Characterization and Effects of a 12.5 mm Nominal Maximum Size Aggregate in Concrete Strengths Optimization

Isaac Akiije

***Abstract*— Using granite 12.5 mm nominal maximum size aggregate in the production of concrete is increasing in Nigeria. For this reason, its optimization in use for satisfactory and adequacy in relationship to strength and durability for highway rigid pavement construction in Nigeria is a concern. In this study, granite of 12.5 mm nominal maximum size aggregate gradation as concrete constituent has been used for four different types of 1:2:3 mixtures along with Portland cement and river sand. Of the four different types of concrete production carried out, Type B0 is of a normal concrete using 0.4 water cement ratio (w/c) with no addition of superplasticizer to the concrete produced. Others are superplasticized concretes Types B1, B2 and B3 that were individually produced with addition of varied 1.0%, 1.25% and 1.5% of superplasticizer to cement weight using 0.3 water cementitious materials ratio (w/cm). A total number of 180 concrete specimens were produced in this study. 60 specimens were 550 mm x 150 mm x150 mm beams; another 60 specimens were 150 mm x 150 mm x 150 mm cubes while additional 60 specimens were 150 mm diameter with 300 mm of length cylinders. Tests were duly carried out upon hardened specimens moist cured for 7, 28, 56, 90 and 120 days for flexural, compressive and tensile strengths accordingly. The results of cement used gave relative density value as 3.15, bulk density as 1160 kg/m^3 with its fineness being 5% retained on 45 µm sieve. River sand used is of well-graded fine aggregate while granite employed is of uniformly graded coarse aggregate. Concrete mix design flexural strength of 5.3 N/mm^2 at 1.25% superplasticizer dosage achieved and satisfied standard specification requirements for highway rigid pavement whereas 4.9 N/mm^2 was achieved by normal concrete which could not satisfy same and uneconomical.**

***Index Terms*— Experimental, Superplasticizer, Concrete, Pavement**

I. INTRODUCTION

Coarse aggregate nominal maximum size for concrete production varies from 4.75 mm to 90 mm according to ASTM D448 of which the commonly used of same varied from 9.5 mm to 25 mm. Using granite material of 12.5 mm nominal maximum size aggregate in the production of concrete is increasing in Nigeria. For this reason, there is need to give concern and attention towards optimizing 12.5 mm nominal maximum size aggregate for concrete production. Hence, this will pave way for providing satisfactory concrete with strength and durable properties that could be used for highway pavement construction in Nigeria. Concrete mineral constituent that predominantly retained on the 4.75 mm sieve or the portion that retained on same is called coarse aggregate ASTM C125 (2015). According to Buertey et al., (2015) coarse aggregate generally takes approximately 60-75% of the total volume of the structural concrete while coarse and fine aggregates typically make up to 70% to 90% of same. Concrete mineral constituent that passed the 9.5 mm sieve and almost entirely passing the 4.76 mm sieve and predominantly retained on the 74-micron sieve is called fine aggregate.

Bhattacharjee et al., (2016) claimed that aggregates were earlier considered as chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. Oduroh et al., (2000) considered the effect of the gradation on the strain-rate tensile behaviour of the concrete upon the maximum size of the aggregate particles at high strains. They concluded that as the surface area increases with the decrease in the maximum size of the aggregates whilst resulting to voids decrease and increase in concrete bond strength.

Normal Portland cement specified as Type I by ASTM C150 (2015) has its application for general concrete work whilst its most suitability in use includes floors, reinforced concrete structures and pavements construction. Normal concrete is usually limited to 0.42 water cement ratio by weight for non-air-entrained concrete or 0.39 water cement ratio by weight for air-entrained concrete ACI 211.1 (2009). Superplasticizer, or high-range water reducer, can either greatly increase the flow of the fresh concrete or reduce the amount of water required for a given consistency. Mamlouk (2006) and Akiije (2017) claimed that superplasticizers can be used in the production of concrete for a low water-cementitious materials ratio with the benefits of higher workability of fresh concrete, higher strength of hardened concrete, reduced porosity with very low permeability.

