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Current Effects of Naphthalene Based Superplasticizer's Addition Process on Water Reduction and Grade C20/25 Concrete's Compressive Strength

Sylvester O. Osuji*, **Dafe Ikogho**

Department of Civil Engineering, University of Benin, Benin City, Nigeria

Abstract Superplasticizer was applied to concrete in two processes: addition of Superplasticizer to 25% of the gauging water adding remaining of gauging water by trials till a constant consistence is reached (CCC process) and by partial reduction of gauging water by amount of superplasticizer added (RGW process). Superplasticizer dosage range tested was limited to the manufacturer's recommendation between 0% - 2% at 0.5% intervals of the binder mass. A total of 9 concrete mixes were produced, the control being plain concrete designed to attain a C20/25 grade concrete strength at 28days and the other 8 were produced varying only the Superplasticizer and water content. Fresh concrete's consistence was measured by slump test, water reduction due to SP inclusion was observed and unconfined compressive strength tests performed at 1,7,28 and 56days. The study revealed SNF addition by the two different processes resulted in varying compressive strength development and water reduction recording maximum water reduction and compressive strength gains of 22.9% and 80.2% respectively compared to the control.

Keywords Compressive strength gain, Concrete, Naphthalene based superplasticizers, Water reduction

1. Introduction

It is widely known that compressive strength is an important parameter in the design and construction of civil concrete works. Compressive strength according to Abram's law is increased with reduction in water/ cement (w/c) ratio inferring that water reduction leads to compressive strength increase. Superplasticizers are known to reduce water up to 30% [1], with modifications and sustained research, superplasticizers are improving in potency in improving concrete's mechanical properties.

Superplasticizers (SPs) are a class of anionic polymer dispersants that inhibit aggregation in hydraulic cement, lowering the yield stress of cement pastes improving workability and reduce water requirement [2]. Superplasticizers are employed in the production of high-strength concrete mostly required where reduced weight is important or where architectural considerations call for small support reducing the total amount of material placed and lowers the overall cost of the structure. When attempts are made to increase workability or reduce water or cement in concrete without admixtures, detrimental impact on critical concrete strength properties occur.

* Corresponding author:
sylvester.osuji@uniben.edu (Sylvester O. Osuji)
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Naphthalene based superplasticizers have been in use since 1930 [3], they are produced from naphthalene by oleum or sulfur trioxide sulfonation of the β- sulfonate [4]. Despite the long history and the advent of polycarboxylates superplasticizers, naphthalene based super plasticizers (SNF) are still in use today with brands being produced with refinements through research aimed at improving their performance. In a study carried out in [3], it was observed that they possess a low Relative Standard Deviation (RSD) values when used on different cement types compared to the new generation polycaboxylate superplasticizers.

Numerous researchers have studied the effects of superplasticizers on concrete reporting how they improve concrete's compressive strength [5-12]. According to [13], regular reporting of successful concrete applications relying on superplasticizers has led to a tendency to think of superplasticizers as a panacea for all concrete problems; however, good batch designs that consider the amount of superplasticisers to be added are critically important to avoid serious segregation, excessive bleeding, and needless extra expense. The right amount of superplasticizer within the manufacturers recommended range is not automatically known and has to be determined through experiments.

The aim of this research is to investigate current effects of naphthalene based superplasticizer's (SNF) on concrete's compressive strength and water reduction estimating SNF's optimum dosage in the different SP addition processes examined. The best results are attained when SP are applied at the optimal dosage within the manufacturer recommended dosage range. Reference [7] recommends that more concrete mixes containing different dosages of admixtures be prepared to obtain the precise optimum dosage of admixture at which maximum strength gain is achieved.

There is the need to determine compressive strength gain and the optimum dosage so as to compensate for future strength losses. Situations arise where strength losses are experienced by concrete at elevated temperatures. Reference [14] reported a compressive strength loss of 43.88% when a C35/40 concrete was exposed to elevated temperatures of 300°C as experienced in facilities like reactor vessels of nuclear facilities. This study attempts to estimate compressive strength gain that can be achieved by use of SNF so as to compensate compressive strength losses that arise from loss of concrete exposed to elevated temperatures.

