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EFFECTS OF A TWO COMBINED COARSE AGGREGATES ON THE STRENGTHS OF NORMAL AND CERTAIN SUPERPLASTICIZED CONCRETES

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ABSTRACT

In this study, properties of a normal and three types of superplasticized concretes produced are characterized. In the process the effects of equally combined coarse aggregates gradation of 12.5 mm and 19 mm were investigated. The normal concrete tagged E0 with 0.4 water cement ratio (w/c) of a 1:2:3 mix ratio served as the based control. The other three superplasticized concretes tagged E1, E2 and E3 were of 0.3 water cementitious materials ratio (w/cm) with varied percentages of a superplasticizer. 60 concrete specimens were cast individually for beams, cubes and cylinders and de-moulded after 24 hours and moist cured till the day of their respective tests. At different days of curing of 7, 28, 56, 90 and 120 days as programmed, compressive, flexural and tensile splitting strength tests were carried out respectively and appropriately. The workability test results on fresh concretes showed that the values of both slumps and compaction factors were increasing progressively as the dosage of superplasticizer was increasing. Also, the flexural, compressive and tensile splitting tests results showed that hardened concrete strength increased similarly as workability of the fresh concrete correspondingly. Significantly, equally combined 12 mm and 19 mm nominal maximum size aggregates at 50% each was found well graded and fitted into an envelope than individual single aggregate gradation of 12 mm and that of 19 mm. The use of 19 mm aggregate gradation in the combined mix makes the concrete more economical for being cheaper than 12.5 mm nominal maximum aggregate.

Keywords: curing, concrete, dosage, gradation, pavement, size.

INTRODUCTION

In concrete production, coarse aggregate that is categorized as medium material varies in diameter from 11.2 mm to 21.3 mm [1]. In this study an equally proportioned combined 12.5 mm and 19 mm aggregates gradation has been used in the production of a normal and three superplasticized concretes upon their suitability for highway rigid pavement. It has been claimed [2] that in designing concrete one attempts to optimize the cost for a given level of strength and durability by considering a concrete design optimization through trying to achieve the lowest possible water and cement contents. Further [2] claimed that the scenario thus leads the designer into specifying: a) stiff mixes as practical under the proposed concrete mixing and casting conditions; b) maximum permissible size of coarse aggregate; and c) adequately sized and properly proportioned fine aggregate and coarse aggregate.

Conventional concrete can either be normal or superplasticized concretes [2]. The main constituents of conventional concrete are: a) water; b) chemical admixtures (plasticizers, superplasticizers, retarders, air-entraining agents); c) cement; d) mineral admixtures (pozzolanic supplementary cementation materials); e) fine aggregate; and f) coarse aggregate. While designing normal or superplasticized concretes, attempts are usually made to optimize proportioning of constituents for a given level of workability, strength and durability. Compacting factor test provides a useful measure of the on-site workability of C40 concrete grade for highway rigid pavement [3]. According to [4] conventional concrete can have normal strength 20-50 N/mm². Furthermore, [4] claimed that any concrete mixture that attained 40 N/mm² or more of compressive strength at 28-days has high-strength concrete design.

Clear, clean and drinkable water is always considered for concrete mix proportioning. Water/cement ratio (w/c) upon the concrete composition is a major parameter affecting workability of fresh concrete as well as the porosity, strength and durability of the cement matrix of hardened, concrete [5]. According to [6] superplasticizer influences concrete properties by: a) decreasing the cement content and the heat of hydration in mass concrete in order to achieve the same workability as an admixture free mix; b) easing concrete placing by increasing the workability: c) increasing fluidity in terms of flowability, self-compacting, self-levelling, penetration and compaction. Admixture such as superplasticizer is an ingredient other than Portland cement, water and aggregates that are associated with the production of concrete for increasing workability, strength and durability [7]. The ultimate goals of using superplasticizers of either chemical or mineral ingredients are to improve one or more aspects of concrete performance, or to maintain the same level of performance [6].

Portland cement has always been in use successfully in the production of normal and superplasticized concretes [5, 8]. Portland cements are composed of four basic chemical compounds with their names, chemical formulas, and abbreviations as: i) Tricalcium silicate = $3CaO{\cdot}SiO_2$ = C_3S; ii) Dicalcium silicate = $2CaO{\cdot}SiO_2$ = C_2S; iii) Tricalcium aluminate = $3CaO.\ Al_2O_3$ = C_3A; and iv) Tetracalcium aluminoferrite = $4CaO.Al_2O_3.Fe_2O_3$ = C_3AF.

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Fine and coarse constituents are the two groups of aggregates for cement [9-10]. Fine aggregate is of a unique gradation of which percent passing sieve 4.75 should not be more by 5%. However, grading requirements for coarse aggregates are of ranges of different bounds depending upon the maximum grain size. By the [9] standard it is permitted to carry out concrete proportioning from combining two or more gradings of aggregate. This is to obtain a desired grading provided that the gradings are not otherwise restricted by the project specifier and the nominal size indicated by the size number is not exceeded.

The method of proportioning of aggregate groups [11] is based on the principle of maximizing the packing density of the mixed aggregates have gained popularity recently especially in Europe. The methodology [11] also aimed at obtaining a combined aggregate batch having a minimum possible voids ratio without referring to an ideal gradation curve.