The aim of this study is about the characterization and effects of a 12.5 mm nominal maximum size aggregate used in normal and superplasticized concretes for highway rigid pavement. Specifically, the main objectives are to:

1. Determine properties of constituents that are readily available to produce satisfactory strength and durable normal and superplasticized concretes.
2. Define concrete mix designs for the purpose of selecting the most economical proportions for a required minimum standard quality.
3. Assess the workability of the fresh concretes produced through laboratory slump and compacting factor tests.
4. Determine the moist cured hardened concretes specimens' strengths properties through the appropriately compressive, flexural and tensile splitting tests.

The scope of work in this study is on proportioning concrete constituents which are cement, fine and coarse aggregates of mix 1:2:3 respectively using water cementitious

Isaac Akiije, Department of Civil and Environmental Engineering University of Lagos, Akoka-Yaba Lagos, Nigeria

materials ratio of 0.4 for normal concrete and of 0.3 aimed at superplasticized concrete. The percentages of superplasticizer by weight of cement are limited to1%, 1.25% and 1.5% by individual batch of concrete production.

II. MATERIALS AND METHODS

Granite of 12.5 mm nominal maximum size aggregate has been used as coarse aggregate along with water, superplasticizer, Portland cement and fine aggregate in the production of normal and superplasticized concretes in this study.

2.1 Concrete constituents

Drinkable water found in the concrete laboratory of the department of Civil and Environmental Engineering, Faculty of Engineering, University of Lagos was employed to produce each concrete batch. Master Rheobuild 850 superplasticizer is the name of the high-range water reducer chemical admixture used for the purpose of increasing the workability of the concrete mixtures whilst reducing the amount of mixing water.

The cement used in this study for the concrete production is somewhat new brand of cement produced in Nigeria and of grade 42.5N ordinary Portland cement Type I. The cement was subjected to laboratory tests to identify its physical properties, chemical and compound composition properties for its level of conformity in accordance to AASHTO M 85 (2018). The cement used bulk density was determined as its weight per unit volume in the laboratory according to ASTM D6023 (2016) while its relative density was determined in accordance to ASTM C 188 (2015). In accordance to ASTM C 430 (2017) procedure, the fineness of the cement used was measured by determining the percent passing the 0.045 mm sieve. Also, the cement initial and final setting time values were determined as well as its consistency value using Vicat apparatus by the method in accordance to ASTM C 191 (2013).

Sand obtained from Ogun River bed at Matogun, Ogun State, Nigeria, was air dried in the laboratory for the production of the concrete specimens whilst its gradation, coefficient of uniformity and curvature were determined according to AASHTO T 27 (2014). The determination of moisture content, relative density, dry density and absorption of the fine aggregate used were determined according to AASHTO T 85 (2018) specification. According to AASHTO T 19 (2014) specification, the bulk densities of both fine and coarse aggregates used were determined separately. 12.5 mm nominal size granite as coarse aggregate used in the production of the concretes in the course of this study was subjected to sieve analysis, coefficient of uniformity and curvature tests according to AASHTO T 27 (2014). Based upon the method according to AASHTO T 84 specification the moisture content, specific gravity, dry density and absorption of the granite used were determined. According to ASTM D4791, (2014) crushing and impact values of the coarse aggregate used were also determined.

2.2 Fresh concrete production, workability tests and casting of specimens

The production of fresh concrete was carried out respectively by the amount of concrete constituents as described in Table 1 and Table 2. Table 1 is showing the relationship among the concrete constituents by mix ratio and water cementitious materials ratio while Table 2 is describing the concrete mix proportioning in kilograms per metre cube of concrete.

Tilting mobile rotating drum type mixer was used inside the laboratory to prepare fresh concrete in batches while using 50 kg of cement per bag for a batch of production. In the process, small amount of water was introduced into rotating drum mixer machine to make the internal condition saturated dry surface and then the ingredients were thoroughly mixed dry. In the case of Type B0 concrete mixture, 80% of the required water was added to the constituents in the rotating drum and after further mixing the fresh concrete was poured on a saturated surface dry platform. The balance of 20% of the required water was poured on the fresh concrete and later thoroughly mixed manually. Similar mixing operation was carried out for Types B1, B2, and B3 concrete production individually using superplasticized water.