2. Literature Review

Naphthalene based superplasticizer (SNF) is produced from naphthalene by oleum or sulfur trioxide sulfonation of β sulfonate. Subsequent reaction with formaldehyde leads to polymerization and the sulfonic acid [4] as shown in Figure 1. It is then neutralized with a suitable alkali and filtration to eliminate calcium sulfate [15].

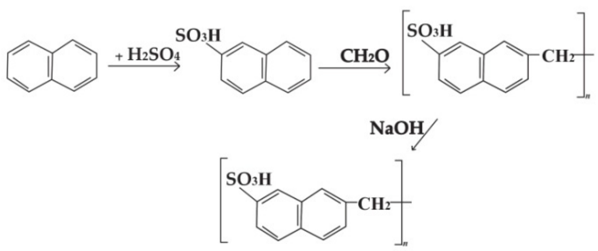

Figure 1. SNF manufacturing process [4]

Superplasticizing admixtures are used in concrete mixes to reduce the w/c ratio while maintaining the initial consistency of the concrete mixture constant, to reduce the cement and water content without affecting the fluidity of concrete mixture and maintaining the same value of compressive strength as the control concrete and to increase workability of the concrete mix while maintaining w/c ratio constant.

According to Astm C494, superplasticizers have the ability of water reduction as much as 35 % more potent water reducers than plasticizers as shown in table 2.1 below. In all types of Portland cements, water reduction occurs, but to different extents [22]. EN 934-2, requires a minimum water reduction of 12% compared to the control at equal consistence.

Due to space limitations, some of the most relevant ones are presented below.

[7, 15, 16, 18, 19] all pointed to the fact that mechanical properties of concrete are improved as a result of water reductions made possible by superplasticizers, leading to considerable improved compressive strength [6, 20, 21]. 26.69% compressive strength increase was recorded by [6] using a Naphthalene based Superplasticizer and [7] reported compressive strength gain of 25% at 1% dosage using Sikament® R2002 superplasticizer.

Reference [6] in the study of SNF on C25/30 grade concrete recorded water savings of 11.29% at 1.5% SP dosage a corresponding compressive strength gain of 27% when a slump of 33 was maintained as the control.

Reference [15] reported on water reduction and compressive strength of SNF (Rehobuild 1125) on 20N/mm^2 and 40N/mm^2 grade concrete maintaining w/c ratios at 0.55 and 0.4 respectively. Compressive strength losses at 28 days of 15% and 5.33% compared to the control for 20 N/mm^2 and 40 N/mm^2 grade concrete respectively were observed with water reduction of 29% recorded for both concrete grades.

Water reduction due to superplasticizer's addition to concrete, depends on factors such as initial slump, superplasticizer type, as well as dosage [4]. Superplasticizer types vary so also their water reduction effect on concrete. According to [22], Naphthalene based superplasticizer's water reduction ability is not as high as the polycaboxylate based superplasticizers.

The average water reduction of Naphthalene based superplasticizer is 26 within 0.3 – 0.5 w/c ratio on cement paste dosage [4].

In another study, the addition of ammonium salt of Naphthalene formaldehyde lead to the decrease of w/c ratio from 0.25 to 0.21 in [23]. According to [24], these reductions are made possible as SNF dissociate in water SO_3 groups in their chemical structure are absorbed by the positive charged cement particles).

From the literature reviewed in this study a number of works has been done relating to the effect of superplasticizers on compressive strength and water reduction on concrete. Behaviour of a SNF on 25N/mm^2 strength was not reviewed.

The thrust of this study, therefore, is to carry out an assessment of a recent naphthalene based superplasticizer effect on compressive strength and water reduction estimating the SP optimum dosage based on compressive strength for a C20/25 grade concrete with a view to making appropriate recommendations for the local construction industries that may not have the wherewithal to perform this. It could also be a basis for them to select appropriately the SP dosage and way of addition of the superplasticizer to be used for different construction works.

