

# THE EFFECT OF PARTIALLY REPLACING CEMENT WITH FLY ASH IN A BEACH WATER ENVIRONMENT

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## ABSTRACT

*In the quest to produce more environmentally friendly concrete, much attention has been diverted to substituting cement in concrete mixtures with more environmentally friendly ingredients such as fly ash, both in terms of raw materials cost and CO<sub>2</sub> footprint. This study aims to analyze the effect of using fly ash as a partial replacement of Portland limestone cement and curing concrete in beach water. Concrete cubes 100 mm x 100 mm x 100 mm were cast using fresh water with 1:1.5:3 mix ratio. All the mixes were prepared using fresh water with cement ratio (w/c) of 0.55 by weight. A total of 96 concrete cubes were cast at 0% (control), 5, 10 and 15% replacement of cement with fly ash. They were cured in fresh and beach water for 7, 14, 28 and 40 days, then tested for compressive strength. The result shows an initial increase in the compressive strength of concrete for concrete specimens cured with beach water at an early age which was more than the concrete specimens cured in fresh water. The result of the research showed that at 40 days the optimum strength was 0% replacement (control) that was cured in river water with value of 34.25 MPa, closely followed by 15% fly ash replacement cured in fresh water with a value of 22.25 MPa. The highest strength for samples cured in beach water was 5% fly ash replacement sample with a value of 18.23 MPa which met the minimum requirement of lightweight concrete within the lower limit of 17.24 MPa in accordance with ACI 213. It is recommended that concrete samples substituted with fly ash can be used for both structural purpose up to 5% replacement and non-structural purpose up to 15% replacement.*

**Keywords:** Fly ash, Concrete, Beach water, Compressive Strength

## 1 INTRODUCTION

Portland cement paste and may replace part of the clinker in order to enhance the pozzolanic materials are enjoying a renaissance as supplementary cementing material in production of hydrated cement. Carbon dioxide is released in large quantities during the calcination of limestone to create Portland cement clinker. It is advantageous to use pozzolans and limit the quantity of cement used in the production of concrete in order to lower CO<sub>2</sub> emissions [1]. A fine, glass-like powder called fly ash is produced from the gases released during the combustion of coal to produce electricity. Millions of tons of fly ash are produced by power plants each year; this waste is often disposed of in landfills. Fly ash is a less expensive alternative to Portland cement that may nevertheless increase the strength and workability of concrete [2]. Using a water cement ratio of 0.31 and 40% fly ash, a high strength concrete with a 28-day compressive strength of 60 MPa could be produced. At 56 days, the compressive strength exceeded 80 MPa. The fly ash concrete strength continued to notably grow for another 56 days [3]. At the conclusion of 28 days and 60 days for normal water curing, the outcomes of fly ash and GGBS concretes when replaced with 20% of cement were superior than

Conventional aggregate concrete [4]. The 28-day compressive strength of the concrete increases with the 10% and 20% replacements of cement with fly ash, but falls with the 30% replacement of cement with fly ash [5]. In comparison to OPC, concrete with fly ash as a mix can be more workable. Moreover, it might lengthen the time needed for cement paste to start and finish setting [6]. This study addressed a research gap by assessing the effect of fly ash mixed concrete by partially replacing cement with fly ash in a beach water environment in Lagos, Nigeria as shown in Plate 1, where little or no work has been done incorporating fly ash concrete in a beach water environment.



Plate 1. A spalled section of a Pile cap in a beach environment in Lagos, Nigeria

## 2 MATERIALS AND METHODS

Dangote 3X a Portland limestone cement of Type 1 grade with specific gravity of 3.18 was used in accordance to [7]. Granite which passed through 14 mm sieve being the coarse aggregate had a maximum size of 12 mm was sourced locally from a Quarry-site at Odeda in Abeokuta, Ogun State Nigeria. Natural fine sand was used as the fine aggregate in this study having a 4.75 mm nominal size and specific gravity of 2.2 obtained from Abeokuta-river at Lat: 07 04 47.8N and Long: 03 18 8.94 E and having a fineness modulus of 2.42. The aggregates were in accordance with [8]. Fly ash shown in plate 2 was obtained from Lafarge Group Nigeria Limited, Ewekoro Cement Plant, Itori, along Lagos-Abeokuta Express way, Ogun State, Nigeria. Beach water was obtained from Elegushi Beach, Lekki, Lagos, Nigeria shown in plate 3 was used in curing the concrete samples. Concrete cubes of 100 mm x 100 mm x 100 mm dimension size were cast with concrete target strength of grade C-30 having a water-cement ratio (w/c) of 0.55 by weight. Borehole water with no trace of suspended particles and chemical substances was used for mixing concrete at Civil Engineering Laboratory, Federal University of Agriculture Abeokuta (FUNAAB) 07°13'50"N Long: 3°26'00"E which was in accordance with [9] for reinforced concrete. Concrete cubes were cured in both fresh borehole water and beach water separately to observe the effect of sulphate attack after curing for 40 days.