Each fresh concrete batch produced was subjected to workability investigation by slump and compacting factor tests together with casting of specimens. In accordance to AASHTO T 119 (2013) the slump test was carried out upon the fresh concrete produced. Also, the compacting factor test upon the fresh concrete was carried out in accordance to BS 1881 (2011). Casting of each specimen was in three layers of fresh concrete of which each layer was rodded using 16 mm diameter rod of 600 mm length.

Concrete specimens of 60 beams, 60 cubes and 60 cylinders as shown in Table 3 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 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. Specimens made from fresh concrete were allowed to stay in their respective moulds for 24 hours before demoulding and they were immediately submerged inside clean water in a container for curing in accordance to ASTM C192 (2016).

Table 1: Concrete constituents' ratio using 12.5 mm size nominal maximum coarse aggregate

Concrete Mix Identification	Water cementitious material ratio by weight of cement (water/superplasticizer)	Cement Content	Fine Aggregate	Coarse Aggregate
Type B0	0.4 (0.4/0)	1	2	3
Type B1	0.3 (0.28/0.02)	1	2	3
Type B2	0.3 (0.275/0.025)	1	2	3
Type B3	0.3 (0.27/0.03)	1	2	3

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

Concrete Mix Identification	Water cementitious material ratio (water/ superplasticizer) by weight of cement	Water content kg/m³	Admixture content kg/m³	Cement content kg/m³	Fine Agg. kg/m³	Coarse Agg. kg/m³
Type B0	0.4 (0.4/0)	160	0	400	800	1200
Type B1	0.3 (0.28/0.02)	112	8	400	800	1200
Type B2	0.3 (0.275/0.025)	110	10	400	800	1200
Type B3	0.3 (0.27/0.03)	108	12	400	800	1200

Table 3: Concrete specimens casting modules

Concrete Mix Identification	Flexural Beam (550x 150 x 150) mm Numbers	Compressive Cube (150 x150 x 150) mm Numbers	Tensile Splitting Cylinder (150 Ø x 300) mm Numbers
Type B0	15	15	15
Type B1	15	15	15
Type B2	15	15	15
Type B3	15	15	15
Total specimens	60	60	60

2.3 Hardened concrete tests

Hardened concrete tests were carried out on the specimens that had been cured 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 ASTM C 78 (2016) using hydraulic flexural testing machine powered manually. Wright and Ashford (1998) claimed 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 BS EN 12390 (2009). Furthermore, each hardened concrete cylinder specimen was also tested for tensile splitting strength in accordance to ASTM C 496 (2011).

III. RESULTS AND DISCUSSIONS

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

3.1 Cement properties

The results of the chemical and compound compositions as well as the physical properties of the cement used are in Table 4, Table 5 and Table 6 respectively. It is obviously seen that the cement is found to be satisfactorily suitable based on chemical composition values than that of compound composition when related to standard specification requirements. Also, as seen in Table 6, the cement values for bulk density and specific gravity are suitable for concrete mix proportioning by weight and absolute method.

Table 4: The cement chemical composition

Chemical Composition	Cement 42.5 R	Specification Requirements Content (%)	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	Cement 42.5 R	Specification Requirements Content (%)	Remarks
Tricalcium Silicate, C3S	70.67	40 - 63	Not Conformed
Dicalcium Silicate, C2S	6.13	9 -31	Not Conformed
Tricalcium Aluminate, C3A	11.45	6 -14	Conformed
Tetracalcium Aluminate, C4AF	2.95	5 - 13	Not Conformed

Table 6: The cement physical properties

Parameters	*Cement 42.5 R*	*Specification Requirements*	*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 Maximum	Conformed
Loss of Ignition , LOI	*0.006*	*0.04-0.05*	Not Conformed
Insoluble Residue, IR	*99.96*	*99.95-99.97*	Conformed

