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# The Effect of Fly Ash as Partial Replacement of Cement on the Compressive Strength of Concrete

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**Abstract**

*The utilization of industrial wastes and a by-product of coal such as fly ash in this study was essential for environmental, economic, and performance-related reasons. It offers a sustainable alternative to traditional concrete production, reducing the environmental impact, conserving resources, and potentially improving the quality of concrete structures. This study becomes imperative to ascertain the optimum usage of fly ash as partial replacement of cement in concrete. Grade 20 concrete was made, tested and compared in terms of the compressive strength at 7 days, 28 days and 90 days of curing life for 0 %, 10 %, 20 %, 30 % and 50 % weighted replacement of cement with Class F fly ash. The results revealed a reduction of compressive strength of fly ash concrete at 7 days comparable with that of Portland cement concrete. However, there was increase in compressive strength that was obtained at higher curing life of 28 days and 90 days respectively. Optimum usage of 30 % of Class F fly ash as a partial weighted replacement of cement in concrete was established. These amounted to about N8,000 saving in 1m$^3$ of concrete and translated to 18.2 % in savings of cementitious materials.*

## 1. Introduction

Fly ash is a finely divided powder looking similar to Portland cement. It is obtained as a by-product of the combustion of pulverized coal in electric power generating plants. The coal's mineral impurities were carried away from the combustion chamber by the exhaust gases during combustion [1]. In these process, the fused material cools and solidifies into spherical glassy particles called fly ash. Electrostatic precipitators or bag filters were used to collect the fly ash through the exhaust gases. Fly ash according to [1] is the most widely used supplementary cementitious material in concrete.

Enhanced workability due to spherical fly ash particles, reduced bleeding and less water demand, increased ultimate strength, reduced permeability and chloride ion penetration, lower heat of hydration, greater resistance to sulfate attack, greater resistance to alkali-aggregate reactivity, and reduced drying shrinkage may be some advantages obtained by using fly ash in concrete [1]. There are mainly two classes of fly ash according to [2] standard. One of them is Class F fly ash, usually derived from the burning of anthracite or bituminous coal, and Class C fly ash, usually derived from the burning of lignite or sub-bituminous coal. The standard of [2] also states that Class F fly ash is pozzolanic, with little or no cementing value alone while Class C fly ash has self-cementing properties as well as pozzolanic properties.

Several studies [4;5] have shown that, fly ash has been used in concrete at levels ranging from 15 % to 25 % by mass of the cementitious material component. The actual amount used varies widely depending on the application, the properties of the fly ash, specification limits. Higher levels (30 % to 50 %) have been used in massive structures (for example, foundations and dams) to control temperature rise. Better properties of concrete suitable for structural applications have been produced lately, using high percentages of fly ash (40 % to 60 %) [3].

A de-dusting system of a power plant by-product was studied by [4] and found out that the fly ash that did not have any pozzolanic properties. The study by [5] favors the use of concrete with a high fly ash content in order to lower the carbon footprint of sustainable concrete structures. The study of [6] reported on the strength development of concrete containing fly ash and the optimum use of fly ash in concrete. These studies have shown that strength increases with increasing amount of fly ash up to an optimum value, beyond which strength starts to decrease with further addition of fly ash. The optimum value of fly ash for the four test groups was about 40 % of cement.

A study [7] was reported on the predictive models for compression strength for 20 % and 40 % fly ash replacement levels that was developed for seven different curing times between 3 days and 180 days. Their results showed that the particle model can predict the compressive strength within ±10 % for 95 % of all measurements at 20 % fly ash mass replacement and for 81 % of all measurements at 40 % mass replacement levels. Another research dealt with the replacement of Class F fly ash and kaolin with cement used in concrete. Replacement of 10 % fly ash with cement improved the compressive strength of concrete in 28 days period, and the workability was increased by 53.8 % [8].

From the numerous research results obtained above, we can see that the utilization and incorporation of fly ash wastes in the construction are some viable solutions to make concrete quality better. This article presents beyond the engineering properties and experimental works but focuses on the economic and environmental advantages of the utilization of these waste materials in concrete to the conventional concrete mixture. The usage of fly ash in concrete may result in positive cost implications over the conventional concrete mixture.