3. Methodology

3.1. Material Properties

The experimental work was carried out using basic constituents of concrete such as coarse aggregates, fine aggregates, cement, water and superplasticizer. The constituents used were as follows:

Coarse Aggregates: The coarse aggregate used was crushed and angular shaped of maximum size 40mm granite from Ofosu, Ondo State. Particle size distribution is shown in Figure 2 and physical properties shown in Table 1.

Table 1. Physical properties of coarse aggregates used

S/No	Property	Results
1	Water Absorption	1.13%
2	Specific Gravity	2.74
3	Aggregate Impact Value (AIV)	20.50%
4	Aggregate crushing value (ACV)	28.90%

Fine Aggregates: Natural river sand from Okhuahe river, in Edo State was used Sieve analysis was performed in accordance to BS812: Part103 as shown in Figure 2.

Water: Tap drinking water from the University of Benin, Benin City was used in all tests.

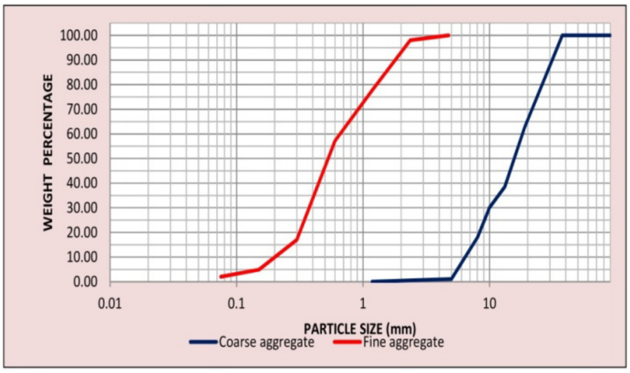

Figure 2. Particle size distribution of fine and coarse aggregates

Cement: Ordinary Portland Cement grade 42.5 conforming to BS 12:1991 made by Dangote from Igbese plant was used.

Superplasticizer: Naphthalene based superplasticizer Betocrete F27 was used. It complies with EN 934-2: T3.1 and 3.2. See Table 2 for details.

Table 2. Naphthalene based Superplasticizer properties

S/No	Property	Result
1	Consistence	Liquid
2	Colour	Dark Brown
3	Density (g/cm^3)	1.13 ± 0.03
4	Recommended Dosage (%)	0.3 - 2
5	Chlorides content	Nil
6	PH	4.8
7	Solids Content (%)	30

3.2. Concrete Mix Proportion and SNF Addition Process

A total of nine concrete mixes were made and SNF was added to concrete from 0.5% to 2% according to the mass of cement within manufacturers recommendation by the following two different processes:

(a) In the first process gauging water was replaced by the amount of the SP which was added. This process will be denoted as RGW in what follows.

(b) In the second process a delayed addition of the SP to 25% of the gauging water was done. Then water was added by trials till a constant concrete consistence of 90mm was attained. This method will be denoted as CCC in what follows.

Control mix was designed using the department of envi ronment (DOE) method for a 28 day strength of 25N/mm^2 with 0% SP. The other 8 concrete mixes were produced by applying the SP using the two methods described above from 0.5% to 2% at 0.5% intervals of the cement mass as shown in Table 3.

Consistence was determined for all fresh concrete mixes by the conventional slump test in accordance to BS EN 12350: 2. After checking the consistence, mixed concrete was placed in a cast iron mould and was well compacted in two layers with the help of a table vibrator for 45 and 30 seconds for double and single cast iron moulds respectively. They were kept for 24 hours and then the casted concrete cubes were demoulded producing a 150 x 150 x 150mm concrete specimens. The specimens were then exposed to continuous moist curing at 100% relative humidity (Wet –cured) in accordance to BS EN 12390 part 2: 2000. Compressive strength tests were performed at 1, 7, 28 and 56 days in accordance to BS EN 12390:4 using a compression testing machine. The mean of three results was recorded as the compressive strength. Water reduction due to SP's addition was also recorded.

