Determination of Strength Characteristics of SuperPlasticized Concrete (Study on Common Concrete in Calabar South of Cross River State, Nigeria)

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Abstract

This research is geared towards determining the strength characteristics of super plasticized concrete commonly used in Calabar South of Cross River State, Nigeria. The samples for all tests were made from concrete with a target compressive strength of 30N/mm$^{2.}$ Concrete were batched by weight and mixed in the ratio of cement: sand: gravel = 1: $1\frac{7}{10}$: $3\frac{9}{10}$ at a water/cement ratio of 0.50. Concrete were prepared in accordance with ACI 318-05 Building Code for Structural Concrete, BS 410 and CP110-1:1972,6. WatersealL (WS) waterproofing compound (specially manufactured for MB London LTD) and JK waterproofing compound (manufactured by Ujala Merchants & Traders Magur, India) were used as superplasticizers. The superplasticizers were then incorporated into the concrete by weight in the ratio of superplasticizer: cement ratio of 1: 50 and 5: 50 respectively to obtain water reduction of 2% and 10%. The results show that the mix series with superplasticizer: cement ratio of 1: 50 decreased the average compressive strength by 14% average while the series with superplasticizer: cement ratio of 5: 50 increased the average compressive strength by 10% average. Hence strength is a function of superplasticizer quantity. The superplasticizers exhibit low workability characteristics and are suitable for mass and reinforced concrete sections with vibration. Furthermore, the superplasticizers act as accelerators by shortening the time of set in concrete by 30minutes average. It is suggestion that apart from water sealing in concrete, WATERSEAL and JK waterproofing compounds should also be used as accelerators for mass and reinforced concrete sections with vibration.

Keywords: *Superplasticizer; Accelerator; Concrete; Aggregate; Compressive strength; Concrete mix design; Batching.*

I. INTRODUCTION

"Strength performance remains the most important property of structural concrete, from an engineering viewpoint" (Ke-Ru et al, 2001).

According to Jiangsu Zhaojia Materials Technology Co. Ltd. (n.d), many efforts have been geared towards obtaining concrete with improved compressive strength, workability, performance and durability criteria to meet the requirement of complexity of modern structures. At the moment, concrete with the aforementioned desired characteristics can be obtained through the use of admixtures. Apart from cement, aggregate and water, admixture material is used as a concrete or mortar constituent to control setting time, early hardening, workability, impermeability, performance and durability, or to regulate other relevant binding properties. Chemical admixtures are available in the form of superplasticizers, water-reducing agents, air entraining agents, accelerators, set retarders, etc. Whilemineral admixtures include rice husk ash, silica fume, fly-ash blast-furnace slag, and more. By their organic nature, superplasticizers/plasticizers and water-reducing agents improve concrete workability by self-lubrication process thereby reducing friction in the concrete. They also improve concrete workability by adsorbing on the cement particles, repelling and dispersing them which results in developing the free water available. Due to the adsorption pro**cess,** a thin layer is formed over the cement particles coating them from hydration thereby increasing the setting time up to circa 30–90 minutes or more.

Plasticizers and water-reducing agents influence concrete properties by:

- Decreasing the cement content and the heat of hydration in mass concrete in order to achieve the same workability as an admixture free mix.
- Easing concrete placing by increase the workability.
- Maintaining at the same workability as an admixture free mix but increasing strength by reducing the water cement ratio in the range 5% < water reduction ≤ 12%.

- Increasing fluidity in terms of flowability, self-compacting, self-leveling, penetration and compaction.

This paper investigates the strength characteristics of superplasticized concrete commonly used in Calabar South of Cross River State, Nigeria. In Nigeria where I come from, masonry structures are fast erupting; therefore, the importance of this study cannot be overemphasized.

II. RELATED LITERATURE

A. Accelerators

Inorganic accelerators occur in the form of chlorides, fluorides, carbonates, silicates, aluminates, borates, nitrites, thiosulphates, diethanolamine, formates, triethanolamine, oxalic acid and sodium carbonate. The cheapest and suitable accelerator is Calcium chloride. The hydration process of C_3S paste confirms that calcium chloride exists in different states in the C3S paste. According to Ramachandran (1971) leaching studies, "depending on the time of hydration, the chloride may exist in a free form (extractable by ethyl alcohol), incorporated strongly into the C-S-H phase (unleachable with water), chemisorbed or in interlayer positions (leachable with water). At 168 h about 20% of the added chloride is incorporated strongly into the C-S-H phase. The rest is in a chemisorbed state in the interlayers (easily leachable with water)".