The aim of this study is to optimise concrete strength using equally combined aggregates of 12.5 mm and 19 mm gradation while employing newly produced cement in Nigeria called Supaset Portland cement. Specifically, the main objectives of this study are to examine:

a) The chemical composition and compound composition of the cement;
b) Gradation of 12.5 mm, 19 mm and combination of the two aggregates at 50% each;
c) Properties of the fresh and hardened concrete incorporating a superplasticizer; and
d) Optimum use of the superplasticizer that would yield the adequate strength (compressive, flexural and tensile strength) for concrete grade C35, C40 and C45

Notwithstanding, an attempt has been made in this study to define the effect of varying superplasticizer content on the properties of fresh and hardened concretes. The effects are based upon consistency, workability, for normal and superplasticized fresh concrete. Also, compressive, flexural and also tensile splitting strengths were investigated and results compared for a normal and three superplasticized concretes.

MATERIALS AND METHODOLOGY

Concrete constituents used included water, superplasticizer (chemical admixture), cement, fine and two types of coarse aggregates that are equally combined. The details of the methods of testing the materials constituents, fresh and hardened concretes produced are as follows. The normal concrete has constituents of 1:2:3 mix using water ratio (w/c) of 0.4. Also, proportioning the three individual superplasticized concretes was similarly to normal concrete but with different water cementitious materials ratio (w/cm) of 0.3. Individual batch of concrete production was based upon limiting the percentages of superplasticizer by weight of cement to1%, 1.25% and 1.5%. Slump and compacting factor tests were carried out per batch on each fresh concrete produced in order to define the workability status. Testing of the hardened concrete samples was carried out respectively as scheduled for flexural, compressive and tensile splitting tests after being appropriately moist cured.

Concrete constituents

Each concrete batch was carried out using water found inside the concrete laboratory of the Department of Civil and Environmental Engineering, Faculty of Engineering; University of Lagos. A high-range water reducer chemical admixture called Master Rheobuild 850 superplasticizer was used for the purpose of increasing the workability of the concrete mixtures whilst reducing the amount of mixing water.

Ordinary Portland cement Type I A which is a relatively new brand of cement produced in the Nigeria and of grade 42.5N was used for the concrete production in this study. Laboratory tests were carried out on the cement in order to identify its properties and the level of conformity to standard specification. Types of tests carried out upon the cement used included chemical and compound composition together with physical properties. According to specification standard of [12] the relative density of cement used was determined. Also, the bulk density was determined as its weight per unit volume in the laboratory in accordance with [13] requirements.

Standard specification requirement [14] was used for the determination of the fineness of the cement used while determining its percent passing the 0.045 mm sieve. Initial and final setting time tests on the cement included the determination of consistency value based upon the Vicat apparatus methodology according to [15].

Fine aggregate used was obtained from Ogun River in Akute, outside Lagos environs. The sand was air dried in the laboratory before being used for the production of the concrete specimens. Both fine and coarse aggregates gradation, coefficient of uniformity and curvature were determined according to [10] standard specification. The moisture content, dry and relative densities and absorption of the fine aggregate used were determined according to [16] standard specification. The bulk densities of fine and coarse aggregates used were determined separately in accordance with [17] specification. Also, the combined 12.5 mm and 19 mm coarse aggregates mixture as used in the concrete production was also subjected to [10] specification. The moisture content, specific gravity, dry density and absorption of the coarse aggregates used were determined separately according to [16] specification. Crushing and impact values were determined according to [18]. Abrasion value test was carried out by the Los Angeles abrasion test as described in [18].

Required average strength

It has been claimed [19] that specified compressive strength f'_c that is of over 35 N/mm² should be related to required average strength f'_{cr} in N/mm².

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$$f'_{cr} = f'_c + 10 \quad (1)$$

Also, according to [19] the tensile splitting strength of concrete is about 10% of its compressive strength.

According to [20] a more accurate estimate of flexural strength can be determined using the related compressive strength of concrete value.

$$\text{Flexural strength} = K\sqrt{\text{compressive strength}} \quad (2)$$

Where
K = a constant value approximately 0.7

Fresh concrete production and casting of specimens

Fresh concrete was produced per batch by given consideration to the use of 50 kg of cement with or without mineral admixture. Table 1 gives relative number of concrete constituents per batch of the concrete production using combined 12.5 mm and 19 mm aggregate gradation at 50% each. Table 2 gives the weight of each constituent of concrete per one metre cube of concrete. Table 3 is showing the programme of concrete specimens casting modules. In accordance with [21], specimens making and curing of concrete were carried out. Concrete specimens of 60 beams, 60 cubes and 60 cylinders as shown in Table-4 were cast individually for flexural, compressive and tensile splitting strengths respectively to a total of 180 specimens. Each flexural beam specimen size is 550 mm by 150 mm by 150 mm while the compressive cube specimen size is 150 mm by 150 mm by 150 and that of cylinder tensile splitting specimen is 150 mm diameter and of 300 mm length. Casting of each fresh concrete specimen was carried out in three layers of which each one of same was rodded using 16 mm diameter rod of 600 mm length for 25 times. The determination of slump value and that of the compaction factor were carried out by workability tests per batch of concrete production. The slump test was carried out on the fresh concrete produced in accordance with [22]. Also, the compacting factor test on the fresh concrete was carried out in accordance with [23]. All the specimens made from the fresh concrete produced were allowed to stay in their respective moulds for 24 hours. After that the specimens were demoulded and they were immediately submerged inside clean water for moist curing.

Table-1. Concrete constituents' ratio using combined at 50% each of 12.5 mm and 19 mm aggregate gradation.

Conc. Mix	w/cm (water/ superplasticizer)	Cement Content	Fine Agg.	Coarse Agg.
Type E0	0.4 (0.4/0)	1	2	3
Type E1	0.3 (0.28/0.02)	1	2	3
Type E2	0.3 (0.275/0.025)	1	2	3
Type E3	0.3 (0.27/0.03)	1	2	3

Table-2. Concrete mix proportions for cement content of 400 kg/m³.