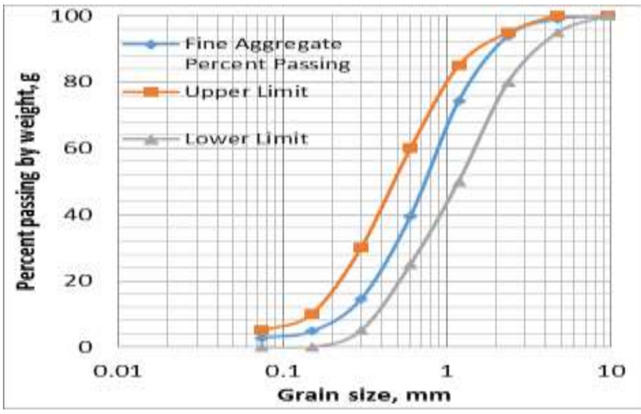

Figure 1: Fine aggregate semi-log gradation chart

3.2 Fine and coarse aggregates properties

The fine aggregate used in this study was a well-graded river sand material based upon the gradation test and as seen in Figure 1. The fine aggregate gradation satisfied the ASTM C 33 (2018) standard requirements specification and could be classified as grading No. 1. Figure 2 is showing that the coarse aggregate used in this study is uniformly graded granite material. It is obvious that Figure 2 gradation curve of the coarse aggregate used fit well closer to the lower limit boundary of the grading envelope. The results of the physical properties of fine and coarse aggregates are in Table 7 of which the value obtained for each property depicts materials representation satisfactorily for concrete production.

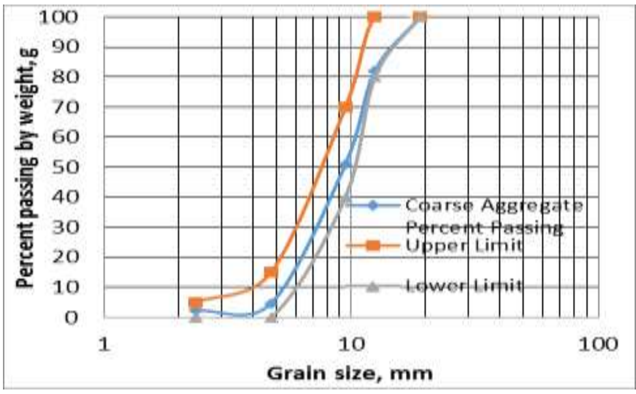

Figure 2: Semi-log coarse aggregate gradation chart

Table 7: The physical properties of fine and coarse aggregates

S/No	Physical Properties	Fine Aggregate River Sand	Coarse Aggregate 12.5 mm Granite
1	Percent of particles retained on the 4.75 mm sieve	1	97
2	Percent of particles passing the 4.75 mm sieve	99	3
3	Percent of particles passing the 0.075 mm sieve	2.9	0
4	Fineness modulus	2.74	2.69
5	Coefficient of uniformity (Cu)	3.71	1.96
6	Coefficient of curvature (Cc)	1.11	0.9
7	Bulk density	1655	1650
8	Specific gravity	2.7	2.7
9	Moisture (water) absorption (%)	1.38	0.43
10	Aggregate crushing value (%)	-	18
11	Aggregate impact value (%)	-	13

3.3 Fresh concrete properties

The workability characteristics thread of the fresh concretes Type B0 through Type B3 produced in this study are presented in Table 8, Figure 3 and Figure 4. 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 the higher the value of both slump and compaction factor. Figure 3 and Figure 4 individually displays similar polynomial graph but different quadratic equations are displayed which resulted to different values of coefficient of determination R-Square in regression function. This is an indication that the compaction factor graph is more suitable for regression function than that of slump model.

Table 8: Workability tests results

Concrete Mix Identification	Superplasticizer Dosage	Slump Values (mm)	Compaction Factor
Type B0	0.0	0	0.780
Type B1	1.0	20	0.790
Type B2	1.25	30	0.795
Type B3	1.5	45	0.80

