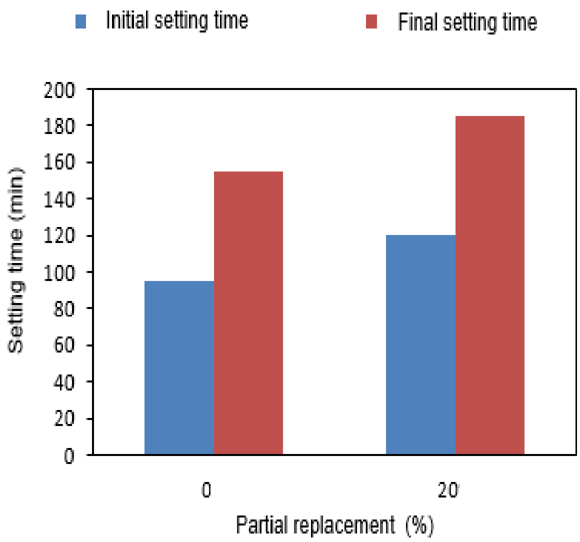


*Figure 1: Setting time of cement paste at 0 % and 20 % partial replacement of OPC with FA*

Workability of the laterized concrete decreases as the percentage of FA and laterite increases. The slump value ranges between 34 - 38 mm and compacting factor value ranges between 0.84 - 0.96. The density of the laterized concrete mixtures decreases as the percentage of FA replacement changes from 0 % to 20 %, so also as the laterite content increases. At 0 % FA / 0 % laterite, the density was 2467 kg/m$^3$; at 0 % FA / 30 % laterite, the density was 2326 kg/m$^3$ representing decrease of about 5.72 % and At 20 % FA / 0 % laterite, the density was 2426 kg/m$^3$; at 20 % FA / 30% laterite, the density was 2300 kg/m$^3$ representing decrease of about 5.19 % as shown in Tables 4.

*Table 4: Summary of density (kg/m$^3$) of FA / OPC laterized concrete*

| FA content (%) | Laterite content (%) | Curing age (d) | | | | |
|---|---|---|---|---|---|---|
| | | 7 | 14 | 21 | 28 | 56 |
| | | Density (kg/m$^3$) | | | | |
| | 0 | 2533 | 2500 | 2400 | 2467 | 2467 |
| 0 | 10 | 2522 | 2421 | 2399 | 2352 | 2347 |
| | 20 | 2456 | 2384 | 2382 | 2342 | 2334 |
| | 30 | 2313 | 2305 | 2286 | 2326 | 2286 |
| 20 | 0 | 2524 | 2468 | 2433 | 2426 | 2406 |
| | 10 | 2517 | 2400 | 2433 | 2403 | 2401 |
| | 20 | 2400 | 2400 | 2300 | 2400 | 2365 |
| | 30 | 2366 | 2433 | 2433 | 2300 | 2300 |

Figures 2 and 3 show that the average compressive strength of the FA / OPC laterized concrete decreases as the percentage FA content increases. Figure 2 shows the 0 % FA /0 % laterite. (i.e. the control mix) sample and 0 % FA / 30 % laterite sample. The 28 d strength gave a value of 35.09 N/mm$^2$ with 0 % decrease and 27.15 N/mm2 representing a decrease of about 20 %. While the 20 % FA / 0 % laterite and 20 % FA / 30 % laterite sample shown in Figure 3 has 28 d strength of 21.94 N/mm$^2$ and 15.02 N/mm$^2$, representing a 37 % and 57 % decrease. The result of later d of hydration (56 d) gave improved strength. The trend shows a gradual strength development of the FA / OPC laterized concrete as the hydration period increases with the 20 % FA / 30 % laterite mix having values. The 20 % FA / 20 % laterite mix was noticed as the limit to which both the sand and cement can be replaced for quality and economy in consonance with the requirements of

ASTM C 618 (2017) for 28-d strength. The sample has a compressive strength value of 19.88 and 21.18 N/mm$^2$ (57 % and 60 % of the target strength) on the 28 d and 56 d from the initial 7- d strength of 9.14 N/mm$^2$ (only 26 % of the 28 d target strength) while code ASTM C 618 (2017) specifies 75 %.
The sample at a later date (56 d) had attained strength value which shows the possibility of other samples with further curing attaining a similar strength value to the control mix sample. The laterized concrete was noticed to present strength values similar to the results of the previous researchers with a 20 % FA / 20 % lat (Olawuyi and Olusola, 2010). sample having 28-d strength value of 19.88 N/mm$^2$ (about 60 % of the target strength) as presented in Figure 3.

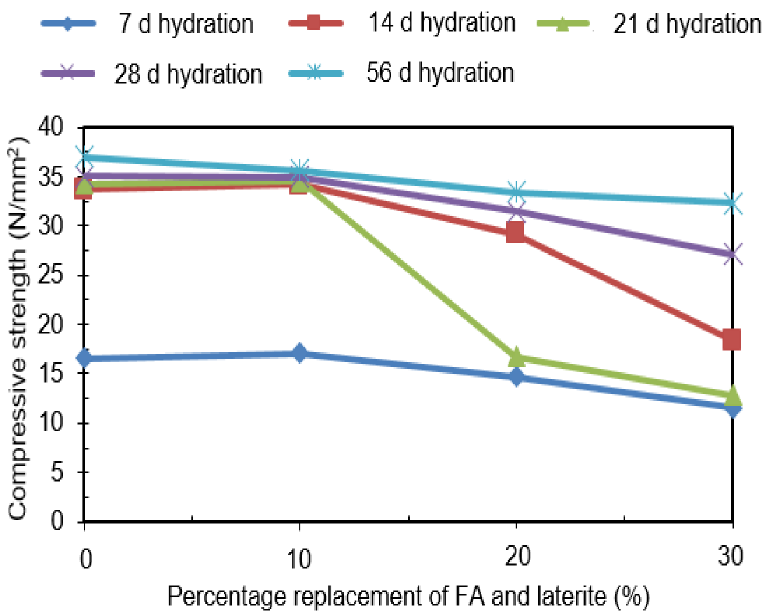


*Figure 2: Average compressive strength corresponding to hydration period for 0 % FA at 0 % - 30 % laterite*