Conc. Mix ID	Water kg/m³	Admixkg/ m³	Cement kg/m³	Fine kg/m³	Coarse kg/m³
Type E0	160	0	400	800	1200
Type E1	112	8	400	800	1200
Type E2	110	10	400	800	1200
Type E3	108	12	400	800	1200

Table-3. Concrete specimens casting modules.

Concrete Mix Identification	**Flexural Beam** (550 x 150 x 150) **Numbers**	**Compressive Cube** (150 x 150 x 150) **Numbers**	**Tensile Splitting Cylinder** (150 Ø x 300) **Numbers**
Type E0	15	15	15
Type E1	15	15	15
Type E2	15	15	15
Type E3	15	15	15
Total specimens	60	60	60

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Hardened concrete tests

Hardened concrete tests were carried out base upon specimens curing scheduled in water respectively for 7, 28, 56, 90 and 120 days. For each testing day, three beams, three cubes and three cylinders' specimens were tested respectively. The average of the experimental results was considered individually for the flexural, compressive and tensile strengths. Each beam cast was tested according to [24] using hydraulic flexural testing machine powered manually. It has been claimed [25] that 28-day to 90-day moist cured flexural beam strengths are being used for roads and streets, since very few stress repetitions occur during the first 90 days of pavement life compared with the millions of repetitions that occur after that time.

Each cube sample as well as every cylinder specimen was tested using a 1500 kN capacity hydraulic compression testing machine powered with electricity. Each of the hardened concrete cube specimens was tested for compressive strength test in accordance to [26]. Furthermore, each hardened concrete cylinder specimen was also tested for tensile splitting strength in accordance to [27].

RESULTS AND DISCUSSIONS

The results of the concrete constituents, fresh concrete and hardened concrete specimens produced in this are discussed as follows:

Cement properties

The chemical and compound compositions result as well as that of the physical properties of the cement used in this study are in Table 4, Table 5 and Table 6 respectively. Based on chemical composition values obtained, it is obviously seen that the cement used is satisfactorily suitable than that of compound composition results when compared to standard specification requirements. The cement values for bulk density and specific gravity are suitable for concrete mix proportioning by weight and absolute method as seen in Table-6.

Table-4. The cement chemical composition.

Chemical composition	Portland cement 42.5 R	Specification requirements content (%); [28]	Remarks
Silicon Dioxide (SiO_2)	21.23	18.7 – 22.0	Conformed
Aluminium Oxide (Al_2O_3)	5.11	4.7 – 6.3	Conformed
Iron oxide (Fe_2O_3)	0.95	1.6 – 4.4	Not Conformed
Calcium Oxide (CaO)	63.74	60.6 -66.3	Conformed
Magnesium Oxide (MgO)	2.10	0.7 – 4.2	Conformed
Sulphur Trioxide (SO_3)	1.02	1.8 – 4.6	Not Conformed
Sodium Oxide (Na_2O)	0.64	0.11 -1.2	Conformed

Table-5. The cement compound composition.

Compound composition	Portland cement 42.5 R	Specification requirements content (%); [28]	Remarks
Tricalcium Silicate, C_3S	21.23	18.7 – 22.0	Conformed
Dicalcium Silicate, C_2S	5.11	4.7 – 6.3	Conformed
Tricalcium Aluminate, C_3A	0.95	1.6 – 4.4	Not Conformed
Tetracalcium Aluminate, C_4AF	63.74	60.6 -66.3	Conformed

Table-6. The cement physical properties.

Compound composition	Portland cement 42.5 R	Specification requirements content (%); [28]	Remarks
Specific Gravity γ_G	3.15	3.13-3.15	Conformed
Bulk Density, γ_b kg/m³	1160	1000-1300	Conformed
Fineness, % retained on 45 μm	2	10	Conformed
Loss of Ignition, LOI	0.006	0.04-0.05	Not Conformed
Insoluble Residue, IR	99.96	99.95-99.97	Conformed

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Fine and coarse aggregates properties

Table-7 is showing the results of the physical properties of fine and coarse aggregates in which the value obtained for each employed material property depicts satisfactory representation for concrete production.

Figure-1 is showing that the fine aggregate used in this study as a well-graded river sand material based upon the gradation test. It is pertinent to note that the fine aggregate gradation curve satisfied the [9] standard requirements specification and it could be classified with grading No. 1.

The combination at 50% per each of the 12.5 mm and 19 mm coarse aggregates used in this study resulted to a uniformly graded granite material as shown in Figure-2 and Figure-3. In Figure-2 and Figure-3, the gradation curves of individual 12.5 mm and 19 mm coarse aggregates are also presented. It is obviously seen that Figure-2 gradation curve proffers a better depiction of the combined aggregates curve for it lies in the middle of the upper and lower limits of the grading envelope than that of same of Figure-3.

Table-7. The physical properties of fine and coarse aggregates.

