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Strength Improvement and Mixing Water Reduction of Combined use of Fly Ash and a Generic Naphthalene Based Superplasticizer in Concrete

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ABSTRACT

Among the most important properties of a concrete are its workability, strength and durability. These properties ordinarily are achieved by varying the grading of aggregates and proportions of the basic concrete components. Today, admixtures have taken over because they are easier to apply and are also more effective. However, the technology and availability of admixture is not easily assured, especially in developing countries. This work is concerned with the use of a combination of fly ash and a generic sulfonated naphthalene-formaldehyde (SNF) condensate superplasticizer to show the water reducing, workability and strength enhancement potentials of their combination. A grade 20 concrete of nominal mix proportion of 1:2:4 and an initial water-cement ratio (w/c) of 0.6 was used; and a constant consistency of 50 mm slump maintained throughout the experiment. The variation of the strength of the concrete and the water-cement ratio (w/c) was studied as the various combined quantities of superplasticizer and fly ash was added. It was observed that the 28-days strength of the concrete increased with increase in either fly ash or superplasticizer in the combination. The strength obtained was much higher than that of the control mix. The water-cement ratio also reduced in the same order, showing more reduction than using fly ash or SNF superplasticizer alone. This showed that there is a great advantage in the combined use of both admixtures.

1. INTRODUCTION

Workability, strength and durability are arguably among the most important properties of a concrete in modern construction industry considering the present state of the art in concreting (Shetty, 2009). In the past, these desired properties for any specific concrete mix was only achieved by varying the mix proportions of the basic concrete components and the grading of the aggregate (Elvery ,1963) which does not impart sufficient workability to the concrete and makes concrete difficult to compact to full strength with increased labor cost. In those days (in the 1960s) admixtures in general were regarded as unimportant, as some of them, especially detergent based workability admixtures impaired the strength of hardened concrete (Jackson, 1981). Nowadays, however, admixtures are preferred because they are better and easier to apply. Workability admixture have grown from simple slump improvement type to those that can make concrete to flow and pumped into formworks. These modern admixtures increase the strength of concrete greatly instead of reducing it. That is why, in today's concrete technology, we talk about high strength concrete, self-compacting concrete, self-leveling concrete, central mixing plants, mobile mixers, all because one can now use the advanced water reducers (workability admixtures) without harm to the strength of the concrete.

Fly ash is a mineral concrete additive and admixture discovered as early as 1930s. It was first used as partial cement replacement in concrete, and replacement of cement with fly ash from 20% to 60% in concrete became practicable (Adinna et al., 2020). As a pozzolana, fly ash is capable of extending cement hydration and increasing the final strength of concrete by an appreciable margin above those of normal concrete. This cement extending action continues till 90 days, imparting greater strength to the concrete than what is expected of a comparable normal concrete. Fly ash is produced during the combustion of pulverized coal in a coal-fired electric power plant. It is normally separated from the flue gas via electrostatic separator or bag filter. They are very fine spherical particles of the order of 10 µm to 100 µm in diameter. In the fresh concrete, these tiny particles are positioned in between the cement particles creating a ball-bearing effect, thus increasing the workability and strength of a fresh concrete. This has endeared fly ash to many concrete makers especially in high strength concrete industry as fly ash and super plasticizers are the main admixtures for high strength concrete (Aitcin and Miao ,1992).

Superplasticizer technology, on the other hand, has come a long way. In the 1960s all that was available were ordinary water reducers like lignosulphonates, which were by-products of wood pulping in paper making industries. Later in 1970s high range water reducers in the form of sulfonated naphthalene- formaldehyde condensate, sulfonated melamine-formaldehyde condensate and improved forms of lignosulphonates were produced (Shetty, 2009). These were the first-generation superplasticizers. The advent of these superplasticizers marked the birth of high strength concrete with chemical and pozzolanic admixtures, in which the first generation superplasticizers, fly ash and silica fume were used to advantage.

In 1990s new generation of advanced superplasticizers were discovered. They doubled the performances of the first-generation superplasticizers in fluidizing and increasing the strength of concrete. A new terminology "high performance concrete" was born and used to describe concrete mixtures with flowing, self-leveling, high strength, high density, high dimensional stability, low permeability properties and high resistance to chemical attacks (Shetty, 2009; Alois ,1998).