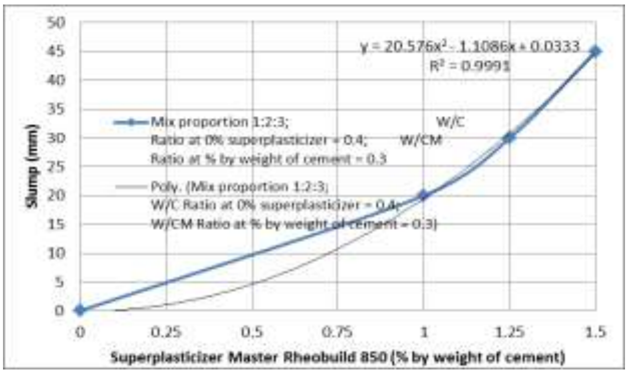

Figure 3: Workability chart for slump values

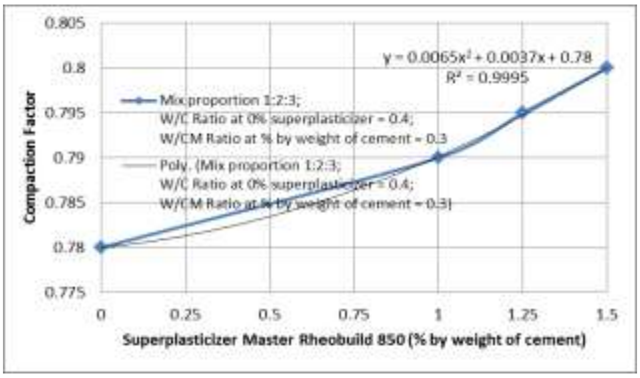

Figure 4: Workability chart for compaction factors

3.4 Hardened concrete properties

The strengths values of each of the superplasticized concrete flexural, compressive and tensile based upon water curing periods are shown in Figures 3 through 5 individually. Each of the three charts shows that as the moist curing period is increasing each one of the strength values is also increasing at decreasing rate. The amount of increment of each of the strengths between 90 and 120 days of moist curing is marginal.

The effects of superplasticizer quantity variations by the way of affecting concrete strengths development as experimented in this study have been displayed in Figure 6 through Figure 8. These figures are showing that within the limits of the experiments carried out in this study individually for concrete flexural, compressive and tensile strengths developed, the higher the amount the superplasticizer dosage the higher the strength. It is obviously also seen that the rate of strength is increasing as the dosage of the superplasticizer is increasing. The highest value of strength is obtained at superplasticizer dosage of 1.5% by weight of cement while the concrete with 0% of it is having the lowest strength value. In this study, results of concrete flexural, compressive and tensile strengths are of similar trend in strength development.

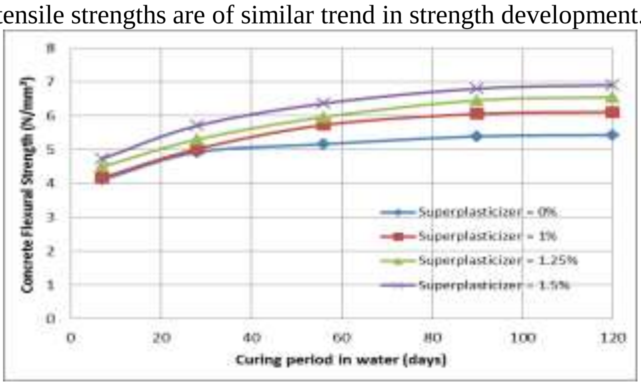

Figure 3: Water curing period-flexural strength in relationship to superplasticized concrete

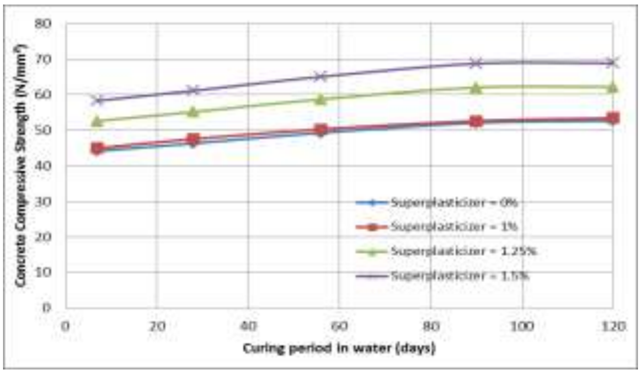

Figure 4: Water curing period-compressive strength in relationship to superplasticized concrete