S. No	Physical properties	Fine Agg. river sand	Coarse Agg. 19 mm Granite	Coarse aggregates combination of 19 mm and 12.5 mm at 50 % of each granite	Coarse aggregate 12.5 mm granite
1	Percent of particles retained on the 4.75 mm sieve, %	1	95	97	97
2	Percent of particles passing the 4.75 mm sieve, %	99	5	3	3
3	Percent of particles passing the 0.075 mm sieve, %	2.8	0	0	0
4	Fineness modulus	2.74	3.75	3.18	2.69
5	Coefficient of uniformity (Cu)	2	2	2	1.96
6	Coefficient of curvature (Cc)	1	1	0.9	0.9
7	Bulk density, kg/m^3	1655	1650	1650	1650
8	Specific gravity	2.67	2.67	2.68	2.7
9	Moisture (water) absorption (%)	1.12	0.5	0.4	0.43
10	Aggregate crushing value (%)	-	18	18	18
11	Aggregate impact value (%)	-	13	13	13
12	Los Angeles Abrasion Value (%)	-	19	19	19

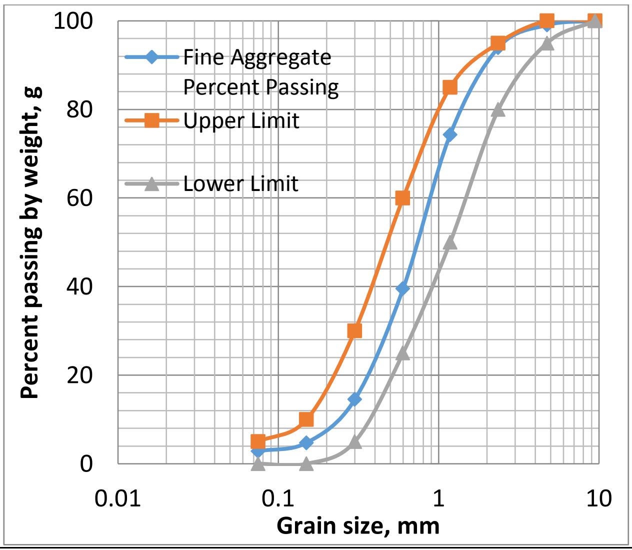

Figure-1. Fine aggregate semi-log gradation chart.

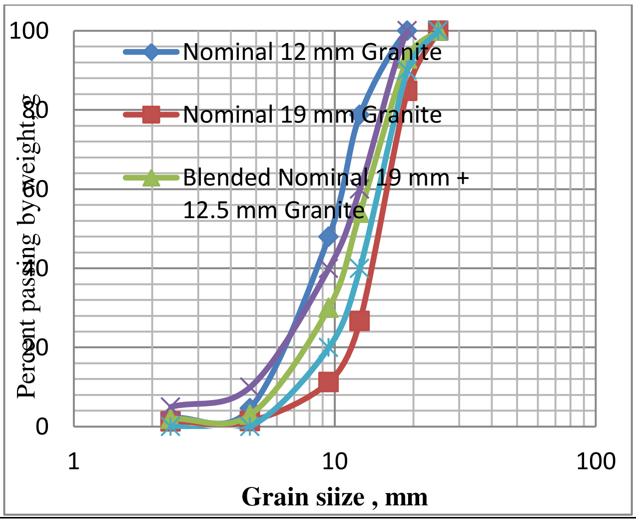

Figure-2. Coarse aggregates semi-log gradation chart by nominal size 12.5 mm.

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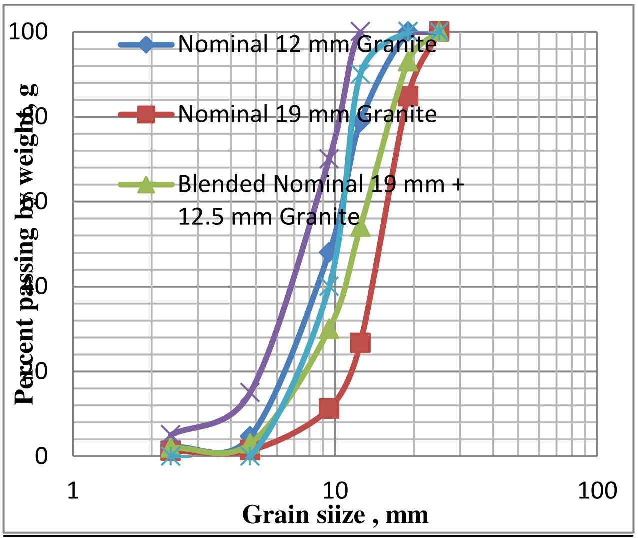

Figure-3. Coarse aggregates semi-log gradation chart by nominal size 19 mm.

Fresh concrete properties

In Table-8, Figure-4 and Figure-5 are presented the characteristics of the fresh concrete's workability produced for Type E0 through Type E3. Slump values and compaction factors obtained are based upon the different usage of percentages of superplasticizer over the production of concrete mixtures. It could be observed in Table 8 that the higher the value of the superplasticizer dosage the higher the value of both slump and compaction factor respectively. Figure-3 and Figure-4 exclusively displays similar polynomial graph but with different quadratic equations which resulted to dissimilar coefficient of determination R-Square values of regression function. This is an indication that the compaction factor graph is more suitable for regression function than that of slump chart model.

Table-8. Workability tests results.

Concrete mix identification	Superplasticizer dosage in % of cement content	Slump values (mm)	Compaction factor
Type E0	0.0	10	0.85
Type E1	1.0	40	0.89
Type E2	1.25	60	0.91
Type E3	1.5	90	0.93

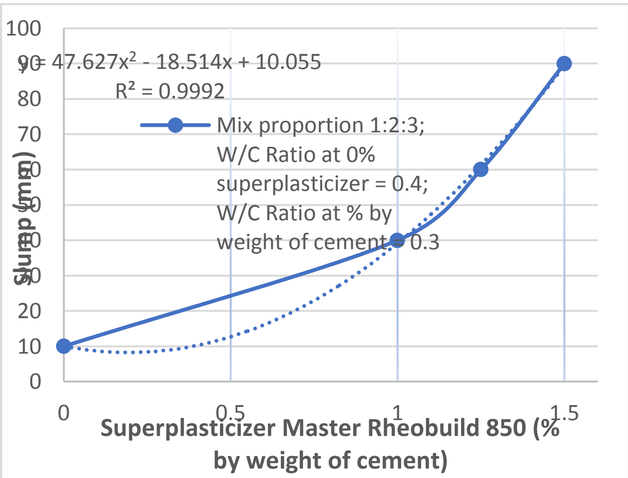

Figure-4. Workability chart for slump values.