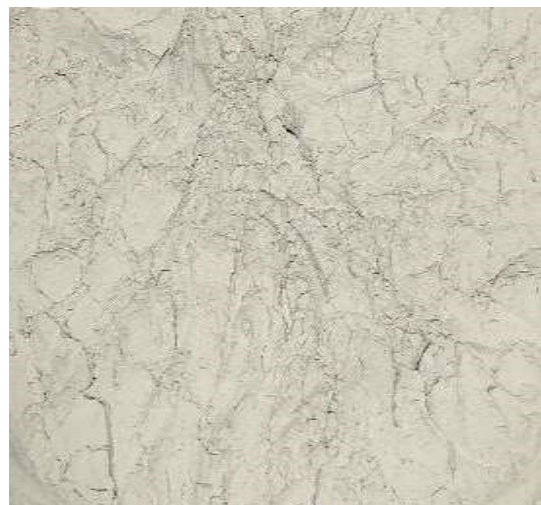


Plate 2. Fly ash obtained from Lafarge Group Nigeria Limited, Ewekoro Cement Plant, Itori, along Lagos-Abeokuta Express way, Ogun State, Nigeria



Plate 3. Beach water obtained from Elegushi Beach, Lekki, Lagos, Nigeria

## 2.1 Batching

The materials used in preparing the concrete were calculated by weight, using 1:1.5:3 mix ratio. The correct weights of material were measured using a digital scale. Concrete cubes with partial replacement of cement with fly ash was done for 0, 5, 10 and 15% replacement.

## 2.2 Water Absorption

The water absorption test was carried out in accordance with [10] to determine the amount of water absorbed by the concrete. The water absorption was expressed as increase in weight percent as shown in Equation 1.

$$WA = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

where,  $WA$  = Water Absorption (%),  $W_1$  = Wet weight of the sample (kg),  $W_2$  = Dry weight of the sample (kg).

## 2.3 Compressive Strength

The crushing of the concrete cube was done in the Civil Engineering laboratory of Federal university of Agriculture Abeokuta, Ogun State Nigeria with the use of the Avery Dension Compression Testing Machine shown in plate 4 having a capacity of 1500 kN in accordance with [11]. The cubes were removed from the curing tank after curing under normal conditions at a temperature of  $23 \pm 5^\circ\text{C}$  depending on the season of the year, for the proper length of time in fresh and beach waters and the weights of the cubes were measured. The average compressive strength of the cubes cast was determined by applying the formula illustrated in Equation 2.

$$\text{Compressive strength} = \frac{F}{A} \quad (2)$$

where,  $F$  = Maximum applied load (N),  $A$  = Cross – sectional area of the specimen ( $\text{mm}^2$ ),



Plate 4. Avery-Dension 1500 kN Capacity Compression Machine in FUNAAB

## 2.4 Chemical Composition

The samples were pulverized and sieved before being analyzed. Skyray EDX3600B X-ray spectrometer shown in plate 5 was used to determine the elemental composition of fly ash and Portland limestone cement (Dangote cement). The X-ray spectrometer was used with a variety of crystals (synthetic, Ge, or LiF) and detectors (flow, scintillator, or combination flow/sealed detector) depending on the element with an acceleration voltage range of 32 to 60 kV and a current range of 10 to 125 mA.



Plate 5. XRF complete system using a Skyray EDX3600B X-ray spectrometer in FUNAAB

## 3 RESULTS AND DISCUSSION

### 3.1 Water Absorption Result

Table 1 shows the test results of the percentage by weight of water absorbed for each of the concrete samples. The concrete cubes that partially replaced cement with fly ash have water absorption (WA) values ranging from between 2.75 to 4.50%. The result depicts that the water absorption was highest at Control (zero) percentage replacement of cement with fly ash. However, 15% replacement of cement with fly ash gives the least water absorption of 2.75 after 24 hours. The lower WA recorded at 5, 10 and 15% replacement of cement with fly ash gives them an edge in terms of efficiency especially in waterlogged areas. This result is in agreement with [12, 13] because the partial replacement of cement with fly ash composition in concrete sample is very influential on the water absorption of concrete sample, due to the fact that as more composition of fly ash is added it makes the water absorption value smaller by closing the pores, this happens because the size of fly ash is very fine and smoother than the size of other materials used so fly ash fills the cavity between particles and cover porosity in concrete. The use of fly ash reduces water absorption in concrete or mortar.