These types of concrete are generally pumped for placing. In such construction sites, the transit mixer empties the concrete into the concrete pump that pumps it through placing booms into the formworks, and this reduces the construction time and labor cost considerably. This is the current state-of-the-art in concreting.

A lot of scholarly works has been done on fly ash, superplasticizer and their combinations. Saeed et al (2005) studied the effect of two propitiatory superplasticizers (rheobuild 561m and rheobuild 1100) on the workability and strength of concrete and observed substantial improvements in the properties of the concrete with rheobuild 561m giving more promising results than rheobuild 1100. They did not, however, discuss the differences in the chemical compositions of these superplasticizers that could cause the difference in their performances. Puertas et al. (2005) studied the effect of polycarboxylate superplasticizer on hydration, microstructural change and rheological behavior of cement paste, and discovered that the admixture induces microstructural modifications in the cement paste which reduces porosity of the hardened paste and improves the fluidity of the fresh paste at low dosage. Okoli (2018) studied the effect of low dosage of a generic sulfonated naphthalene-formaldehyde condensate superplasticizer on the strength and mixing water reduction of concrete and obtained 18% mixing water reduction and 35% improvement in the strength of the concrete. The report only showed results from 0 to 1.0% addition of the super plasticizer, while up to 3% addition was possible. Okonkwo (2019) studied the mixing water reduction of fly ash on a grade 20 concrete and obtained a compressive strength of 34N/mm^2 and maximum water reduction of 6% at a fly ash content of 8% but did not include super plasticizer in the study. A good number of popular buildings and suspended bridges constructed of high strength concretes are recorded in Shetty (2009) containing concrete mixes of different combinations of fly ash, silca fume, slag and superplasticizer.

The technology of admixture hardly goes around the globe as rapidly as they are discovered or developed, thus leaving many stakeholders in ignorance. This report is concerned with the use of a generic sulfonated naphthalene- formaldehyde condensate (SNF) and fly ash jointly for concrete making, to showcase their combined water reducing and strength improvement potentials. This will help engineers and other stakeholders, most of whom are practicing at low or medium profiles, to improve their professionalism, reed concrete products of honeycombs which can cause unexpected structural failures.

2. MATERIALS AND METHODS

2.1. Material Collection and Preparation

Materials used include a class-F fly ash obtained from thermal electric power plant in Oji River in the Eastern part of Nigeria, a generic sulfonated naphthalene- formaldehyde condensate superplasticizer locally prepared to standard, a 3 mm clean river sand, a grade 42.5N Portland limestone cement by Nigerian Standard (NIS, 2013), 12 mm granite coarse aggregate and a portable water. The laboratory equipment employed were 150 x 150 x 150 -mm concrete mould, slump test apparatus, curing tank and a universal testing machine.

2.1.1. Preparation of superplasticizer

The SNF superplasticizer was prepared locally in a commercial lab using the following procedures adopted in a customized manner from NAVKAR chemicals industry's technical leaflets and other literature (Fujio and Shuichi, 2006; Okoli, 2018). Crude naphthalene crystals were weighed and introduced into a clean heat resisting glass beaker and heated to a temperature of about 120 ºC to melt. Sulphuric acid, 214 g and 98% concentration, was added gradually for about 1½ hours allowing maximum temperature to reach 160 ºC and maintained at that level for 3 hours for the precipitates to dissolve. The sulfonated product was cooled to a temperature of 120 ºC and water was added. The second stage was polymerization process which was initiated by heating the sulfonated product to a temperature of approximately 90 ºC with stirring. Formaldehyde solution was added gradually, in drops, for about one hour. The temperature was raised to 100-105 ºC and maintained at the level for four hours. The temperature was again raised 120 ºC under pressure (2 bar) and maintained for about four hour and the polymerized product was cooled to about 90 ºC. The third stage was neutralization process. Sodium hydroxide solution (formed by adding water to sodium hydroxide crystals) was added to the cooled condensate till the ph. was about 7 – 8, and then allowed to cool to 50 ºC. The SNF liquid was placed in the oven till it dried to a brown solid product which was ground to fine particles that was rolled using metal roller on a smooth surface to fine powder.

