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Relevance of Fly Ash As Supplementary Materials In Concrete Produced With Manufactured Sand As Fine Aggregate

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ABSTRACT

The work was conducted to investigate the relevance of fly ash as supplementary materials in concrete production using manufactured sand as fine aggregate. Various laboratory tests were conducted to determine the slump value, the compacting factor ratio and the compressive strength of the concrete specimen. Parameters considered in this work include mix ratio of 1:1.5:3.5 with water cement ratio of 0.45 based on the concrete mix design conducted (cement =380kg/m3, sand =570kg/m3, granite =1330kg/m3, and water = 170litre). A total of thirty –six concrete specimen of 150mm x 150mm using the mix were cast in Civil Engineering Workshop, Auchi polytechnic, Auchi. In proportioning the cement with fly ash of the mix to prepare the compressive strength specimen, the quantity of cement was replaced at 0%, 5%, 10% fly ash The results showed that maximum compressive strength of 34.02Nmm2 at 28 days was obtained in the proportion of 95% cement: 5% fly ash, and decreases with corresponding increase in quantity of fly ash.

Keywords: concrete, fly ash, compressive strength, aggregate, supplementary.

1. INTRODUCTION

Concrete is the most used construction material in the world for all kinds of structures. This assertion has continued to place a high demand for the constituent concrete materials which have led to high cost of concrete production (Aho & Utsev, 2008). Concrete is a Sustainable material. Sustainability is about balancing the associated economic, social and environmental factors, not only at inception but during use. From an economic viewpoint, although cement is costly to produce in both financial terms and in terms of embodied energy, the amount of cement used in concrete is only about 10% of the total raw materials. And, in turn, the combined embodied impact of cement, aggregates, water and admixtures used in concrete accounts for only 10% of the impact of the operating phase of conventional buildings.

In the long-term, concrete's durability, low maintenance and re-usability coupled with a myriad of other environmental advantages have very positive long-term economic and environmental effects. In the construction industry this balance is of great importance not only before and during the construction stage, but is also about making the right decisions at the design stage, and choosing materials and construction methods to ensure long-term sustainability. A model available freely from www.cnci.org takes into account "cradle-to-grave" emissions of common raw materials used in concrete, including transport of those materials, and gives average emission numbers expressed in kg CO2 /ton of material produced. By using this data, the designer can experiment with different material combinations to minimise the environmental impact and quantify the effect of the material properties on cost per cubic metre of concrete. For more about concrete's innate cost-effectiveness, energy efficiency, thermal mass, light reflectance, fire resistance, low maintenance, acoustic performance, pollution reduction, water conservation, construction flexibility, retrofitting, recycling and re-use.

Concrete is an extraordinary and key structural material in the human history (Brunauer and Copeland, 2004), "Man consumes no material except water in such tremendous quantities". It is no doubt that with the development of human civilisation, concrete will continue to be a dominant construction material in the future. However, the development of modern concrete industry also introduces many environmental problems such as pollution, waste dumping, emission of dangerous gases, depletion of natural resources etc. In other words, Concrete can be defined as a stone like material that has a cementitious medium within which aggregates are embedded. In hydraulic cement concrete, the binder is composed of a mixture of hydraulic cement and water (ACI Committee, 116: 2004). Concrete has an oven-dry density greater than 2000 kg/m3 but not exceeding 2600 kg/m3 (BS EN 206-1:2000).

Presently Portland cement and supplementary cementitious materials are cheapest binders which maintain/ enhance the performance of concrete. However, out of these binders, production of Portland cement is very energy exhaustive along with CO2 production. About 1 tonne of CO2 is produced in manufacturing of each tonne of Portland cement (PC). Thus, cement production accounts for about 5% of total global CO2 emissions (Nixon, 2002). Concrete is an artificial stone-like material used for various constructional purposes and manufactured by mixing cement and various aggregates, such as sand, pebbles, gravel, stone, shale, etc with water and sometimes admixture and allowing the mixture to harden by hydration. Better still, concrete could be a composite material, which is made up of filler and a binder (Falade, 2009).