Table 3. Concrete Mix Proportion Details

SP Dosage	OPC (kg/m^3)	Consistence (mm)	FA* (kg/m^3)	CA* (kg/m^3)	w/c
(0%)	360	90	640	1190	0.580
Process 1: RGW					
0.5%	360	Vrs*	640	1190	0.579
1%	360	Vrs*	640	1190	0.574
1.5%	360	Vrs*	640	1190	0.570
2%	360	Vrs*	640	1190	0.566
Process 2: CCC					
0.5%	360	90	640	1190	Vrs*
1%	360	90	640	1190	Vrs*
1.5%	360	90	640	1190	Vrs*
2.0%	360	90	640	1190	Vrs*

*FA = Fine Aggregate. CA= Coarse Aggregate. Vrs = Varies

4. Results and Discussions

There is a general increase in both compressive strength and water reduction as SNF dosage increases. The compressive strength test results due to SNF partial replacement of water at the different doses (RGW) at 1, 7, 28 and 56 days are plotted in Figure 3. The compressive strength development due to SNF's addition by CCC process is shown in Figure 4. Water reductions observed as a result of method of addition of SP are plotted in Figure 5 and the effect of SP dosage on initial slump by RGW and CCC processes is presented in Figure 6.

There is a general increase in compressive strength with time as seen in Figures 3 and 4. Water reduction from initial gauging water increases as SP dosage increases in both CCC and RGW SP addition processes as seen in Figure 6. Results also show a trend of increase in SP dosage and a corresponding decrease in w/c ratio as seen in Figure 6.

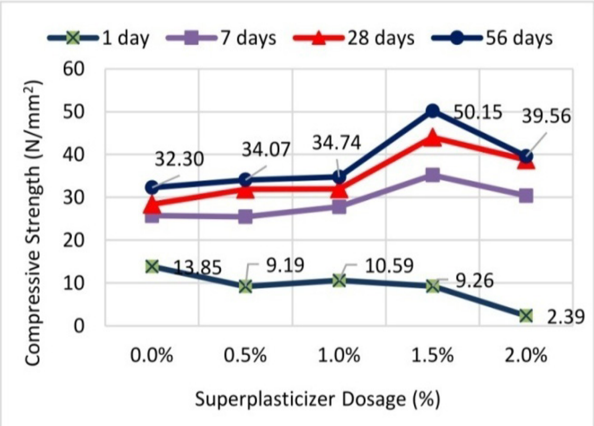

Figure 3. 1, 7, 28 and 56 day compressive strength development due to SP partial replacement of water (RGW)

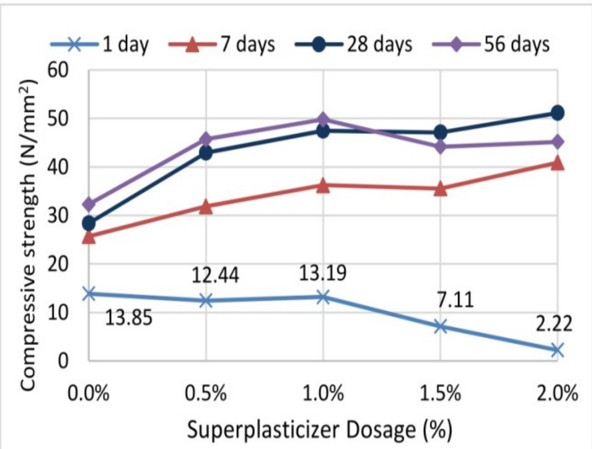

Figure 4. Compressive strength development due to SNF addition to attain constant consistence (CCC)

