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Effects of Blended Portland-Fly Ash Cement on Compressive Strength of Seawater Mixed and Cured Lateritic Concrete

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ABSTRACT

The use of cement in the construction industry is accompanied by the release of greenhouse gases (GHGs) into the ecosystem, and freshwater usage is on the rise globally, putting the world in a potential freshwater scarcity. This study investigated the effects of blended Portland-fly ash cement on the compressive strength of seawater-mixed and cured lateritic concrete by partially replacing the concrete materials: cement with fly ash at 0%, 5%, 10%, 15%, and 25%; fine aggregate, with laterite at 0%, 10%, 20%, and 30%. A concrete mix ratio of 1:1.5:3 was used in the production of concrete cubes with an expected target compressive strength of 20 N/mm^2. The compressive strength of the cubes was measured at 7, 28, and 56 days using standard testing procedures. Cubes cast with and cured in seawater (SW-SW) had strength values relatively higher than those cast with and cured in freshwater (FW-FW) at 28 days of curing. At 28 days, SW-SW cubes gave 22.44 N/mm^2 while FW-FW cubes gave 21.80 N/mm^2 as the highest strength values at 10% Lat and 10% FA. However, the FW-FW cubes had strength values higher than those of seawater mixed and cured concrete (SW-SW) at 56 days. FW-FW cubes gave 26.82 N/mm^2 while SW-SW cubes gave 26.34 N/mm^2 as their highest strength values at 10% Lat and 10% FA. Generally, an increase in fly ash and laterite content significantly reduces the compressive strength of concrete. Overall, seawater is recommended for curing and mixing, especially in non-reinforcing concrete. 10% fly ash and 10% laterite are also recommended for use in blended Portland cement-fly ash concrete as they give the highest strength values.

Keywords: Concrete, Fly Ash, Laterite, Seawater, Compressive strength

INTRODUCTION

Concrete has been extensively used as a construction material ever since it was introduced to the construction industry (Basavana et al., 2015). Concrete is used for numerous purposes in the construction industry, such as the construction of buildings, foundations, parking structures, pipes, dams, pools, and other similar structures (Ogunjiofor, 2020). The average annual production is approximately 1 ton of concrete per human being in the world (Marie and Quiasrawi, 2012). The need to prevent the depletion of non-renewable materials and make concrete construction sustainable led to the replacement of the constituent materials of concrete with alternative ones. The partial replacement of sand with laterite resulted in laterized concrete (Folagbade and Aluko, 2019).

Over two billion tons of freshwater is consumed every year, which is approximately 9% of the global industrial water demand (Monteiro and Miller, 2017; Miller et al., 2016). Predictions show that in 2050, 75% of the water demand for concrete production will occur in regions most likely to experience water shortages (Miller et al., 2018).

Given the increase in freshwater usage globally which may lead to a potential freshwater shortage, seawater becomes plausible as an alternative mixing water for concrete (Mekonnen and Hoekstra, 2016; Miller et al., 2015). Although the use of seawater in concrete mixtures is currently prohibited because of its high chloride contents that promote corrosion of reinforcing steel (El-Reedy, 2017), the issue can be addressed by using non-corrosive reinforcement such as fibre-reinforced polymer (FRP) bars (Younis et al., 2018).

Several works have been carried out on the possibility of using seawater for mixing and curing concrete. Khatib and Bayasi (2003) studied the strength and durability of seawater-mixed concrete and concluded that the compressive strength of seawater (SW)-mixed concrete was slightly lower than that of freshwater (FW)-mixed concrete but the difference was not significant. Lee *et al.*, (2008) also investigated the influence of curing in SW on the properties of concrete and showed from the study that the compressive strength of concrete cured in FW was slightly higher than that of concrete cured in SW but the difference was not significant.

Attempts have been made to also partially replace the cement content of laterized concrete with pozzolanic materials such as fly ash, cassava peel ash and volcanic ash, among others (Ogunbode, 2010; Al-Ani and Hughes, 1989).