Fly ash is a pozzolans material. The use of pozzolans in concrete production brings positive effects to the environment, since by substituting large quantities of cement in concrete production, reduces the problem associated with their disposal and the decrease in the emission of greenhouse gases (CH4 and CO2) the main cause of global warming. Each ton of cement produces about one tonne of CO2 and the cement industry is responsible for 5% of CO2 emissions worldwide (Krovvidi,2014). Fly ash is defined by the American Concrete Institute, ACI 116R, as "the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system" (ACI Committee, 232 2004).

Fly ash is a by-product collected in the de-dusting of gases derived from the combustion of pulverized coal used in power plants. Fly ash is composed of fine particles, and its chemical composition is related to the different types and relative amounts of incombustible materials present in the coal. Fly ash particles are typically spherical, ranging in diameter from less than 1 µm to no more than 150 µm (Malhotra , 1996). Generally, its constitutive elements are: aluminum, silicon, calcium, magnesium, and iron.

Thus, depending on the combustion process and the type of combustible, the ash can be silica, sand-lime or lime sulfur, in some cases with pozzolanic and hydraulic properties. Referring to the pozzolanic activity shown by fly ashes, the American Society for Testing and Materials (ASTM C125, 1975) defines a pozzolan as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value, but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties". Basically, the great interest for the use of fly ashes comes from their ability to react with calcium hydroxide to form calcium silicate hydrates which possess pozzolanic and hydraulic properties.

The work is to determine the relevance of fly ash as supplementary materials in concrete production. And to achieve this goal, the following objectives were set:

i. To investigate how (fly ash) affect the compressive strength of concrete.
ii. To investigate the effects of various replacement levels of fly ash (FA) on compressive strength and durability properties of concrete.

The work was carried out under compressive strength test. Mix ratio of 1:1.5:3.5 was used to prepared concrete specimens, and were tested at the curing age of 7, 14, 21, and 28 days. The focus of the research was the definition of parameters for concrete management practice and this necessitated 'on-site' selection, sampling and production of concrete.

1.1 Significance of the Study

Concrete is widely used in the world today, and its chiefly component is cement, which often contribute high degree emission of carbon to the atmosphere. Most design guides are limited to compressive strength of concrete produced with cement. This work is a step in understanding the compressive strength of concrete produce at various percentage replacement of fly ash with cement. This is to guide users of these materials (fly ash) on their usuage effectiveness.

2. LITERATURE REVIEW

The need to provide cheaper housing and find alternative to ordinary Portland cement in most part of the world has necessitated research in blending and replacing the constituent materials of concrete. The production of ordinary Portland cement is characterised by emission of (CO2) which is one of the greenhouse gases that cause global warming. The dependence on sand as the sole material for fine aggregate in concrete had also led to continuous increase in the cost of concrete production. The use of fly ash therefore as partial replacement of cement may minimise consumption of ordinary Portland cement in concrete since low income earners will prefer blending their cement with fly ash in concrete production. Utilising fly ash as partial replacement of ordinary Portland cement in concrete production will also save the environment from dumping this waste into open lands which poses serious threat to the society by polluting the air and waste bodies (Melo, & Djialli, 2006).

Fly ash is a by-product from coal industries which is burnt to generate power required for different activities in the factory. This has a pozzolanic property that would potentially be used as a cement replacement material. Fly ash has recently been tested in some parts of the world for its use as a cement replacement material (Nixom, 2002). The fly ash was found to improve some properties of the paste, mortar and concrete including compressive strength and water tightness in certain replacement percentages and fineness.