Table 1. Water absorption test of the samples

| Samples (Fly ash - Cement) | Water Absorption (%) |
|----------------------------|----------------------|
| 0 – 100                    | 4.5                  |
| 5 –95                      | 4                    |
| 10 – 90                    | 3.25                 |
| 15 – 85                    | 2.75                 |

### 3.2 XRF Test Result

XRF (X-ray fluorescence) is a non-destructive analytical technique used to determine the elemental composition of materials. An XRF test was used to confirm the chemical composition of all the materials used and ensure they have pozzolanic properties. Table 2 shows the chemical composition of Fly ash and Dangote Cement. The result is in line with [14] where the Fly ash falls under class F because it contains more than 70% of combined SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> content. Due to the fact that almost all organic matter is burned away during coal combustion, fly ash is mainly formed by incombustible mineral matter.

Table 2. XRF Result for Dangote cement and Fly ash

| Element                        | Fly ash | Dangote Cement |
|--------------------------------|---------|----------------|
| SiO <sub>2</sub>               | 59.27   | 17.769         |
| Al <sub>2</sub> O <sub>3</sub> | 27.22   | 4.308          |
| Fe <sub>2</sub> O <sub>3</sub> | 4.9     | 2.757          |
| CaO                            | 1.37    | 59.888         |
| MgO                            | 0.63    | 1.378          |
| SO <sub>3</sub>                | 0       | 2.295          |
| K <sub>2</sub> O               | 1.13    | 0.125          |
| Na <sub>2</sub> O              | 0       | 0              |
| P <sub>2</sub> O <sub>5</sub>  | 0.35    | 0.136          |
| LOI                            | 2.48    | 9.8            |
| M <sub>2</sub> O <sub>5</sub>  | 0.74    | 0              |
| TiO <sub>2</sub>               | 0.17    | 0              |

### 3.3 Compressive Strength Test Result

From Table 3, the entire compressive strength for 7, 14, 28 and 40 days increased in strength from 7 days to 40 days with the optimum compressive strength value noticed in concrete cube samples cured in fresh water with a value of 34.25 MPa. The least compressive strength was noticed at 15% percentage replacement of cement with fly ash with a value of 9.34 MPa at 7 days. From the compressive strength results, the strength of the samples keeps increasing with the number of curing days till it gets to 40 days which has the highest compressive strength which conforms to the work of [15]. The sulphate attacked the concrete that was cured in beach water and this affected the compressive strength, as there was an early increment in compressive strength noticed at 7, 14 and 28 days for both 10 and 15% replacement of cement with fly ash. This result was in line with [16] confirming that external source of sulphate attack affected the compressive strength and degraded the concrete samples that were submerged in a lagoon aggressive environment.

Table 3. Results of Compressive Strength of partially replacing cement with fly ash cured in fresh and beach waters

| Curing Environment<br>% Replacement of<br>Fly Ash | Fresh water   | Beach water | Fresh water | Beach water | Fresh water | Beach water | Fresh water | Beach water |
|---|---------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|   | 7 Days        |             | 14 Days     |             | 28 Days     |             | 40 Days     |             |
|   | (Unit in MPa) |             |             |             |             |             |             |             |
| 0%  | 21.16         | 17.7        | 29.3        | 24.53       | 32.55       | 27.26       | 34.25       | 28.68       |
| 5%  | 13.36         | 12.99       | 18.51       | 17.99       | 20.56       | 19.99       | 18.87       | 18.23       |
| 10%   | 9.79          | 10.47       | 13.56       | 14.5        | 15.06       | 16.11       | 19.4        | 15.95       |
| 15%   | 9.34          | 11.11       | 12.92       | 15.38       | 14.36       | 17.09       | 22.35       | 17.61       |

From the results, the compressive strength of 5% replacement of cement with fly ash at 28 days fell in the class of structural concrete usage from the three classes of light weight concrete according to [17] with a compressive strength ranging 17.24-41.36 MPa. It can be concluded that 10 and 15% can be used for non-structural purpose since the compressive strength at 28 days did not meet the ACI standard.

#### **4 CONCLUSIONS**

The present study has efficiently and effectively demonstrated the effect of using fly ash pozzolana in an aggressive beach environment. The following results were drawn from the experimental work and numerous tests performed on the specimens: At 40 days, the highest percentage replacement compressive strength of the concrete samples was observed in the specimens containing 15% of fly ash and 85% cement cured in fresh water with a compressive strength value of 22.35 MPa. This value was higher than the ACI 213 standard for the minimum compressive strength for a structural member. Concrete samples cured in beach water after the hydration of cement period and strength gain of 28 days exhibited a reduction in the compressive strength at 40 days. The partial replacement of cement with fly ash showed a positive application as a good substitute material in the construction of structural and non-structural components in accordance with ACI 213 (2014). The usage of fly ash also served as a solution for the disposal of fly ash waste in landfill. An increment in the percentage replacement of fly ash reduced the compressive strength of concrete cured in both fresh and beach water in comparison with the conventional concrete. The use of fly ash reduced the water absorption in the concrete cube. The water absorption of the concrete samples decreased as the increment of cement content substituted with fly ash increased till 15%. The decrease in water absorption was attributed to the fact that fly ash is very smooth and fine, as it filled the voids between the particles during the concrete hydration paste form.

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