Azad et al., (2016) studied the effects of fly ash on the mechanical properties of concrete and found that the addition of fly ash to concrete can increase its compressive strength, tensile strength and flexural strength. Kishore et al., (2017) however found that the compressive strength and flexural strength of concrete reduce with an increase in fly ash content.

The scope of this study included casting and curing blended Portland fly ash lateritic concrete made with fly ash in FW and SW. In this study, fly ash was used as a partial replacement for cement at 0%, 5%, 10%, 15%, and 25% levels, and laterite for sand at 0%, 10%, 20%, and 30% replacement levels in the concrete mix. The effects of the laterite and fly ash on the compressive strength of the concrete were studied and compared with that of ordinary Portland cement (OPC) concrete mixed and cured with FW as a control.

MATERIALS AND METHODS

Sources and preparation of materials

The materials used for this study were sourced locally and tested to ensure that they meet all the necessary standards. Lafarge Portland cement, grade 42.5, type 1 general-purpose cement as per the ASTM C150, (2012) was used in this study as shown in Figure 1a.

Fly ash sample was obtained from the Olokwu coal mining site, Omala Local Government, Kogi State, Northcentral Nigeria. The specific gravity test was carried out following BS EN 12620:2002 as well as X-ray Fluorescence (XRF) analysis, and X-ray diffraction (XRD) were carried out to examine the chemical composition and the mineralogical composition of the fly ash. It is light brown in colour (Figure 1 b). The results of other physical properties of the binders are shown in Table 1.

Laterite was sourced from a laterite quarry within the Akure metropolis, Southwestern Nigeria (Figure 1 c). Physical properties such as specific gravity test was carried out on the laterite samples. Clean and dry fine river sand (Akure pit sand, APS) that was well-graded was used for casting all the specimens. They were sourced from Akure, Southwestern Nigeria, and kept clean and dry to prevent bulking of aggregates. Crushed granite stones with a maximum size of 20 mm conforming to the requirements of ASTM C33/C33 M and BS 882 (1992) were used. A sieve analysis test and specific gravity test were carried out following BS EN 12620:2002 on both the fine and coarse aggregates.

Potable water and seawater following the requirements of BS EN 1008:2002, were used for the mixing and curing of concrete cubes. The water samples were tested to have pH values of 6.03 and 7.14 for the FW and the SW, respectively.

The freshwater and seawater used for the mixing and curing of the concrete cubes were tested at the Department of Chemistry, Federal University of Technology, Akure, Nigeria, for several chemical properties and physical properties. The freshwater was found weakly acidic/neutral while the seawater was very neutral. As expected, the seawater used had very high content, 22.465 mg/L of Na^+ of and 76.205 mg/L of K^+ compared to the 2.017 mg/L and 5.621 mg/L respectively for freshwater.

(a) (b) (c)

Figure 1. Materials used (a) ordinary Portland cement (OPC) (b) fly ash (FA) (c) Lateritic soil.

Table 1. Properties of the binders

Properties / Parameters	OPC	FA
Specific gravity (kg/m^3)	3.02	2.35
Initial setting time (minutes)	75	-
Final setting time (minutes)	270	-
Normal consistency (%)	26	-
Moisture content (%)	-	16.35
Dry density (g/cm^3)	-	0.458

Methods

The constituents of concrete were batched by weight based on the mix ratio of 1:1.5:3 with a target strength of 20 N/mm^2 at 28 days of curing.

Fly ash was added as a partial substitute for cement at 0%, 5%, 10%, 15%, and 25%, while laterite was used to replace fine aggregate at 0%, 10%, 20%, and 30%. Fine aggregate and binders (cement and fly ash) were first thoroughly mixed before coarse aggregates were added. A water-binder ratio of 0.55 was adopted, and a slump test was carried out. The freshly mixed concrete was filled into moulds in three layers of approximately 50 mm before compacting with 25 strokes of the tamping rod. Four different types of combinations were made with a total of 360 cubes. The first mixture included mixing the constituents with freshwater and curing the cubes in freshwater. This served as the control mix. Two other combinations included mixing with freshwater and curing in seawater, and vice-versa. The last mix had seawater as both the mixing and curing water.