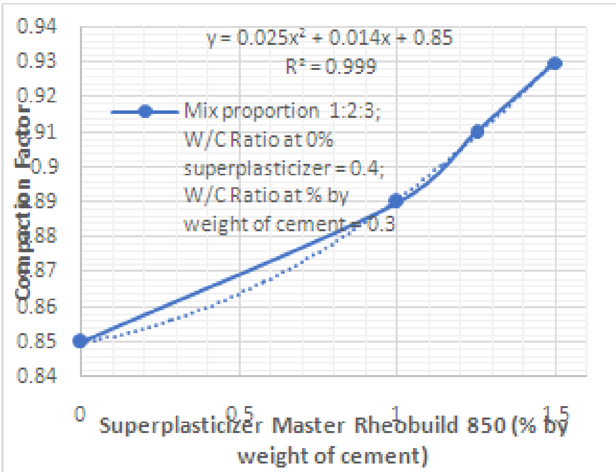

Figure-5. Workability chart for compaction factors.

Hardened concrete properties

Effect of water curing on the concrete specimens

The normal and superplasticized concretes flexural, compressive and tensile strengths based upon water curing periods correspondingly are shown in Figure 6 through Figure-8. Each of the three charts is showing that as the moist curing period is increasing each one of the strength values is also increasing at decreasing rate. It pertinent to note that there exists marginal amount of increment of each of the strengths between 90 and 120 days of moist curing. The highest value of strength is seen with the superplasticizer dosage of 1.5% by weight of cement while the concrete with 0% of same is having the lowest strength value. In this study, results of concrete flexural, compressive and tensile strengths are of similar trend in strength development.

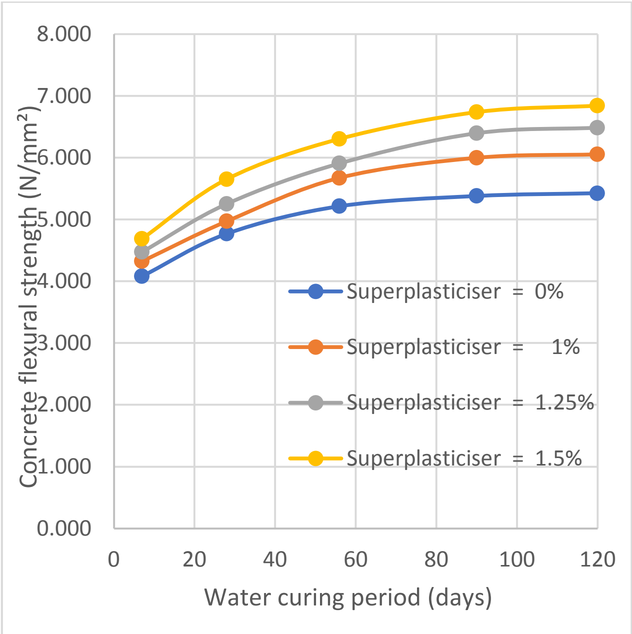

Figure-6. Water curing period-flexural strength in relationship to superplasticized concrete.

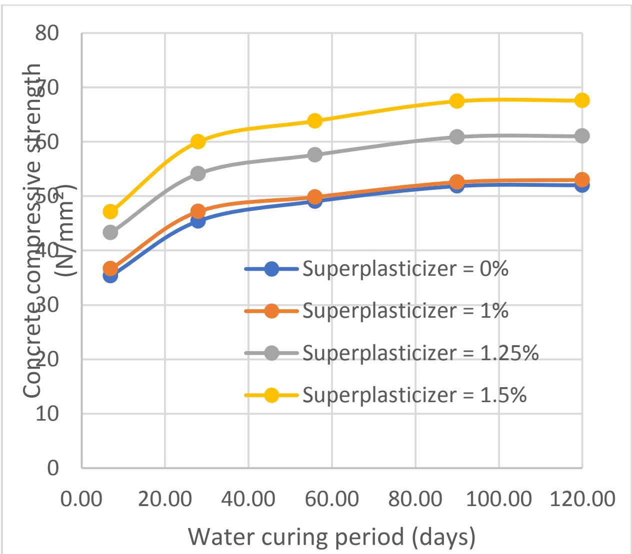

Figure-7. Water curing period-compressive strength in relationship to superplasticized concrete.

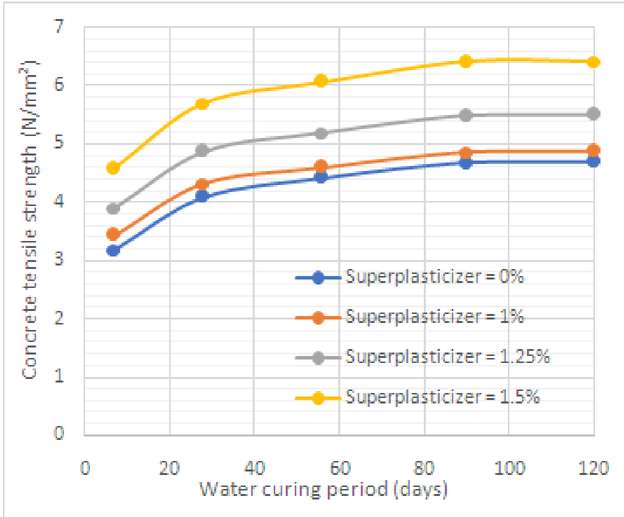

Figure-8. Water curing period-tensile strength in relationship to superplasticized concrete.