## 2.0. Materials and Method

### 2.1. The study Area

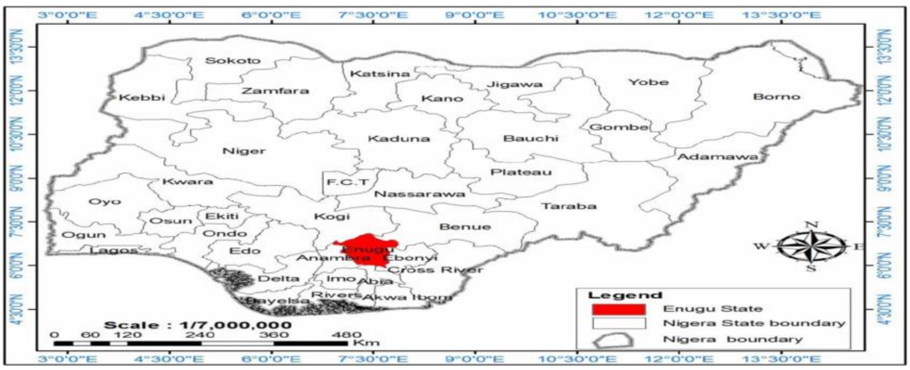


Figure1: Map of Nigeria showing Enugu State in red colour [9]

The fly ashes used were sourced from the coal by-product stockpiles at Oji-River Power Holding Company of Nigeria (PHCN) Power Station in Enugu State (Latitude: 6º 30' 00" N, Longitude: 7º 30' 00" E), Nigeria. Oji River is in Enugu State, Nigeria to the south bordering Anambra State and

Abia State with the LGA made up of several towns and villages such as Akugoeze, Ugwuoba, Achi, Inyi, Awlaw, Umuokpara, Obune, and Amankpunator. Its headquarters are in the town of Oji River as shown in Figure 1. Using the properties of fly ash as described by [2], the fly ash from Oji-River PHCN thermal station power plant in Nigeria, can be termed Class F fly ash.
The materials included grade 42.5N Portland cement, fine aggregate, coarse aggregate, Class F fly ash and water were used in this study to produce fly ash blended concrete. The tools used comprises of steel moulds (150 mm x 150 mm x 150 mm size), shovel and head pans. The fly ashes obtained from the location were passing through sieve size No.200 and used for the blended concrete. The 150 mm x 150 mm x 150 mm steel moulds were used which conforms to the minimum standard of [10]. However, the fly ash concrete was prepared by partially replacing cement in concrete by 0 %, 10 %, 20 %, 30 %, and 50 % of the fly ashes by weight respectively. A mix design of grade 20 concrete was used in this work and cured at 7 days, 28 days and 90 days by immersion method of curing.

All samples were crushed after their due dates of curing in order to know their compressive strength. Data were also obtained from some laboratory test conducted which included X-Ray Fluorescence (XRF) analysis of Class F fly ash, particle size distribution test of Class F fly ash, slump test of the fly ash concrete and compressive strength test of the fly ash blended concrete respectively.

## 3.0. Results and Discussion

In this study, preliminary tests were carried out to ascertain that the materials used in the making of concrete test specimens comply with their various British standard so that acceptable results were presented.

### 3.1. Particle size distribution test

The result obtained for the particle size distribution carried out on the fine aggregate and the Class F fly ash are presented below in Table 1 and Table 2. The particle size distribution was carried out according to [11] methodology.

Table 1: Fine aggregate particle size distribution

| Sieve No | Mesh Size(mm) | Weight Retained (gm) | Weight Passing (gm) | % Weight Passing |
|---|---|---|---|---|
| 7 | 2.36 | 0.00 | 200.00 | 100.00 |
| 14 | 1.18 | 0.04 | 199.96 | 99’98 |
| 25 | 600 | 4.52 | 195.44 | 97.72 |
| 36 | 425 | 7.90 | 187.54 | 93.77 |
| 52 | 300 | 46.28 | 141.26 | 70.63 |
| 72 | 212 | 29.00 | 112.26 | 56.13 |
| 100 | 150 | 36.60 | 75.66 | 37.83 |
| 240 | 63 | 63.60 | 12.06 | 6.03 |
| - | pan | 12.06 | 0,00 | 0.00 |