A total of 360 cubes were cast and tested for compressive strength at 28 days of curing. The compressive strength test was carried out on cubes with a size of 150 mm x 150 mm x 150 mm in accordance with BS EN 12390-2. An ELE Compression Testing Machine with a loading capacity set to 2000 kN was used to determine the strength. Concrete specimens of size 200 mm x 50 mm x 50 mm were tested according to BS 812-120: 1989. They were cast and demoulded after 24 hours and placed in air to cure for the shrinkage to be monitored.

RESULTS AND DISCUSSION

Physical properties of materials used

The specific gravity test was carried out on fine aggregate, coarse aggregate, fly ash, and laterite. The results were 2.74, 2.63, 2.35, and 2.63, respectively. All the values conform to the required standard as specified in ASTM C127 (2015), so they can be used in concrete works. The sieve analysis test was carried out following BS EN 12620:2002. The result of the test carried out on Akure Pit Sand (APS) and laterite is shown in Figure 2. The sand was well graded with coefficients of uniformity (C_u) and coefficient of gradation (C_c) of 1.71 and 1.04 respectively. The laterite used was a silt-clay material, as 50.18% of its sample passed through sieve No. 200 (0.075mm). The sand was fine sand, with 92.67% passing the 75 mm sieve size and retaining the 2 mm sieve size. For the crushed granite stones used, they were purely grave material.

The fly ash used for the preparation of concrete specimens was characterized using X-ray fluorescence (XRF) analysis. The results, as shown in Figure 3 show that it contains a high percentage of SiO_2. The oxide composition test also indicated that the fly ash contained a SiO_2 content of 57.35% which is more than the 25% recommended by BS EN 197-1 (2011) for pozzolans. It was also a class F pozzolan ($SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$) according to ASTM C618-12a, so it was suitable for replacing cement (see Figure 2).

The setting times of cement were determined using freshwater and seawater. The initial and final setting times were 148 minutes and 205 minutes for freshwater, and 106 minutes and 128 minutes when seawater was used. These values are in line with Ghalehnovi et al., 2010 and Uzoh et al., 2017. They also conform to the limit set by BS EN 197-1:2011 for grade 42.5N cement. The fineness value for the cement was 1.77%. The average water absorption for fine aggregate and coarse aggregate are 0.55% and 0.71% respectively. The bulk density of crushed granite stone was 1.71 g/cm^3.

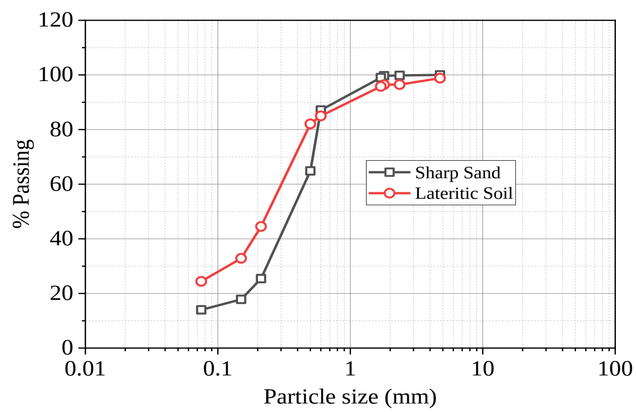

Figure 2. The grain size distribution of sand and lateritic soil.