Effect of the superplasticizer dosage variations on the concrete specimens

The effects of superplasticizer quantity variations by way of affecting concrete strengths development as experimented in this study are displayed in Figure-9 through Figure-11. These figures are showing that within the limits of the experiments carried in this study and for concrete flexural, compressive and tensile strengths developed, the higher the amount the superplasticizer dosage the higher the strength. It is obviously seen that as the amount dosage of the superplasticizer is increasing the rate of strength is also increasing. The highest value of strength is obtained at the superplasticizer dosage of 1.5% by weight of cement while concrete production with 0% of same is having the lowest strength value. In this experimental study, results of concrete flexural, compressive and tensile rates of strengths development are of similar trend.

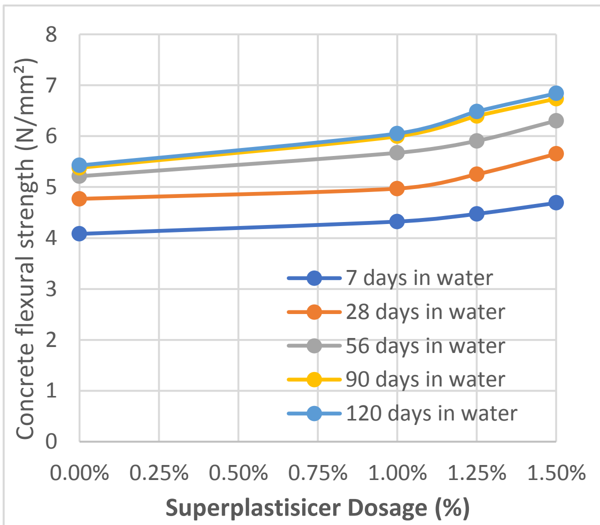

Figure-9. Superplasticizer dosage-flexural strength.

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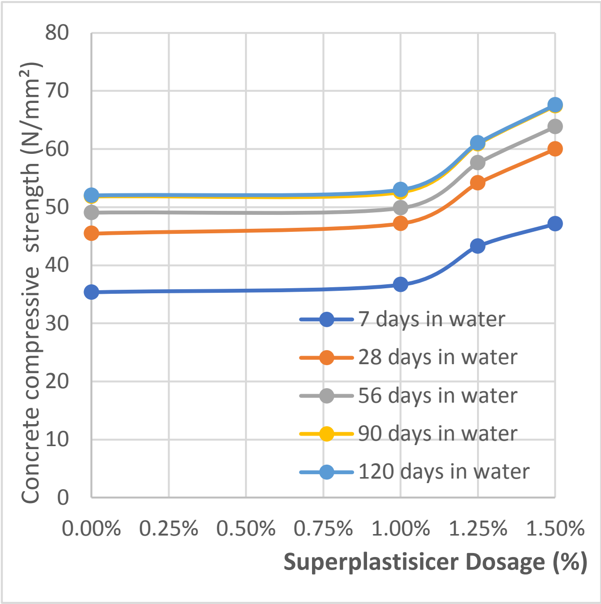

Figure-10. Superplasticizer dosage-compressive strength Relationship.

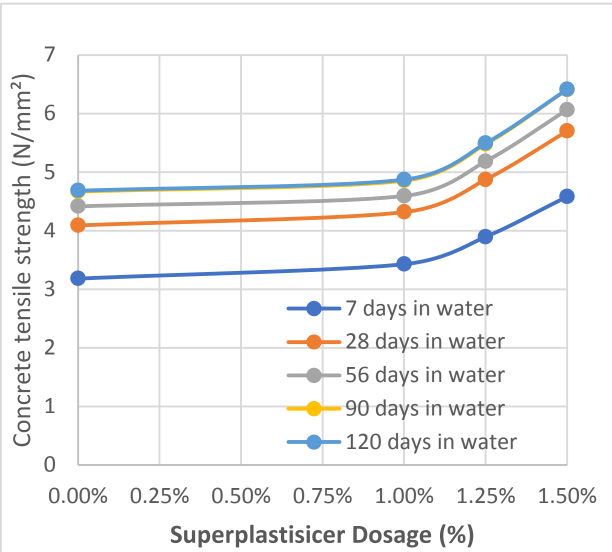

Figure-11. Superplasticizer dosage-tensile strength Relationship.

Relative strengths of concretes as affected by type of concrete mix

In Table-9 through Table-11 the normal concrete strength developmental trend of type E0 is compared with the superplasticized concretes which are types E1, E2 and E3. The flexural, compressive and tensile strengths of the superplasticized concretes are found to be increasing in relationship to that of normal concrete as the percent of the superplasticizer is increasing.

Table-9. Relative flexural strength of concrete produced as affected by type of concrete mix.

Type of concrete mix	**Flexural strength** (% of strength of Type E0 concrete mix)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	100	100	100	100	100
E1	101	104	109	111	112
E2	109	110	113	119	120
E3	115	119	121	125	126

Table-10. Relative compressive strength of concrete produced as affected by type of concrete mix.

Type of concrete mix	**Compressive strength** (% of strength of Type E0 concrete mix)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	100	100	100	100	100
E1	104	104	102	101	102
E2	122	119	117	117	117
E3	133	132	130	130	130

Table-11. Relative tensile strength produced as affected by type of concrete mix.