Table 2: Class F fly ash particle size distribution

| Sieve No | Mesh Size(mm) | Weight Retained (gm) | Weight Passing (gm) | % Weight Passing |
|---|---|---|---|---|
| - | 4.75 | 0.00 | 200.00 | 100.00 |
| 5 | 3.35 | 0.24 | 199.76 | 99.88 |
| 7 | 2.36 | 9.00 | 190.76 | 95.38 |
| 14 | 1.18 | 20.80 | 169.96 | 84.98 |
| 25 | 600 | 46.40 | 123.56 | 61.78 |
| 36 | 425 | 40.20 | 83.36 | 41.68 |
| 52 | 300 | 33.20 | 50.16 | 25.08 |
| 72 | 212 | 22.80 | 27.36 | 13.68 |
| 100 | 150 | 24.00 | 3.36 | 1.68 |
| 240 | 75 | 2.80 | 0.56 | 0.28 |
| - | pan | 0.56 | 0,00 | 0.00 |

### 3.2. Chemical composition of Class F fly ash

The chemical composition of the class F fly ash are shown in Table 3.

Table 3: Make up of fly ash from Oji-River PHCN thermal power plant [12].

| Oxide | Concentration (%) of Ordinary Portland Cement | Concentration (%) of Fly Ash Type F |
|---|---|---|
| Ca O | 60 – 67 | 1.78 |
| $SiO_2$ | 17 – 25 | 46.02 |
| $Al_2O_3$ | 3.0 – 8.0 | 24.16 |
| $Fe_2O_3$ | 0.5 – 6.0 | 13.68 |
| MgO | 0.1 – 4.0 | 1.91 |
| $SO_3$ | 1.3 – 3.0 | ND |
| $MnO_2$ | --------- | 0.56 |
| $Na_2O$ | 0.4 – 1.3 | 5.31 |
| $K_2O$ | 0.4 – 1.3 | 5.58 |
| Loss on ignition | - | 1.3 |

### 3.3. Effects of the fly ashes on the compressive strength of concrete

Table 4 have shown the compressive strengths of the fly ash concrete at various curing durations. The results obtained have shown a gradual decrease in compressive strength of the fly ash concrete at early ages. This might be due to the small quantity of Ca $(OH)_2$ release by cement for the pozzolanic reaction at the early curing durations which was corroborated the findings of [4]. At 28 days curing duration, the compressive strength of the blended concrete soared up at 10 % weighted replacement by 10.7% above the control concrete. This may be due to the increase pozzolanic reactions taking place in the blended concrete which was corroborated by [8]. However, the optimum compressive strength at 28 days curing duration was 23.25 N/mm$^2$ for the 10 % weighted replacement of fly ash in concrete. Furthermore, the compressive strength of the blended concrete at 20 % and 30 % weighted replacement of the fly ashes in concrete falls within the minimum design compressive strength. The curing duration of 90 days result for the blended concrete has shown a gradual decrease of compressive strength of the blended concrete at various percentages replacement. This was corroborated by [6].

Table 4: Compressive strengths of fly ash concrete at different curing durations

| Fly ash weighted percentages replacement in concrete | Curing duration (days) | | |
|---|---|---|---|
| | Compressive strengths (N/mm$^2$) | | |
| | 7 days | 28 days | 90 days |
| 0 % | 21.5 | 21 | 29.5 |
| 10 % | 20 | 23.25 | 26 |
| 20 % | 17 | 20.2 | 25.77 |
| 30 % | 15 | 20 | 25.9 |
| 50 % | 6 | 7.62 | 12.47 |

However, at 20 % and 30 % weighted replacements, the compressive strengths had also the same compressive strength as the control concrete. Since at 30 % of the fly ash replacement in the blended concrete, the compressive strength obtained was above the 20 N/mm$^2$ design strengths, therefore up to 30 % weighted Class F fly ash can be used to replace cement using design grade 20 concrete as shown in Figure 1.