The higher silica content in the fly ash was suggested to be the main cause for these improvements it has been reported that the silicate undergoes a pozzolanic reaction with the hydration products of the cement and results in a reduction of the free lime in the concrete. The main objective of this study is, therefore, to study the suitability of fly ash produced, as a pozzolanic material to partially replace cement in mortar and concrete production. Towards this, experimental investigations were carried out to examine the strength variation of the concrete in extreme conditions like sea water.

2.1 Composition of Fly Ash

Generally, the constitutive elements of fly ash are aluminum, silicon, calcium, magnesium, and iron, although its composition varies with the source of coal. According to ASTM C618, there are two types of fly ash – Class C, normally produced from lignite or sub-bituminous coals, and known as high calcium fly ash – Class F, usually formed from bituminous coals, and identified as low calcium fly ash. In order for a fly ash material to be classified as Class C, the silica (SiO2), the alumina (Al2O3), and the iron oxide (Fe2O3) constituents should not exceed by much 50% of the composition, while for Class F the summation of this three components can be greater than 70% (ACI committee,226 report).

As mentioned earlier, low calcium class F fly ash is being used for this study; hence,. It should be noted that Class F fly ashes possess pozzolanic properties. Soft to the touch, they (class F) are in the form of powder from gray to black in color depending on the unburned fuel and iron oxide contents. Whereas, Class C fly ashes have the form of a fine gray powder, with physical properties and/or pozzolanic characteristics. They mainly contain reactive lime, reactive silica, and alumina. The amount of lime (CaO) in this type of ash is high; therefore they are likely to consolidate without the use of binder. Overall, a fly ash material is considered suitable to be used as pozzolan for concrete if the majority of its particles pass the No. 325 (45µm) sieve.

2.3 Durability of Concrete

As stated by Mehta and Burrows (2001), at the dawn of the 21th century, the construction industry faces the challenge to build concrete structures that are environmentally more sustainable. They also pointed that before 1930 the deterioration of concrete was mostly attributable either to crumbling or leaching from leaking joints or poorly consolidated concrete. The literature did not mention any deterioration correlated to cracking during that period. According to Burrows (2001), the deterioration of concrete structures by cracking appeared when the producers of cement started making faster-hydrating Portland cements by raising the fineness and the C3S content.

2.3.1 Fly Ash Contribution to Concrete Durability and Strength

Durability can be defined as the ability of a concrete structure to maintain integrity and strength over a period of time. Strength is a measure of the ability a structure to sustain loads at a given point in time. Therefore, two concrete cylinders might have an equal compressive strength at 28 days, but their behaviour in terms of permeability, resistance to aggressive agents, resistance to cracking and deterioration over time can differ widely (Headwater resources).

3. MATERIALS AND METHODOLOGY

3.1Cement

The Bua Portland brand of cement was used for the entire work.

3.1.1 Aggregate

Quarry dust often known as manufacture sand was used in this work. The size which passed through 4.75mm is called fine aggregate. The aggregate which retained above 4.75mm sieve is called coarse aggregate: 19mm size coarse aggregate was used.

3.2. Preparation of Coarse Aggregate (Granite To BS 812: Part 1. 1995)

Particle size distribution analysis was carried out on the coarse aggregate in the course of this work and it was in accordance with the recommendation of BS 812: part 1 1995. The coarse aggregate was granite.

3.2.1 Preparation of Fine Aggregates. (manufacture sand) To BS: 812: Part 1:1995)

Fine aggregates are often considered as inert material. The manufactured sand used in this work is quarry dust and was obtained from a quarry site in Imeke, Edo state. Manufactured sand is sand obtained from processed crushed rock or gravel. The aggregates were thoroughly washed (to remove unwanted materials) and dried; they were graded in accordance with BS 812 part 1: 1995.

3.2.2 Water

Ordinary clean portable water free from suspended particles and chemical substances was used for both mixing and curing of concrete cubes cast with fresh water.