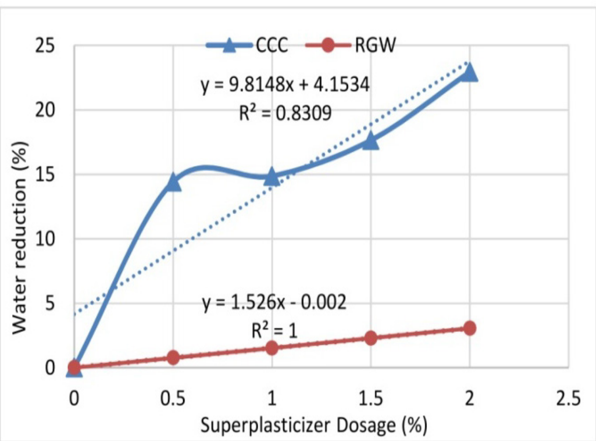

Figure 5. Water reduction attained by use of SNF

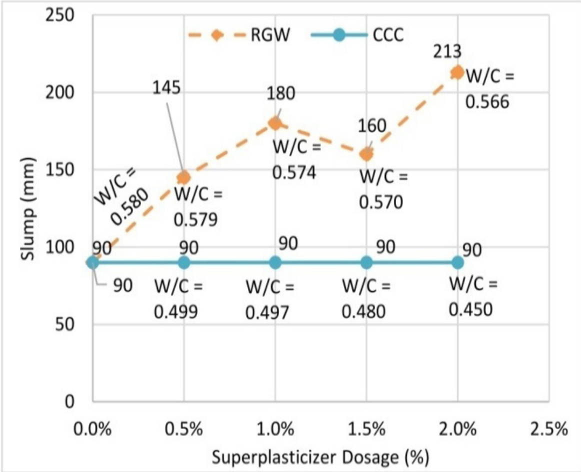

Figure 6. Effect of SP dosage on initial slump by RGW and CCC

4.1. Effect of SNF on Grade C20/25 Grade Concrete's Compressive Strength

It is observed that there is a general compressive strength increase with time over the range of doses tested compared to the control regardless of which SNF addition process was applied as shown in Figures 3 and 4. 1 day compressive strength however, are observed to have lower compressive strengths than the control.

SNF added by the CCC process showed significant increase in 7 and 28day compressive strength as observed in Figure 4. 56 days compressive strength increased up to 1% SP dosage and then loss in strength was observed at 1.5% and 2%. This loss is unexplained.

SNF added to concrete through the CCC process failed to behave as a superplasticizer as per EN 934-2 1 day compressive strength gain requirement but passed the 28 day strength requirement over all doses tested based on requirements of EN 934-2. Results showed that at 0.5%, 1%, 1.5%, and 2% dosage, 28 day compressive strengths are 151%, 167%, 166% and 180% of the control respectively at equal consistence. Although there is no EN 934-2 specification for the behaviour of SP at 56days, it is observed that the reduction in compressive strength at 1.5% and 2% corresponds to the sharp increase in water reduction at same SP doses as shown in Figure 5.

The early low compressive strength loss can be attributed to the superplasticizer delaying the action of C_3S and C_3A [7]. Strength gain was improved at 7 and 28 days over the range of doses examined. The superplasticizer despite its low early strength, at 28 days is observed to turn a C20/C25 concrete to a C40/50 concrete at 2% dosage as shown in Figure 4 a compressive strength gain 80% higher than the control.

SNF applied by the RGW process, resulted in a general increase in compressive strength. The estimated optimum dosage based on the highest attained compressive strength is 1.5% (Figure 3).

As per clause 8.2.1.2 of BS EN 206 (2013), a variation greater than 15% from the mean compressive strength is significant. If this is adopted as basis of comparism of the strengths to the control, SNF added through RGW process at 0.5% and 1% caused no significant increase at 7 day compressive strength. Compressive strength variations are pronounced between 1% and 2% see Figure 3. This coincides with the drastic increase in percentage water reduction at 1.5% to 2% increased water reduction as a result of the SNF's elctrosteric action see Table 4. At this SP dosage, significant strength increases of 37% and 18% respectively were observed. At 28 day strengths only 1.5 and 2% caused significant compressive strength increase (Figure 3).