Type of Concrete mix	**Tensile strength** (percent of strength of Type E0 concrete mix identification)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	100	100	100	100	100
E1	108	106	104	104	104
E2	122	119	117	117	117
E3	144	139	137	137	137

Relative strengths of concretes as affected 28-day moist curing

It is obviously seen in Table-12 through Table-13 that the flexural strength development at 7-day moist cured of the normal and super plasticized concrete is at the average of 84% of same at 28-day moist curing. Whereas the compressive and tensile strengths development individually at 7-day moist cured for normal and superplasticized concrete is at the average of 79% of same at 28-day moist curing. However, there is a very small range of strength value between 90-day strengths and 120-day while comparing same found for between 7-day and 28-day, 28-day and 56-day as well as 56-day and 90-day. It is vividly seen that as the curing day increases the range of strength development exhibited by flexural, compressive and tensile strengths individually decreases as the testing day increases.

Table-15 is showing the relationship of concrete strengths in percent of 90-day moist cured to that of 28-day while considering flexural, compressive and tensile

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strengths individually. It is vividly observed that while considering flexural strength at 90-day moist cured as100 percent, the 28-day moist cured strength is on the average of 84 percent of it. Whereas, while considering both compressive and tensile strengths individually at 90-day moist cured as100 percent, their 28-day moist cured mean strengths is on the average of 89 percent.

Table-12. Relationship of flexural strength in percent of 28 day moist cured of concrete produced as affected by curing days.

Type of Concrete mix	**Flexural strength** (percent of strength of 28 days curing by moist curing)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	86	100	109	113	114
E1	83	100	114	121	122
E2	85	100	112	122	123
E3	83	100	112	119	121

Table-13. Relationship of compressive strength in percent of 28-day moist cured of concrete produced as affected by curing days.

Type of Concrete mix	**Compressive strength** (percent of strength of 28 days curing by moist curing)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	78	100	108	114	114
E1	78	100	106	111	112
E2	80	100	106	112	113
E3	79	100	106	112	113

Table-14. Relationship of tensile strength in percent of 28-day moist cured of concrete produced as affected by curing days.

Type of Concrete mix	**Tensile strength** (percent of strength of 28 days curing by moist curing)				
	7 days	**28 days**	**56 days**	**90 days**	**120 days**
E0	78	100	108	114	114
E1	79	100	106	112	113
E2	80	100	106	112	113
E3	80	100	106	112	113

Table-15. Relationship of concrete strengths in percent of 90-day moist cured to that of 28-day.

Type of Concret e mix	**Flexural strength**		**Compressiv e strength**		**Tensile strength**	
	28 days	**90 days**	**28 days**	**90 days**	**28 days**	**90 days**
E0	89	100	89	100	89	100
E1	83	100	90	100	89	100
E2	82	100	89	100	89	100
E3	84	100	89	100	89	100

Relative strengths of concretes as affected specified grade of concrete

Table-16 gives the results of the 28-day and 90-day moist cured specimens strengths of prepared cube samples in this study and as they satisfied the required average compressive strength for C35, C40 and C45. The use of 1.25% of cement as superplasticizer dosage satisfied grade C40 that is required for highway pavement economically while considering 28-day moist cured average compressive strength requirements. However, while giving consideration for 90-day moist cured average compressive strength requirements, normal concrete and the superplasticized concrete with superplasticizer dosage of 1% of cement satisfied requirements for highway pavement economically.

Table-17 gives the 28-day and 90-day moist cured specimens strengths of the prepared samples in this study as they satisfied the required average flexural strength for C35, C40 and C45 individually. The use of 1.24% of cement as superplasticizer dosage at the maximum amount of superplasticizer applied in this study satisfied grade C40 whilst the requirement for highway pavement economically while considering 28-day moist cured average flexural strength requirements. However, while giving consideration for 90-day moist cured average compressive strength requirements, normal concrete and the superplasticized concrete with superplasticizer dosage of 1% of cement satisfied requirements for highway pavement economically. Table-18 gives the 28-day and 90-day moist cured specimens strengths of prepared samples in this study as they satisfied the required average tensile strength for C35, C40 and C45 minimally. The use of 1.25% of cement as superplasticizer dosage satisfied grade C40 that is required for highway pavement economically while considering 28-day moist cured average tensile strength requirements. However, while giving consideration for 90-day moist cured average compressive strength requirements; it is only the superplasticized concrete with superplasticizer dosage of 1.25% of cement satisfied requirements for highway pavement economically.

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Table-16. Required average compressive strength, f'cr level of satisfactory.

Specified grade of concrete	Required average compressive strength, N/mm²	Average compressive strength at 28-day moist cured result	Average compressive strength at 90-day moist cured result
C35	45	Normal concrete is satisfactory at 45.43 N/mm². Superplasticized concrete is also satisfactory at 46.62 N/mm² using superplasticizer dosage of 1% of cement content.	Normal concrete is satisfactory at 51.08 N/mm². Superplasticized concrete is also satisfactory at 51.6 N/mm² using superplasticizer dosage of 1% of cement content.
C40	50	Normal concrete is not satisfactory being 45.43 N/mm². Superplasticized concrete is satisfactory at 54.12 N/mm² using superplasticizer dosage of 1.25% of cement content	Normal concrete is satisfactory at 51.08 N/mm². Superplasticized concrete is satisfactory at 51.6 N/mm² using superplasticizer dosage of 1% of cement content.
C45	55	Normal concrete is not satisfactory being 45.43 N/mm². Superplasticized concrete is satisfactory at 59.97 N/mm² using superplasticizer dosage of 1.5% of cement content.	Normal concrete is satisfactory at 51.08 N/mm². Superplasticized concrete is satisfactory at 60.86N/mm² using superplasticizer dosage of 1.25% of cement content.