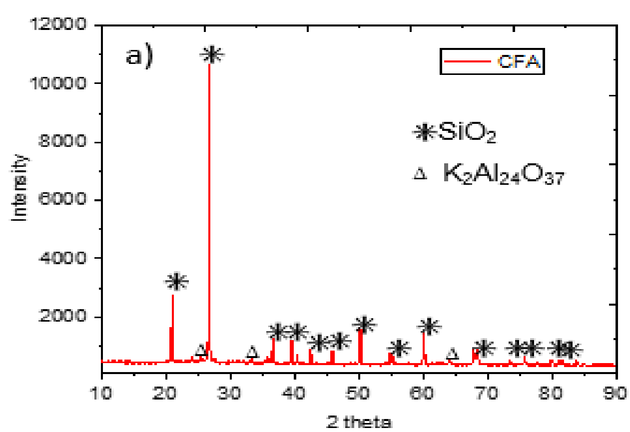

Figure 3. X-ray Diffraction (XRD) pattern of coal fly ash.

Table 2. Chemical and physical properties of OPC and FA.

Oxide (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	SO_3
FA	1.72	57.2	28.6	6.58	1.78	2.81	0.02

Compressive strength

The strength values for the four different environments are presented in Figures 4, 5, 6 and 7. The compressive strength for the different concrete cube samples generally increases with an increase in curing days. This agrees with the findings of Sata *et al.* (2007). It is evident that all the conventional concrete produced from the control had a higher strength than the blended Portland cement-fly ash laterized concrete at 28 days of curing. At 28 days of curing, the SW-SW cubes gave the best strength values: 22.38 N/mm^2, 22.53 N/mm^2, 22.67 N/mm^2, 22.62 N/mm^2, and 22.16 N/mm^2 for 0%FA/0% Lat., 5% FA/0% Lat. 10% FA/0% Lat., 15% FA/0% Lat., and 25% FA/0% Lat., respectively. These values were found to be higher than 21.91 N/mm^2, 21.87 N/mm^2, 21.85 N/mm^2, 21.88 N/mm^2, and 21.85 N/mm^2 obtained for corresponding FW-FW cubes at 28 days of curing.

However, at 56 days, FW-FW cubes gave the highest strength values of 26.59 N/mm^2, 26.79 N/m^2, 27.47 N/mm^2, 26.82 N/mm^2 and 27.79 N/mm^2 for 25% FA/0% Lat., 15% FA/0% Lat., 10% FA/0% Lat., 5% FA/0% Lat., and 0% FA/0% Lat., respectively which exceeded the target strength of 20N/mm^2.

Cubes produced with 10% fly ash and 10% laterite generally gave the highest strength of 26.82 N/mm^2 in terms of replacement, next to the control mix.

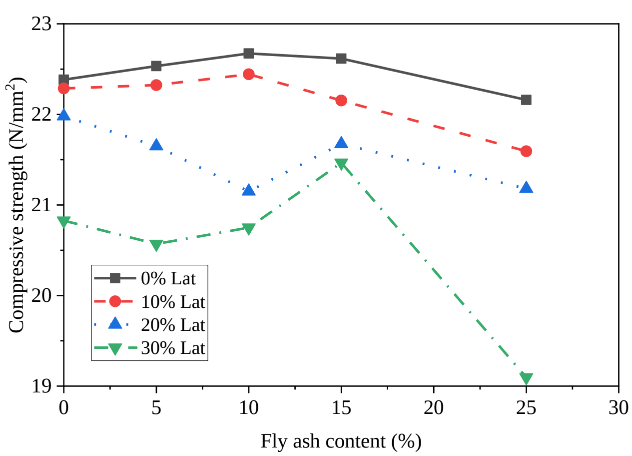

Figure 4. Compressive strength (N/mm^2) against % of fly ash for SW-SW cubes at 28 days.

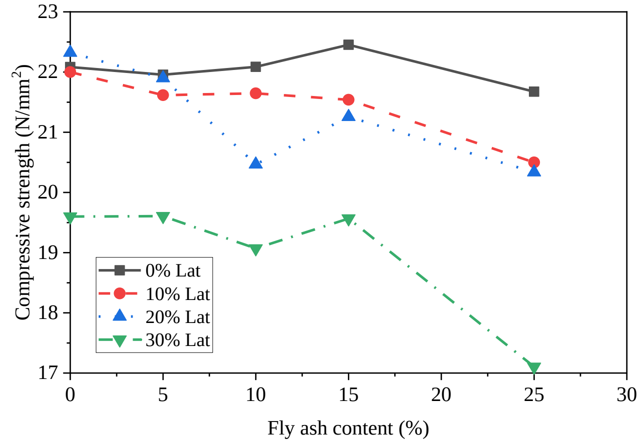

Figure 5. Compressive strength (N/mm^2) against % of fly ash for SW-FW cubes at 28 days.