3.3 Experimental Program

The batching of concrete was done by weighing the different constituent materials based on the adopted mix ratio of 1:1.5:3.5 with water cement ratio of 0.45. The cement portion of the mix was partially replaced with fly ash at three level of cement replacement. The levels of cement replacement are 100% cement: 0% fly ash, 95% cement: 5% fly ash, 90% cement: 10% fly ash. They were mixed together with the aid of a shove and in the course of mixing, the corresponding quantity of water was added when the mixture had been mixed to a homogeneous state, the mixture was poured into a head pan. 150mm x 150mm cubes were cast.

This was to test the average compressive strength of concrete for this study. Each mould was filled with concrete in three layers using a trowel. Each of this layer was compacted using a 20mm diameter tamping rod to tap 25 times in accordance with BS 1881(15) After demoulding, the specimens were then transferred into a curing tank that contains clean water where they were store till 7, 14, 21 and 28 days before compressive test was carried out. A total of thirty- six (36 No.) numbers of concrete specimens were made for this operation. The concrete specimens were prepared in civil Engineering concrete workshop of Auchi polytechnic, Auchi.

3.4 Tests on Concrete

3.4.1 Determination of the workability of concrete Mix by Slump test to BS: 1881: part 102: 1983

The slump test in accordance with BS: 1881: part 102: 1983 was used to detect the uniformity of the concrete mix and workability of the concrete.

4. RESULTS AND DISCUSSION

4.1 Introduction

Below is a detailed discussions on the results obtained. The analysis is presented in tables 4.1 to 4.19 and Fig. 4.1 to fig. 4.4

4.2 Test Results

4.2.1Workability:

The ability of concrete by which it can be mixed, transported, placing and compacting is known as workability.

4.2.2 Slump test

Ingredients of mixes were properly mixed so as to produce homogeneous and uniform fresh concrete in macro scale. its workability ascertain using slump test and compacting factor ratio test. The slump is in between 20mm-60mm.

4.3 Compressive Strength of Concrete Cubes:

This test is done to determine the cube strength of concrete mix prepared. The test is conducted on the 7, 14 21 and 28 day and their observations are listed below in the form of a graph.

Table 4.1 slump tests and compacting factor ratio results.

Proportion of cement and fly ash	Slump value(mm)	Compacting factor ratio
100% cement :0% fly ash	20	0.80
95% cement :5% fly ash	60	0.76
90% cement :10% fly ash	50	0.72

Table 4.2: Rate of compressive strength development at 7 days for the various proportions of cement and fly ash

Proportion of cement and fly ash	Compressive strength(N/mm2)
100% cement :0% fly ash	18.27
95% cement :5% fly ash	15.76
90% cement :10% fly ash	10.22

Table 4.3: Rate of compressive strength development at 14 days for the various proportions of cement and fly ash

Proportion of cement and fly ash	Compressive strength(N/mm2)
100% cement :0% fly ash	22.54
95% cement :5% fly ash	19.92
90% cement :10% fly ash	14.20

Table 4.4: Rate of compressive strength development at 21 days for the various proportions of cement and fly ash

Proportion of cement and fly ash	**Compressive strength(N/mm2)**
100% cement :0% fly ash	28.56
95% cement :5% fly ash	25.85
90% cement :10% fly ash	22.33

Table 4.5: Rate of compressive strength development at 28 days for the various proportions of cement and fly ash

Proportion of cement and fly ash	Compressive strength(N/mm2)
100% cement :0% fly ash	34.02
95% cement :5% fly ash	30.00
90% cement :10% fly ash	29.00