Table-17. Required average flexural strength, R level satisfactory.

Specified grade of concrete	Req. average compressive strength, N/mm²	Req. average flexural strength, N/mm²	Average flexural strength at 28-day moist cured result	Average flexural strength at 90-day moist cured result
C35	45	4.7	Normal concrete is satisfactory at 4.77 N/mm². Superplasticized concrete is satisfactory at 4.97 N/mm² using superplasticizer dosage of 1% of cement content.	Normal concrete is satisfactory at 5.38 N/mm². Superplasticized concrete is satisfactory at 6 N/mm² using superplasticizer dosage of 1% of cement content.
C40	50	4.95	Normal concrete is not satisfactory being 4.77 N/mm². Superplasticized concrete is satisfactory at 5.25 N/mm² using superplasticizer dosage of 1.25% of cement content.	Normal concrete is satisfactory at 5.38 N/mm². Superplasticized concrete is also satisfactory at 6 N/mm² using superplasticizer dosage of 1% of cement content.
C45	55	5.19	Normal concrete is not satisfactory being 4.77 N/mm². Superplasticized concrete is satisfactory at 5.25 N/mm² using superplasticizer dosage of 1.25% of cement content.	Normal concrete is satisfactory at 5.38 N/mm². Superplasticized concrete is satisfactory at 6 N/mm² using superplasticizer dosage of 1% of cement content.

Table-18. Required average tensile strength, T level of satisfactory.

Specified grade of concrete	Req. average compressive strength, N/mm²	Req. average tensile strength, N/mm²	28-day moist cured specimen average tensile strength level of suitability	90-day moist cured specimen average tensile strength level of suitability
C35	45	4.05	Normal concrete is satisfactory at 4.09 N/mm². Superplasticized concrete is satisfactorily at 4.32 N/mm² using superplasticizer dosage of 1% of cement content.	Normal concrete is satisfactorily at 4.66 N/mm². Superplasticized concrete is satisfactory at 4.85 N/mm² using superplasticizer dosage of 1% of cement content.
C40	50	4.5	Normal concrete is not satisfactory being 4.09 N/mm². Superplasticized concrete is satisfactorily at 4.87 N/mm² using superplasticizer dosage of 1.25% of cement content.	Normal concrete is satisfactorily at 4.66 N/mm². Superplasticized concrete is satisfactory at 4.85 N/mm² using superplasticizer dosage of 1% of cement content.
C45	55	4.95	Normal concrete is not satisfactory being 4.09 N/mm². Superplasticized concrete is satisfactorily at 5.70 N/mm² using superplasticizer dosage of 1.5% of cement content.	Normal concrete is not satisfactorily at 4.66 N/mm². Superplasticized concrete is satisfactory at 5.48 N/mm² using superplasticizer dosage of 1.25% of cement content.

CONCLUSIONS AND RECOMMENDATIONS

This paper presents an experimental study and details of the effects of combined nominal size aggregates of 19 mm and 12.5 mm. Strengths of normal and three other types of superplasticized concretes with the 1:2:3 mix ratio were determined. The superplasticizer called Master Rheobuild was used at the quantity variation of 0%, 1%, 1.25% and 1.5% cement content for defining flexural, compressive and tensile splitting individual design strength of optimization. The water cement ratio (w/c) for the normal concrete is 0.4% while the water cementitious materials ratio (w/cm) for the other three superplasticized concretes is 0.3%. The following main conclusions and recommendations are drawn:

CONCLUSIONS

a) The normal concrete produced at 0.4% water cement ratio (w/c) has low degree of workability as well as the superplasticized concretes manufactured at 0.3% water cementitious materials ratio (w/cm) using superplasticizer dosage of 1% cement content.
b) Superplasticized concrete produced with 1.25% cement content of superplasticizer gave medium degree of workability while using 1.5% of same gave high degree.
c) The higher the amount of superplasticizer used in the production of the fresh concrete the higher the value of slump amount and that of compacting value.
d) The higher the value of superplasticizer dosage the higher the individual compressive, flexural and tensile strength of the concrete specimen.
e) The design strength of normal concrete attained at 28 days moist cured in this study failed to satisfy the individual required average flexural, compressive and tensile strength for the specified grade of concrete C40 that is required for highway pavement.
f) Only at 90 days moist cured was the design strength of normal concrete successfully attained the individual required average flexural, compressive and tensile strength for the specified grade of concrete C40 at 28 days moist cured that is required for highway pavement.
g) The design strength of superplasticized concrete of 1.25% of cement content as superplasticizer successfully attained at 28 days moist cured to satisfy the individual required average flexural, compressive and tensile strength for the specified grade of concrete C40 that is required for highway pavement.

RECOMMENDATIONS

a) Normal concrete using combined 12.5 mm and 19 mm aggregates gradation at 50% each should be encouraged where the use of superplasticized concrete is not compulsory for being economical to attain satisfactory strength for highway rigid pavement at 90 days moist cured although not at 28 days of curing.
b) In this facet, the use 1.0% of cement content as superplasticizer is to be encouraged where the use of superplasticized concrete is compulsory or designed for it gave satisfactory strength and also economical for highway rigid pavement at 90 days moist cured.
c) The use of the designed strength at 90 days of concrete specimen curing for highway pavement construction should be encouraged. This is because very few stress repetitions occur during the first 90 days of pavement life, compared with millions of repetitions that occur after that time [29]

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