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Experimental Study on the Effect of Fly Ash on Concrete

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Abstract
An experimental study was carried out to investigate the strength properties of concrete produced with fly ash (FA) as partial replacement for cement. Concrete specimens (cubes and cylinders) were cast and tested for compressive and split-tensile strengths at 0% (control mix), 10%, 20% and 30% replacement of cement by weight with FA with a mix ratio of 1:2:4 and water/cement ratio of 0.45 after curing in water for 28 days. The results obtained reveal that the replacement of cement with FA had appreciable impact on the compressive, split-tensile and flexural strength of concrete. An optimum of 20% replacement of cement with FA is therefore recommended for concrete production.

Keyword*: fly ash, cement, concrete, strength*

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I. Introduction

Concrete is the most widely used construction material in the world. The global population growth has resulted in an increased demand for infrastructure, and by effect, a higher demand for construction materials such as cement and natural aggregates[1]. The depletion of natural deposits of raw materials used for concrete production and the increased environmental pollution due to industrial activities has been an issue of dire concern globally.

The cement industry contributes to global warming by about 7% due to the raw materials used and the manufacturing process[2], as 1 tonne of CO_2 is emitted into the atmosphere for every ton of cement produced. Coal powered plants are also major contributors to global CO_2 emissions as coal is the major energy resource worldwide resulting from coal combustion processes[3]. The burning of coal results in the production of CO_2 and coal combustion products (CCP) which pollute the environment[4]. CCPs have been established as valuable inputs for manufacturing construction and building materials. They provide functional benefits in these applications and, as substitutes for energy intensive materials and provide options for lower embedded carbon. In year 2016, the global production estimate for CCPs was 1.2 billion tonnes. Of this volume, 32.2 million tonnes was produced in the Middle East and Africa with 3.4 million tonnes utilized representing 10.6% utilization. This indicates that the bulk of CCP (about 90%) produced in the Middle East and Africa may be disposed off in the environment, causing environmental hazards[3]. Fly ash (FA) is a by-product obtained from the burning of pulverized coal at power generating plants. A huge quantity of FA is disposed and land filling[2]. This waste material has over the years gained global acceptance as a useful material, as over 20 million metric tonnes of fly ash is used annually in a variety of engineering applications[5].

The emission of large amount of greenhouse gases such as carbon dioxide (CO_2) during the production of cement which depletes the ozone layer has necessitated the research on alternate cementitious materials such as fly ash that would reduce the cement production and help achieve goal 11 of the sustainable development goals[6]. FA is commonly used as a supplementary cementitious material (SCM) in concrete production among other applications, because of its pozzolanic property[7].

Various researches have been carried out to investigate the effect of fly ash on concrete. [8] investigated the effect of FA when used to replace cement (at 0%, 25%, 50%, 75% and 100%) in M20 concrete. The effect of FA on workability, setting time, compressive strength and water content were investigated. They recommended 25% replacement of cement with FA by weight in concrete. [9] studied the influence of fly ash on hydration compounds of high-volume fly ash concrete. They carried out compressive strength, rapid chloride permeability, ultrasonic pulse velocity, acid resistance, x-ray diffraction, scanning electron microscopy and energy dispersion spectroscopy tests to examine the effect of varying proportions of FA (0%, 10%, 20%, 30%, 40%, 50%, 60%) on cement replacement. From the results they obtained, an optimum of 40% replacement of cement with FA was recommended.

The current study was carried out to investigate the effect of FA on the strength properties of concrete when FA is used as partial replacement of cement in the production of concrete, and to strengthen existing literature as well.

II. Materials And Methods

Materials: The following materials were sourced and used for this study:

Cement: Portland-Limestone Cement, CEM II/B-L, Grade 42.5, (purchased in Idah, Nigeria), manufactured in conformity to [10], which is equivalent to [11] was used for this research. Table no 1 show the results of the specific gravity and consistency of the cement.

Table no 1: Basic Properties of the Cement

Tests conducted	Result Obtained
Specific gravity	3.15
Initial setting time (minutes)	97
Final setting time (minutes)	231
Soundness (minutes)	3.7

Fly Ash: The FA used for this research was gotten from Cinafindev Ltd. Allo, Kogi state. It is dark grey in colour with specific gravity of 2.6. FA passing through BS sieve size 0.075mm was used for this research. Figure 1 shows a sample of the FA used.

Figure 1: Sample of Fly Ash used

Fine Aggregates: Sharp river quartzite sand that is free of clay, loam, dirt and any organic or chemical matter, and maximum size of 4.75mm, having a specific gravity of 2.62 and water absorption of 0.61; sourced from Idah environs, Idah, Nigeria was used for this research.

Coarse Aggregates: Crushed granite coarse aggregates of 20 mm maximum size, having a specific gravity of 2.68 and water absorption of 0.45; free from impurities such as dust, clay particles and organic matter, etc, sourced from Idah environs, Idah, Nigeria, was used for this research. Table no 2 shows the physical properties of coarse aggregates.