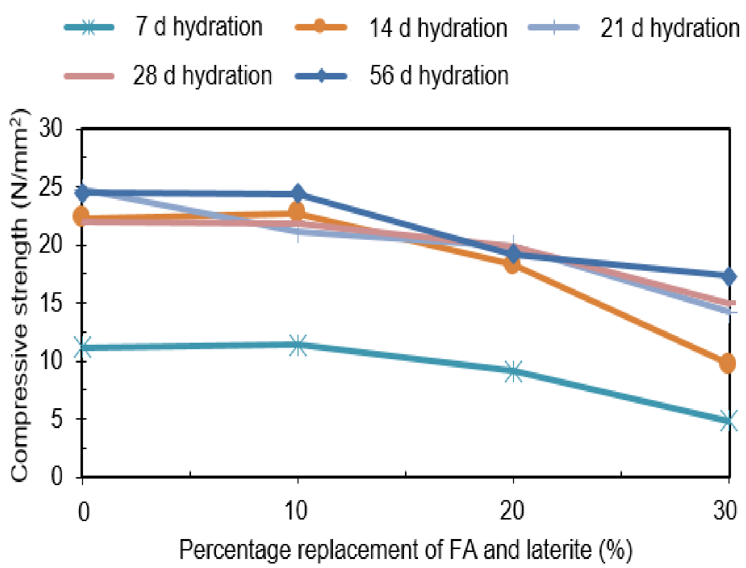


*Figure 3: Average compressive strength corresponding to hydration period for 20 % FA @ 0 % - 30 % laterite*

## 4. Conclusions

The study demonstrates that although the FA / OPC laterized concrete only had compressive strength values ranging between 14 % and 71 % of the 28-d strength (for 20 % FA / 0 % to 30 % laterite), the introduction of FA presents a good tendency of pozzolanic activity. The FA / OPC laterized concrete can be adopted for construction of masonry walls and simple foundations for effective waste management. The laterized concrete sample investigated for longer hydration periods of 56 d ascertain its pozzolanic tendencies.

### References

Al-Ani M., Hughes B., 1989, Pulverized-fuel ash and its uses in concrete, Magazine of Concrete Research, 41 (147), 55–63.

Australian Standard, AS 2350.3, 2006, Methods of testing portland, blended and masonry cements, Sydney, Australia.

American Society for testing and Materials, ASTM C 150, 2017, Standard specification for Portland cement, Annual Book of ASTM Standards, Philadelphia, USA.

American Society for testing and Materials , ASTM C 618, 2017, Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete, Annual Book of ASTM Standards, Philadelphia, USA.

Ata O., 2007, Effect of varying curing age and water /cement ratio on the elastic properties of laterized concrete, Journal of Civil Engineering Science and Application, 19 (2), 85-89.

Bilodeau A, Malhotra V.M., 2000, High volume fly ash system: Concrete solution for sustainable development, ACI Material Journal, 99 (1), 41–48.

British Standard, BS EN 197: Part 1, 2000, Cement composition, specifications and conformity criteria for common cements, London, UK.

British Standard, BS 812: Part 103, 1985, Method for determination of particle size distribution, London, UK.

British Standard, BS EN 196: Part 3, 2005, Methods of testing cement: Determination of setting times and soundness, London, UK.

Fermor L.L., 1981, What is laterite?, Geology Magazine, 5 (8), 453-462.

Hossain K.M.A., 2003, Blended cement using volcanic ash and pumice, Cement Concrete Research, 33 (10), 1601–1605.

Hussein A.H., Jaya R.P., Hassan N.A., Yaacob H., Huseien G.F., Ibrahim M.H.W., 2017, Performance of nanoceramic powder on the chemical and physical properties of bitumen, Building Construction and Materials, 156, 496–505.

Mohammadhosseini H., Abdul Awal A.S.M., Mohd Y.J., 2017, The impact resistance and mechanical properties
of concrete reinforced with waste polypropylene carpet fibres, Construction and Building Materials, 143, 147–157.

Mohammadhosseini H., Awal A.S.M.A., 2015, Influence of palm oil fuel ash on fresh and mechanical properties of self-compacting concrete, Sadhana, Springer, 40 (6), 1-11.

Neville A.M., 2006, Properties of Concrete, Person Education Pte. Ltd, Asia.

Ogunbode E.B., Egba E.I., Olaiju O.A., Elnafaty A.S., Kawuwa S.A., 2017, Microstructure and mechanical properties of green concrete composites containing coir fibre, Chemical Engineering Transactions, 61, 1879-1884.

Olawuyi B.J, Olusola K.O., 2010, Compressive strength of VA/OPC laterized concrete, Civil Engineering Dimensions, 12 (1), 23-28.

Olusola K.O., 2005, Factors affecting compressive strength and elastic properties of laterized concrete, PhD. Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria.

Osunade J.A., 2002, Effect of replacement of lateritic soils with granite fines on the compressive and tensile strengths of laterized concrete, Building and Environment, 37 (1), 491-496.

Varghese P.C., 2006, Building Materials, Prentice, New Delhi, India.