1) Formates

Calcium formate accelerator is used in the formation of more ettringite in cements than is formed with calcium chloride (Bensted, 1978).In fresh, plastic concrete, ettringite is a stiffening control agent. It is a colourless to yellow hydrous calcium aluminium sulfate ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$) mineral crystallizing in the trigonal system. At ordinary temperatures, calcium formate increases the formation of more ettringite by forming the complex C3A.3Ca(HCO2)2 .30H2O similar to ettringite. The presence of calcium acetate and calcium propionate further enhanced formation of ettringite (Singh, 1983).

2) Triethanolamine

According to Ramachandran (1976), Triethanolamine accelerates the reaction between gypsum and Tricalcium aluminate (C3A) which is one of the primary ingredients of Portland cement. C3A is less than 10% of the total Portland cement ingredients, but it is a powerful hydration catalyst that can cause a rapid cement setting called flash set. Triethanolamine, however, can retard C_3S hydration (Ramachandran, 1972).

3) Oxalic acid

Djabarov (1970) discovered that apart from acting as accelerator by shortening the setting time of cement more than 40%, Oxalic acid may also enhance strengths by more than 10%. The strength enhancement occurs as a result of the formation of some calcium oxalate.

4) Sodium carbonate

Sodium carbonate shortens the setting time of cement by up to 3 hours average. After up to 10 hours, Na 2C03 reacts with lime within the pores of the product to produce CaC03 precipitation that then retards the hydration process (Collepardiet al, 1973).

III. METHOD

A. Theory

1) Concrete Mix Design

Prescribed Concrete Mix: Grade C30
(References to CP110-1:1972, 6, Design Charts and Hughes, 1968, unless otherwise stated)
Trial Mix
Characteristic cube strength f_{cu}: 30Nmm^{-2} at 28 days
Work Description: Heavily reinforced sections with vibration. Simply reinforced sections with vibration
Degree of exposure: Mild
Cement: Lafarge UniCem Portland Limestone Cement
Fine aggregate: Natural fine quartz sand
Coarse aggregate: Irregular natural coarse gravel (20-5mm)
Specific gravities of the fine and coarse aggregates and cement are 2.46, 2.60 and 3.0 respectively
Site control (previous data): Standard deviation $\beta s = 15$Nmm^{-2}
The probability of observed f_{cu} being less than (f_{cm}-βs) = 1 in 20 (normal distribution)
The best estimate of mean strength f_{cm}:
$f_{cm} = f_{cu} + \beta s = 30 + 15 = 45.0$ Nmm^{-2}
Strength requirement: Cement/water ratio (c/w) by volume: 0.68
Water/cement ratio (w/c) by weight: $= \frac{1}{0.68 \text{ x } 3.0} = 0.50$
Expected workability: Medium- Compacting factor (0.92), slump (25-100mm)
Basic volume fraction of cement c: 11 per cent
Durability requirement: 250kgm^{-3} (minimum)

Table 1:Aggregate grading

BS 410 test sieve (mm)	37.5	20.0	10.0	5.00	2.36	1.18	0.60	0.30	0.15	0.075	0
per cent passing											
Natural sand			100	99.46	97.17	83.15	33.69	5.59	1.48	0.54	
Irregular gravel	100	95.55	0.15	0							
per cent retained											
Natural sand				0.54	2.29	14.02	49.46	28.10	4.11	0.94	0.54
Irregular gravel		4.45	95.40	0.15							

Aggregate grading parameters

BS 410 test sieve (mm)	37.5	20.0	10.0	5.00	2.36	1.18	0.60	0.30	0.15	0.075	0
Grading modulus ($\times$ 0.90mm^{-1})		$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	16	32	63	126
Equiv. mean diameter ($\times$ 0.90mm)				8	4	2	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$

Aggregate grading moduli, G equivalent mean diameter, D

Gravel (G_a)	Sand (G_b)	Sand (D_b)
$4.45 \times \frac{1}{4} = 1.12$	$0.54 \times 1 = 0.54$	$0.54 \times 8 = 4.32$
$95.4 \times \frac{1}{2} = 47.70$	$2.29 \times 2 = 4.58$	$2.29 \times 4 = 9.16$
$0.15 \times 1 = \underline{0.15}$	$14.02 \times 4 = 56.08$	$14.02 \times 2 = 28.04$
41.52	$49.46 \times 8 = 395.68$	$49.46 \times 1 = 49.68$
	$28.10 \times 16 = 449.60$	$28.10 \times \frac{1}{2} = 24.05$
	$4.11 \times 32 = 131.52$	$4.11 \times \frac{1}{4} = 1.03$
	$0.94 \times 63 = 59.22$	$0.94 \times \frac{1}{8} = 0.12$
	$0.54 \times 126 = \underline{68.04}$	$0.54 \times \frac{1}{16} = \underline{0.03}$
	1165.26	116.21