It is observed that compressive strength development is slower with the RGW SP addition process compared to the CCC process (Figure 3). This is as a result of water reduction limited to SP amount added and the interaction of the SP with the cement particles by electrosteric action.

4.2. Water Reduction Due to SP Addition by CCC

Addition of SNF by CCC process led to water reduction with increasing SP dosage as shown in Table 4. Results indicate that water cement ratio decreases with increase in SNF dosage as shown in Figure 5.

Optimum water reduction in concrete mix due to addition of SNF by CCC is 22.93% at 2% dosage at constant concrete slump of 90mm as shown in Figure 5. Water reductions made possible by addition of SNF by CCC at constant slump increase with the increase in SNF dosage as shown in Table 4. EN 934 superplasticizer requirements for water reduction were met for all doses examined. Water reduction is possible due to the deflocculation of cement particles caused by the superplasticizer's electrosteric action making the fresh concrete more fluid making it require less water to attain the consistence of the control. Water reduction is observed to be higher with CCC SP addition process compared to the RGW process as seen in Figure 6.

Table 4. SNF'S water reduction due to SNF's addition by CCC

SNF Dosage	w/c ratio	Slump (mm)	Water Reduction (%)
0%	0.580	90	0.00
0.5%	0.499	90	14.42
1.0%	0.497	90	14.86
1.5%	0.480	90	17.64
2.0%	0.450	90	22.93

4.3. Water Reduction Due to SP Addition by RGW

SNF applied by RGW led to water reduction of 0.76%, 1.52%, 2.29% and 3.05% at 0.5%, 1%, 1.5% and 2% SP dosage respectively much less than water reductions attained by the CCC SP addition process as shown in Figure 5. The indirect relationship between the SP dosage and w/c ratio is observed (w/c ratio decreases with increase in SP dosage) as seen in Figure 6. This is expected as water saved is limited to only the amount of SP added compared to the CCC method where water reduction is 20% greater. RGW process led to improved slump across the dosages (Figure 6). It is observed that there is improvement in slump when RGW is preformed resulting in an increase in slump up to 213mm from initial 90mm. The increase in slump is attributed to electrosteric rejection due to the high charge of SO_3 groups from SNF on the surface of cement particles [24].

5. Conclusions

An investigation has been performed to study the current effects of SNF's superplasticizer's addition process on water reduction and grade C20/25 concrete's compressive strength. From the results presented earlier, the following conclusions are drawn:

SNF addition to concrete mixes by CCC and RGW processes led to maximum water reductions of 22.93% and 3.05% respectively at SP dosage of 2%.

SNF applied by RGW process led to a 55% compressive strength gain and a 137% increase in slump producing a C32/40 grade concrete at estimated optimum dosage of 1.5% compared to C20/25 grade concrete of the control at 28 days.

Optimum superplasticizer dosage based on compressive strength is 1.5% when SNF partially replaces gauging water. At this dosage, a 55% compressive strength increase and a slump 137% slump increase is observed transforming a 28 day C25/30 grade concrete to a C32/40 grade concrete.

The SNF addition to concrete by CCC addition process led to compressive strength gain of 80% turning a C20/25 concrete to C40/50 with constant slump of 90mm with an estimated optimum dosage of 2%. The maximum dosage recommended by the manufacturer.

SNF addition by the CCC and RGW processes to concrete generally improved concrete's compressive strength at 7, 28 and 56 days with SNF failing to improve 1day compressive strength in both processes. SNF applied by CCC process however led to a strength loss at 56 days.

Water reductions of 22.93% in concrete mix is possible by inclusion of SNF to concrete. The process of application at the right dosage of the superplasticizers leads to increased compressive strengths. Situations arise when high compressive strength is desired, SNF should be applied at maximum dosage recommended by the manufacturer with control slump maintained if convenient. However, if workability improvement is the controlling criteria, SNF should be added to partially replace water at the optimum dosage. This small water reduction by SP amount has been shown to contribute to compressive strength gain.

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