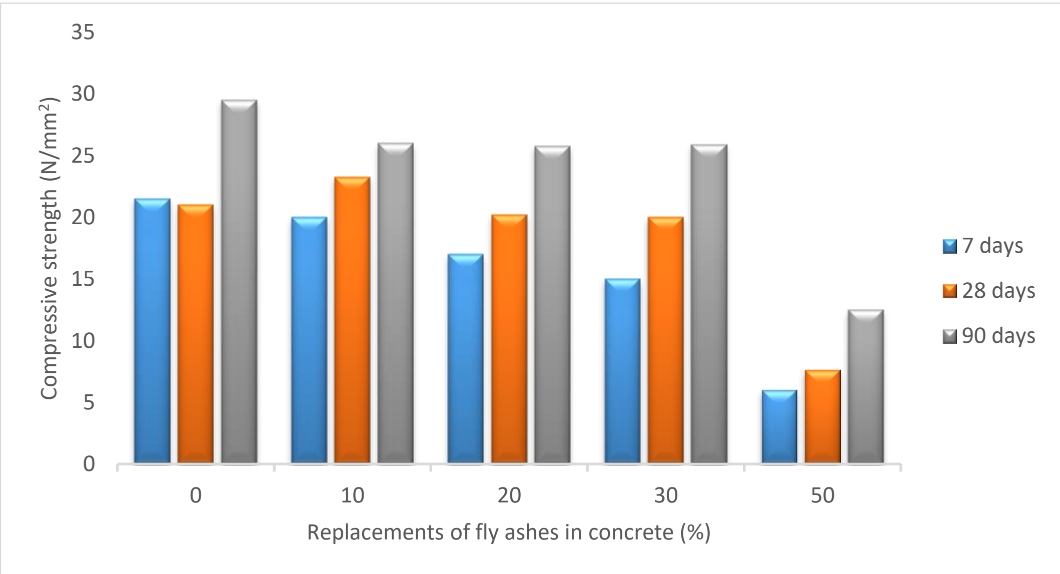


Figure 1: Compressive Strength of fly ash concrete at various curing durations

### 3.4. The economic value of fly ash concrete

Cost analysis was carried out for the blended fly ash concrete that met grade 20 concrete strength which was 30 % weighted replacement of fly ash in concrete. The various materials needed for producing 1m$^3$ of concrete for both the control concrete and 30 % blended concrete are shown by the following calculations.

The price of cement was determined using market rates (₦ 6,000 per 50 kg), whereas the cost of the waste fly ash and transportation was (₦ 2,500 per 50 kg)

For a control mix (0 % fly ash) the quantity of cement required is 370 kg/m$^3$. Hence, the cost of 370 kg of cement @ ₦ 6,000 per a bag of 50kg is $\frac{370}{50}\ x\ 6{,}000 = ₦44{,}400$

For optimum replacement of cement by fly ash (30% fly ash) the quantity of cement required is 259 kg/$m^3$

Hence, the cost of 259 kg of cement @ ₦ 6,000 per a bag of 50 kg was

$\frac{259}{50}\ x\ 6{,}000 = ₦31{,}000$

Add ₦ 5,000 for purchase of waste fly ash materials and transportation from site gives ₦ 36,000.

Savings was ₦(44,000-36000) =₦8,000 per $m^3$ of concrete

Percentage cost savings from 30% replacement= $\frac{(44{,}400-36000)}{44{,}000}$ x100 =18.2 %

## 4.0. Conclusion

The effect of fly ash as partial replacement for cement in concrete using the compressive strength of the blended concrete was examined. The results revealed a reduction of compressive strength of fly ash concrete at 7 days curing duration for 10 %, 20 %, 30 % and 50 % weighted replacements using grade 20 concrete. The compressive strengths of the blended concrete results of higher and comparable compressive strengths with that of control concrete was obtained at higher ages of 28 days and 90 days for 10 %, 20 % and 30 % respectively. However, up to of 30 % by weight of fly ash can replace cement in grade 20 concrete without reducing the compressive strength of the blended concrete. This amounted to about ₦8, 000 saving in 1$m^3$ of concrete which translated to 18.2 % in cementitious materials. The usage of fly ash in concrete was able to reduce the amount of cement material. Therefore, it is clear that the cost of fly ash concrete will be cheaper when compared to Portland cement concrete, and it offers significant economic and environmental benefits when used in larger constructions.

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