Gravel grading modulus $G_a = 0.90(41.52) \times 10^{-2}$ $= 0.37\ mm^{-1}$
Sand grading modulus $G_b = 0.90(1165.26) \times 10^{-2}$ $= 10.49 mm^{-1}$
Sand equivalent mean diameter $D_b = 0.9(116.21) \times 10^{-2} = 1.05mm$
The fine aggregate grading modulus G_b is not greater than $16mm^{-1}$ or not less than $9mm^{-1}$, and coarse aggregate grading modulus Ga does not differ from 0.46. Therefore, correction to cement volume fraction is required.
Durability requirement:

$$250kgm^{-3} \equiv \frac{250 \times 100}{(\text{s.g of cement })1000} = \frac{250 \times 100}{3.0 \times 1000} = 8.3$$

per cent < 11.1 per cent
Therefore, volume fraction of cement c:
11.1 per cent,
And volume fraction of water w:
$= 0.111/0.68 = 0.163m^3$, or $163kgm^{-3}$
Ga. x $D_b = 0.37 \times 1.05 = 0.39$
Solid fraction of loose aggregate (20-5mm) $a_b = 0.58$
Volume fraction of coarse aggregate a = $0.5m^3$
$w + c + a = 0.163 + 0.111 + 0.5 = 0.774m^3$
Volume fraction of fine aggregate $b = 1- (w + c + a)$ $= 1- 0.774 = 0.23m^3$
Batch quantities: W
Water: $0.163m^3 \times 1000kgm^{-3} = 163kgm^{-3}$
Cement: $0.111m^3 \times 1000(3.0) = 333kgm^{-3}$
Sand: $0.23m^3 \times 1000(2.46) = 566kgm^{-3}$
Gravel: $\underline{0.5m^3} \times 1000(2.60) = \underline{1300kgm^{-3}}$
$1.00m^3$ $2362kgm^3$

($23.62KNm^{-3}$)

Design mix by volume:

Cement	: Sand	: Gravel
$0.111m^3$	: $\frac{0.23m3}{0.111m3}$	: $\frac{0.5m3}{0.111m3}$
1	: $2\frac{1}{14}$	: $4\frac{1}{2}$

B. Experimental Work

1) Raw Materials

a.Cement

Lafarge UniCem Cement Produced from Lafarge UniCemMfamonsing plant,Akampka LGA, Cross River State, Nigeria by intergrinding Portland cement clinker with a regulated quantity of limestone and gypsum to conform to the NIS 444- 1: 2003 & EN 197-1:2011 specifications. The compressive strength is 23-27 N/mm^2 strength at 2 days and 53-57 N/mm^2 strength at 28 days.

b.Aggregate

Natural Fine Quartz Sand and Natural Coarse Pebble Gravel aggregate. The coarse aggregates are crushed particles with particle size between 5mm and 20mm.

c.Superplasticizer

WATERSEAL (WS) waterproofing compound (specially manufactured for MB London

Design mix by weight:

Cement	: Sand	: Gravel
$333kgm^{-3}$	: $\frac{566kgm^{-3}}{333kgm^{-3}}$	: $\frac{1300kgm^{-3}}{333kgm^{-3}}$
1	: $1\frac{7}{10}$	: $3\frac{9}{10}$

LTD) and JK waterproofing compound (manufactured by UJALA MERCHANTS & TRADERS MAGUR, India).

3.2.1.4. Potable Water

2) Mixture Proportions

The samples for all tests were made from concrete with a target compressive strength of $30N/mm^2$. Control concrete was batched by weight and mixed in the ratio of cement: sand: gravel = 1: $1\frac{7}{10}$: $3\frac{9}{10}$ at a water/cement ratio of 0.50, as shown in table 2. The superplasticizers were then incorporated into the concrete by weight in the ratio of superplasticizer: cement ratio of 1: 50 and 5: 50 respectively to obtain water reduction of 2% and 10%. The fresh concrete was tested for workability (slump test) and setting time. After casting and curing in the water tanks for 28 days, concrete cubes were tested for compressive strength.