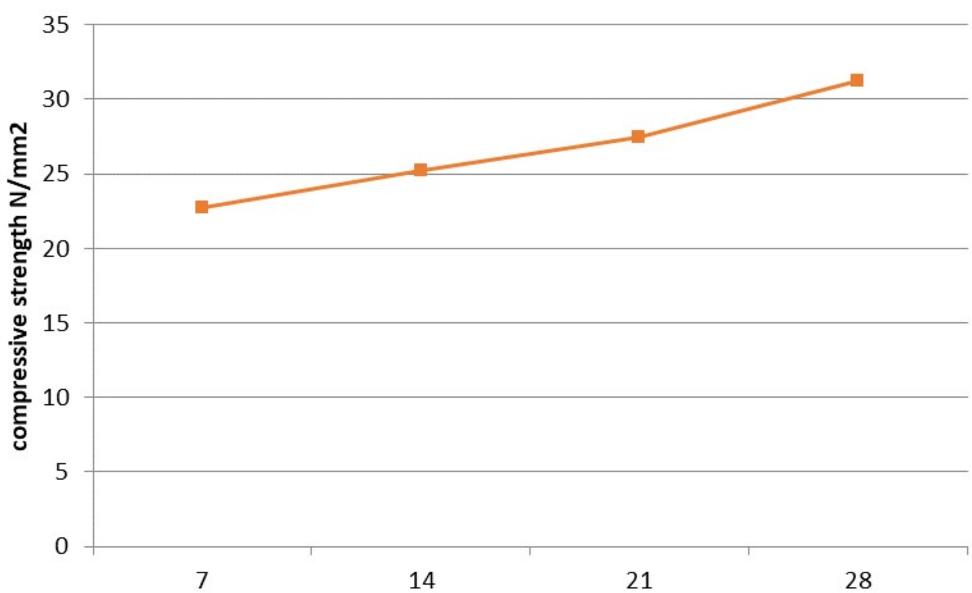

figure 4.1. rate of compressive strength development 100% cement: 0% fly ash coarse aggregate