2.2. Preparation of Concrete Test Cube Samples

A grade 20 concrete of nominal mix-proportion of 1:2:4 and an initial water-cement ratio of 0.6 was used throughout. The property of the concrete studied in the experiment was the variation of the strength of the concrete and the water-cement ratio (w/c) reduction as the combined quantities of superplasticizer and fly ash was added. The experimental concrete cubes were prepared in seven groups, each group consisting of 4 cubes, two from each group to be tested at 7 days, and the remaining two at 28 days water-curing ages. The combination of fly ash and superplasticizer used for the various groups of test cubes were 0% fly ash and 0% superplasticizer, 4% fly ash and 0.5% superplasticizer, 8% fly ash and 0.5% superplasticizer, 4% fly ash and 1.0% superplasticizer, 8% fly ash and 1% superplasticizer, 4% fly ash and 2% superplasticizer, 8% fly ash and 2 % superplasticizer. The fly ash and superplasticizer (SNF) were measured by weight of the cement content of the mix before addition. All the concrete cubes were prepared and tested to British standard code of practice (BS 1881,1970)

Thus, the materials required for all the test groups of cubes were weighed out and keep aside; that is fly ash, superplasticizer, water, cement, fine aggregate and coarse aggregate (every other component remind the same quantity except fly ash and superplasticizer). For the first group of test cubes (the control cubes containing 0% fly ash and 0% superplasticizer), the materials were mixed on a hard surface, with all the measured quantity of water used and the slump determined, and it gave 50 mm.

Preparation of the other group of cubes were done by first mixing the cement with superplasticizer and fly ash to ensure uniform distribution of these admixture in the cement before aggregates were mixed with it. The measured water was then added gradually with mixing until a consistency of the control mix was obtained, and the slump was determined to check. Once the slump was approximately 50 mm, four cubes were cast from the fresh concrete, water saved weighed and the new water-cement ratio (w/c) calculated. This procedure was applied to the rest of the test groups. The cubes were cured in the curing tank and the compressive strength tested with the universal testing machine by simply placing the cube in the machine and noting the failure load in compression, which is divided by the area of one face of the cube to get the compressive strength in N/mm^2 at 7 days and 28 days for each group.

3. RESULTS AND DISCUSSION

The results of the tests are tabulated in Table 1. Reading through Table 1, column 4 and 5, it is easily observed that the quantity of water needed to make concrete of the same wetness reduced with either increase in superplasticizer content or fly ash content; as such the 28 days strength increased with increase in either fly ash or superplasticizer contents. The reduction in water used in the concrete resulted in a new water-cement-ratio shown in column 6 of Table 1. This new water-cement ratio reduced with increase in superplasticizer and fly ash contents which resulted in improved strength of the concrete This shows that the fly ash and superplasticizers complement each other. It is worthy of note here that the maximum value of 8 % and 2 % percent, for fly ash and superplasticizers respectively used in this research were based on earlier publication by other scholars on similar topics (Adinna and Okonkwo, 2020). A maximum percentage water reduction of 37.8% and a 28-days strength of 38.22 N/mm^2 were achieved. This is much higher than that of the control mix which was 21.5 N/mm^2 and also better than that obtained using the admixtures individually (Adinna et al, 2018; Abul et al., 2019). This shows there is an advantage in combining the first-generation superplasticizer (SNF) with fly ash to enhance results of workability, mixing- water reduction and strength of concrete.

Table 1: Variation of strength and water reduction of concrete with combined quantity of fly ash and superplasticizer

Test group	Fly ash content (%)	Superplasticizer content (%)	Water saved (kg)	Water used (kg)	New w/c ratio	Water reduction (%)	7days strength (N/mm^2)	28days strength (N/mm^2)
1	0	0	0	1.725	0.60	0	15.20	21.5
2	4.0	0.5	0.478	1.247	0.53	10.31	16.20	25.60
3	8.0	0.5	0.324	1.421	0.49	18.67	16.65	29.81
4	4.0	1.0	0.536	1.189	0.41	31.60	18.25	35.35
5	8.0	1.0	0.584	1.141	0.39	33.56	18.90	37.26
6	4.0	2.0	0.365	1.363	0.47	20.10	17.00	30.43
7	8.0	2.0	0.652	1.073	0.37	37.80	19.10	38.22

4. CONCLUSION

In conclusion, the research has shown that better results of concrete property can be obtained by adding fly ash to super plasticized concretes. Engineers and other stakeholders are advised to explore this method to improve the quality of their concrete products.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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