Table 2: Concrete Batching

Relative proportions of concrete mix (kg)water content

Mix	Cement	: Superplasticizer	: Sand	: gravel	water	water/cent ratio	water reduction
Control	1	: -	: $1\frac{7}{10}$	: $3\frac{9}{10}$	0.5	0.5	-
WS	1	: $\frac{1}{50}$	: $1\frac{7}{10}$	: $3\frac{9}{10}$	0.5	0.49	2%
JK	1	: $\frac{1}{50}$	: $1\frac{7}{10}$	: $3\frac{9}{10}$	0.5	0.49	2%
WS5	1	: $\frac{5}{50}$	: $1\frac{7}{10}$	: $3\frac{9}{10}$	0.5	0.45	10%
JK5	1	: $\frac{5}{50}$	: $1\frac{7}{10}$	: $3\frac{9}{10}$	0.5	0.45	10%

For W/C = 0.5, total binder (cement) = $333kgm^{-3}$; for W/C = 0.49, total binder (cement + Superplasticizer) = $340kgm^{-3}$; for W/C = 0.45, total binder (cement + Superplasticizer) = $366kgm^{-3}$

C. Tests

*1) **Compressive strength (f_{cu})***

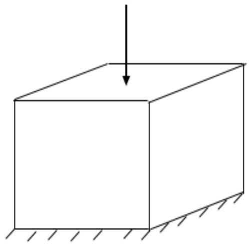

Fig. 1: Compressive Test Specimen

Three 150x150x150mm cube specimens were cast for each concrete mixture and the strength value was calculated by the following equation: $\frac{P}{A}$

where P = Test Load (KN) and A = section area normal to P

Figure 2: 150mm x 150mm x 150mm moulds

Table 3: Strength and Specific Weight of Concrete Mixes

Mix	Cube	Fresh Concrete Unit Weight tensile (KN/m^3)	Average	Compressive strength (N/mm^2) 28 days	Average
Control	1	25.8	25.7	37.10	37.07
	2	25.6		36.89	
	3	25.8		37.22	
WS	1	25.5	26.1	32.76	32.58
	2	25.8		31.13	
	3	27.0		33.84	
JK	1	25.6	25.43	31.13	31.18
	2	25.5		30.87	
	3	25.2		31.54	
WS5	1	25.6	25.2	41.18	41.29
	2	25.0		40.15	
	3	25.0		42.54	
JK5	1	26.90	27.0	40.20	40.51
	2	27.22		40.25	
	3	26.88		41.08	

Table 4: Strength Comparison Between theNormal and Superplasticized Concrete

Mix	Average Compressive strength (N/mm^2) 28 days	Strength Change Compared with control (%)
Control	37.07	-
WS	32.58	-12
JK	31.18	-16
WS5	41.29	+11
JK5	40.51	+9

Table 4 shows that the mix series with superplasticizer: cement ratio of 1: 50 decreased the average compressive strength by 14% average. While theseries with superplasticizer: cement ratio of 5: 50 increased the average compressive strength by 10% average.

Slump Test

In order to measures the consistency and to check the workability of fresh concrete before it sets, slump test was carried out in accordance with BS EN 12350-2. Slump cone specimen was cast for each concrete mixture and the slump or reduction in height of the cone is considered a measure of workability. the average compressive strength by 14% average. While theseries with superplasticizer: cement ratio of 5: 50 increased the average compressive strength by 10% average.

Fig. 3: Slump Testing

Table 5: Workability Boundaries

Work Type	Slump (mm)	Workability
Heavily reinforced sections with vibration. Simply sections reinforced without vibration.	25-100	Medium
Simply reinforced sections with vibration. Mass concrete without vibration.	10-50	Low
Mass concrete and large sections with vibration. Road slabs vibrated using power-operated machines	-	Very Low

Table 6: Workability Comparison Between the Normal and Superplasticized Concrete

Series	Slump (mm)	Workability
Control	50	Medium
WS	2	Very Low
JK	35	Low
WS5	2	Very Low
JK5	10	Low

Setting Time Test

Table 7: Setting Time Comparison

Series	Setting Time
Control	1 hour, 25 minutes
WS	1 hour
JK	51 minutes
WS5	55 minutes
JK5	56 minutes

Table 7 shows that these superplasticizers act as accelerators by shortening the time of set in concrete by 30 minutes average

IV. CONCLUSIONS AND SUGGESTION

A. Conclusions

Based on the experimental, theoretical and analytical results obtained in this study, the following conclusions are given:

- The mix series with superplasticizer: cement ratio of 1: 50 decreased the average compressive strength by 14% average. While the series with

superplasticizer: cement ratio of 5: 50 increased the average compressive strength by 10% average.

- The superplasticizers exhibit low workability characteristics and are suitable for mass and reinforced concrete sections with vibration.
- The superplasticizers act as accelerators by shortening the time of set in concrete by 30minutes average.

B. Suggestion

Apart from water sealing in concrete, WATERSEAL and JK waterproofing compounds should also be used as accelerators for mass and reinforced concrete sections with vibration.

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