Table no 3 and figure 2 show the combined aggregate gradation and particle size distribution respectively curve.

Table no 2: Physical Properties of Coarse Aggregates

Test conducted	Result obtained
Aggregate crushing value (%)	23.6
Aggregate impact value (%)	16.8
Los angeles abrasion value (%)	18.8
Specific gravity	2.68
Aggregate moisture absorption (%)	0.45
Flakiness Index	27

Table no 3: Combined Aggregate Gradation

Sieve Size (mm)	Percentage Retained	Cumulative Percentage Retained	Cumulative Percentage Passing
25.00	-	-	100
19.00	2.7	2.7	97.3
12.50	9.7	12.4	87.6
9.50	9.2	21.6	78.4
6.30	12.7	34.3	65.7
4.75	10.3	44.6	55.4
2.36	10.9	55.5	44.5
1.18	12.0	67.5	32.5
0.60	10.0	77.5	22.5
0.30	7.7	85.2	14.8
0.15	6.2	91.4	8.6
0.075	2.1	93.5	6.5
Pan	6.5	100	-

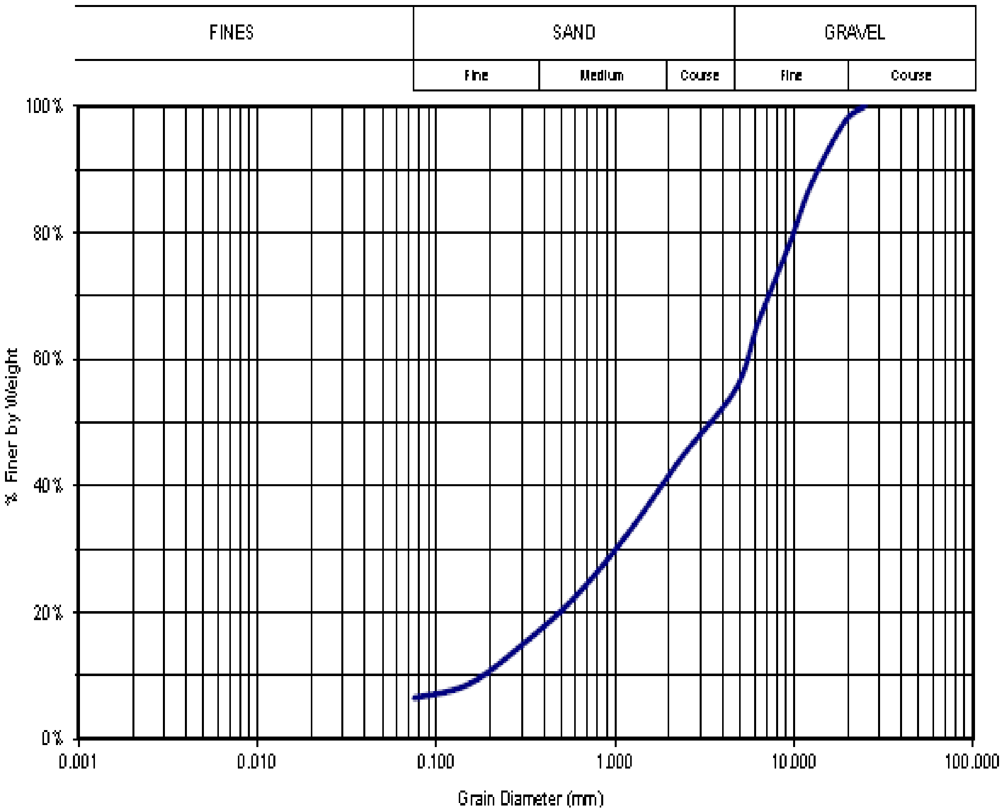


Figure 2: Particle Size Distribution Curve

Water: Fresh, colourless, odourless and tasteless potable water that is free from injurious amounts of oils, alkalis, salts, sugar organic matter or any other substances, was used for this research.

Experimental Investigation

Experimental investigations were carried out to evaluate the strength properties of grade M30 concrete mixes in which cement was partially replaced with FA. The compressive and split-tensile strength of the specimens after replacing the cement by 0% (control), 10%, 20% and 30% with FA (by weight) was investigated after 28 days of curing in a water bath. The concrete cubes (150 mm X 150 mm X 150 mm) and concrete cylinders (Φ150 mm X 300 mm) were cast for conventional mix as well as other mixes.

Mix Proportioning

The concrete mix proportion was 1:2:4 (i.e. cement: fine aggregates: coarse aggregates) with a water/cement ratio of 0.45. Table no 4 shows the mix proportions of FA modified concrete mixes

Table no 4: Mix Proportion of Waste Modified Concrete

Mix ID	Percentage of replacement	Cement (kg/m^3)	FA (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water/ Cement ratio
M1	0	10.73	0	22.33	47.63	0.45
M2	10	9.66	1.07	22.33	47.63	0.45
M3	20	8.59	2.14	22.33	47.63	0.45
M4	30	7.52	3.21	22.33	47.63	0.45

2.2.2 Casting and testing of specimens

Casting, compaction and curing of the specimens were conducted in accordance to B.S. EN 12390 [12, 13]. Three specimens each of the waste modified and control concrete were tested for compressive and split-tensile strength. Slump test was carried out on fresh concrete in accordance with [14]. The tests of compressive and split-tensile strengths were conducted in accordance to [15, 16]. The average compressive and split-tensile strength of the specimen was recorded after 28 days of curing. Figure 3 shows a specimen been tested.