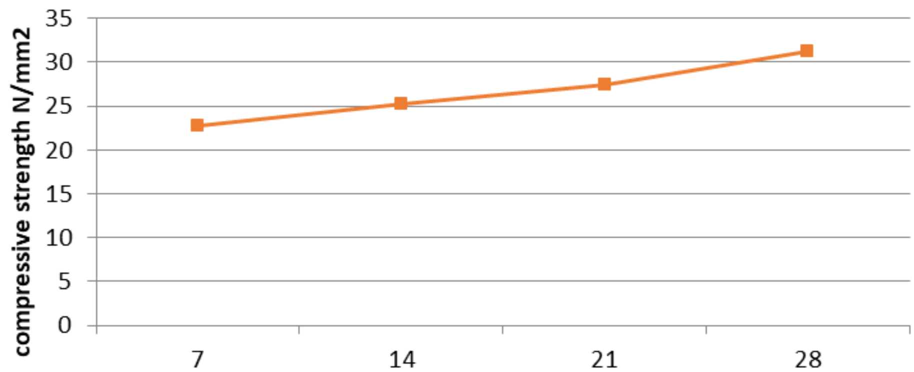

figure 4.2. rate of compressive strength development 95% cement: 5% fly ash

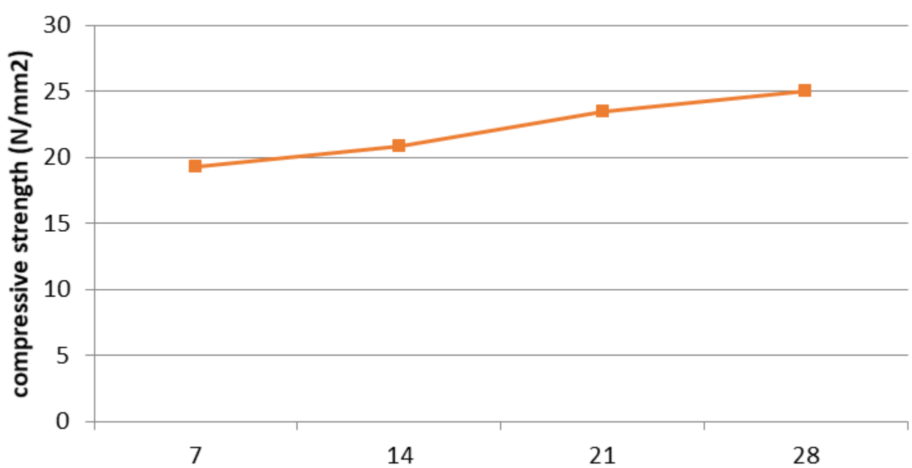

figure 4.3. rate of compressive strength development 90% cement: 10% fly ash

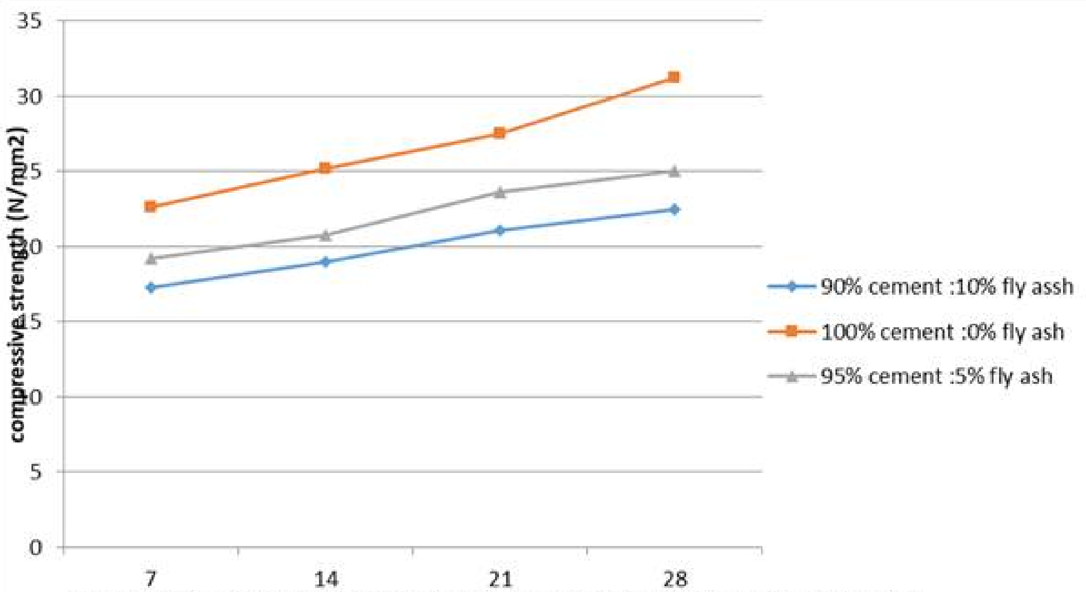

figure 4.4 rate of compressive strength development for all the level of replacement of cement

4.4 Discussion of Results

Result of the experimental program on fly ash concrete where fly ash has been used as partial replacement of cement in concrete mixes. From the concrete mix design, the mix proportion was 1:1.5:3.5 with water cement ratio of 0.45. Table 4.1 to 4.4 showed the rate of compressive strength development with age, The relationship between the compressive strength and age of concrete using the mix ratio are as shown in Fig. 4.1 and Fig. 4.4.from the graph, it was deduce the strength of 5% fly ash concrete was more than 10% fly ash concrete .

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- **i.** The incorporation of high volumes of fly ash at 10% (FA) in the cement paste mixes produced a lower slightly the strength value of the concrete. From above point of view, it can be suggested that a combination of 5% FA can be beneficially used to improve the hydration properties and compressive strength of the concrete.
- **ii.** With partial replacement of cement with fly ash in concrete production, the embodied carbon emission into the atmosphere is gradually reduced, and it helps to reduce climate change.

5.2 Recommendations

Although this research has indicated the limits to which ordinary Portland cement (OPC) can be replaced with fly ash using manufacture sand. The following further research is recommended in order to broaden the use of fly ash in concrete production.

- **i.** It is recommended that more work be done in trying to achieve high strength concrete using different concrete mix with fly ash.
- **ii.** Also different water cement ratio should be used in subsequent edition.

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