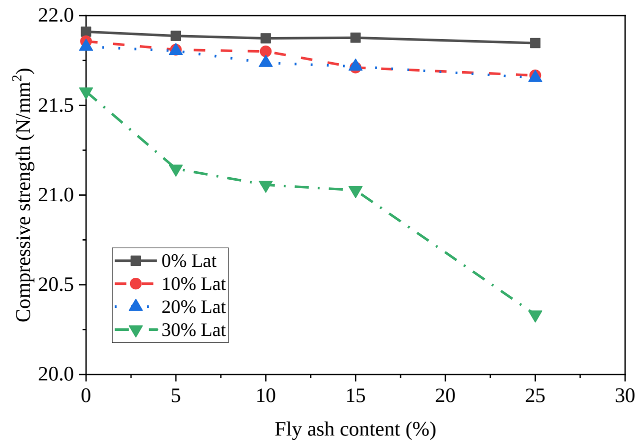

Figure 6. Compressive strength (N/mm^2) against % of fly ash for FW-FW cubes at 28 days.

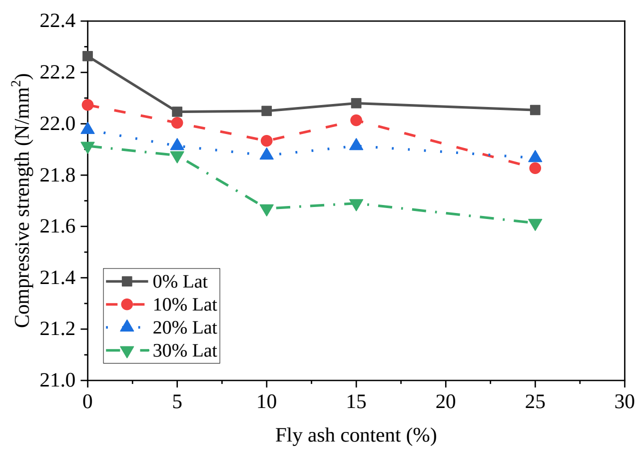

Figure 7. Compressive strength (N/mm^2) against % of fly ash for FW-SW cubes at 28 days.

CONCLUSION

A study on the effects of Blended Portland-Fly Ash Cement on Compressive Strength of Seawater Mixed and Cured Lateritic Concrete and the following conclusions can be drawn:

(1) Fly ash possesses pozzolanic properties and can therefore be used as a cementitious material in concrete. Drying shrinkage and compressive strength of concrete reduce with an increase in fly ash content. Curing periods had a significant effect on the strength development of blended Portland cement-fly ash laterized concrete, as there was strength gain with increasing curing age for all fly ash and laterite replacement levels.

(2) The strength of the control mix was generally slightly higher than that of the blended Portland cement-fly ash seawater-mixed and cured laterized concrete. Though the strength compared well.

(3) 10% fly Ash and 10% laterite are recommended for the replacement of cement and sand, respectively, in plain concrete works. Recycling activities for wastes like fly ash should be encouraged by all institutions. Technology should be developed for the production of fly ash and other pozzolans so they can be readily available for concrete work.

Finally, seawater can be used for mixing and curing plain concrete in place of freshwater and for reinforced concrete if the reinforcing material is non-corroding.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Authors' contribution

SA Alabi developed the concept for the research and designed the experimental process. C Arum and AR Akande assisted in the design of the experimental process of writing the manuscript. SA Alabi, J Mahachi and JO Afolayan carried out the bench work and wrote the draft manuscript. All the authors read and approved the final manuscript

Competing interests

The authors declare no competing interests in this research and publication.

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