Figure 3: Specimen been tested

III. Results

Workability

The slump test values are presented in Table no 5.

Table no 5: Slump Test Result

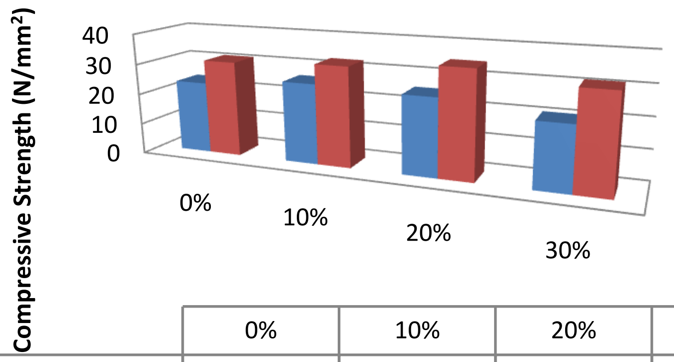
MIX ID	SLUMP VALUE (mm)
M1	60
M2	62
M3	64
M4	65

Compressive and Split-Tensile Strength

The compressive and split-tensile strength tests results are presented in Table no 6 and figures 4 – 5 respectively.

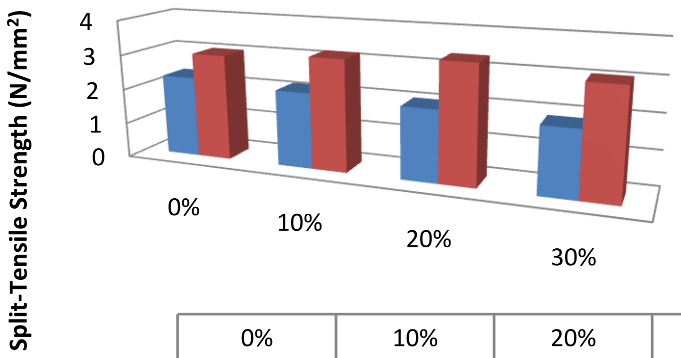
Table no 6: Compressive and Split-tensile Strength Test Results

% FA	Compressive Strength (N/mm^2)		Split-Tensile Strength (N/mm^2)	
	7 days	28 days	7 days	28 days
0%	23.50	31.17	2.32	3.03
10%	26.20	32.59	2.17	3.19
20%	25.30	34.78	2.04	3.35
30%	20.91	31.46	1.88	3.07



	0%	10%	20%	30%
Compressive Strength (N/mm2) 7 days	23.5	26.2	25.3	20.91
Compressive Strength (N/mm2) 28 days	31.17	32.59	34.78	31.46

Figure 4: Graph showing results of compressive strength test



	0%	10%	20%	30%
Split-Tensile Strength (N/mm2) 7 days	2.32	2.17	2.04	1.88
Split-Tensile Strength (N/mm2) 28 days	3.03	3.19	3.35	3.07

Figure 5: Graph showing results of split-tensile strength test

IV. Discussion

Workability

The slump values increased as the volume of FA was increased in the concrete mix. All the concrete mixes produced true slump and the slump values were within the normal range for good workable concrete. The addition of FA to the concrete mixes therefore had positive impact on its workability. This is because the spherical shape of FA improves concrete fluidity in consonance with the findings of [5].

Compressive and Split-Tensile Strength

The results obtained show that as FA was used to replace cement at 10%, 20% and 30%, the compressive strength of concrete increased as compared with the control mix. However, further increase beyond 20% replacement of cement with FA, resulted in a decrease of the compressive and split-tensile strength of concrete as compared with the 10% and 20% replacement.

At 28 days of curing, for the 20% replacement of cement with FA, there was an increase of 11.58%, and 10.56% in the compressive and split-tensile strength respectively as compared with the control mix. The results obtained also indicate that concrete early strength decreased as the replacement level of cement with FA increased.

The decrease in early strength with increase in percentage of FA in concrete mixes may be attributed to the low fineness and high carbon content of the FA, which agrees with the findings of [17, 18].

V. Conclusion

The following conclusion can be drawn from the results of this experimental investigation;

1. FA is a good SCM for concrete production.
2. The utilization of Fly Ash in concrete production will lead to improved environmental waste management and profitable use of industrial wastes.
3. The use of FA in concrete production will significantly enhance environmental sustainability and the attainment of SDG goal 11 especially in the Middle East and Africa that are lagging behind in FA utilization.
4. An optimum of 20% replacement by weight of cement with Fly Ash in a concrete mix is recommended for concrete production.

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