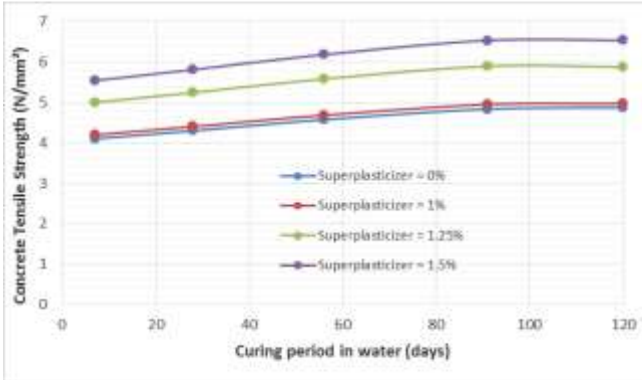

Figure 5: Water curing period-tensile strength in relationship to superplasticized concrete

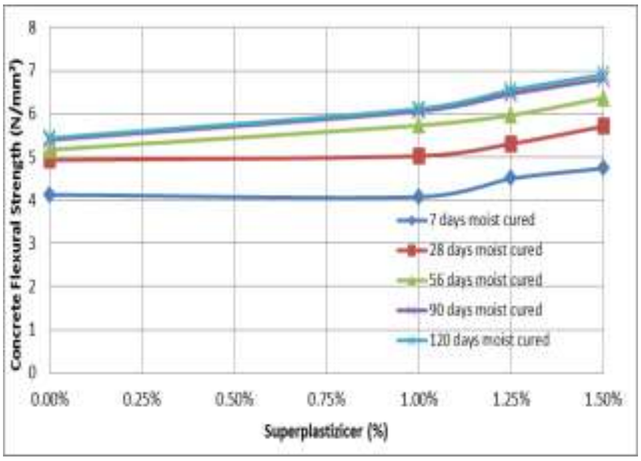

Figure 6: Superplasticizer dosage-flexural strength relationship

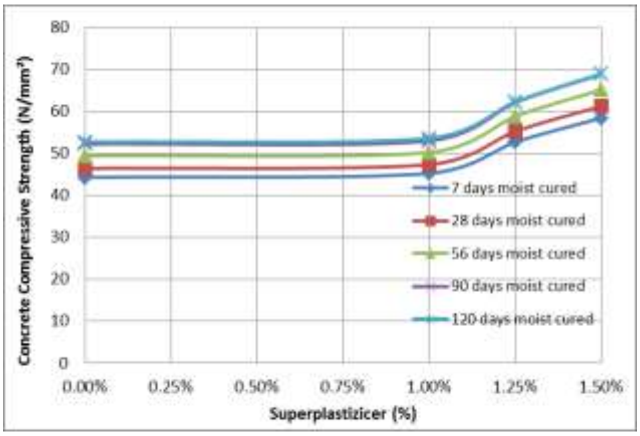

Figure 7: Superplasticizer dosage-compressive strength relationship

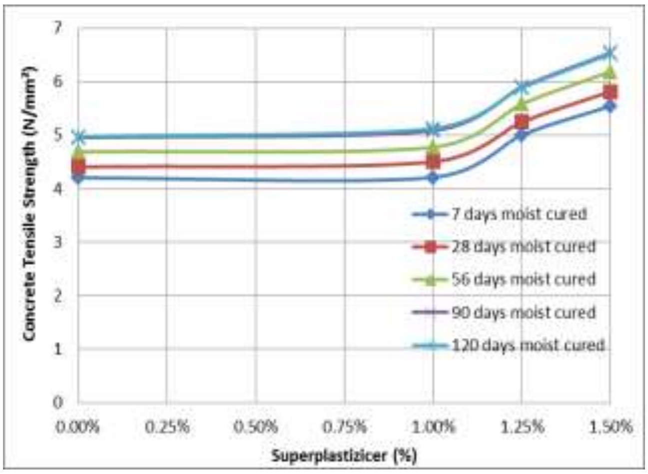

Figure 8: Superplasticizer dosage-tensile strength relationship

Tables 9, 10 and 11 respectively give moist cured specimens compressive, flexural and tensile mix design strengths at 28-day and 90-day based upon the specified concrete grade C35, C40, C45 and C50.

As shown in Table 9, moist cured specimens compressive mix design strengths 55 N/mm² at 28-day was achieved at superplasticizer dosage of 1.25% by cement content weight. The compressive mix design strength obtained satisfied specified concrete grades C35, C40 and C45. It is also shown in Table 9 of which moist cured specimens mix design strength of 52 N/mm² and 53 N/mm² at 90-day were achieved respectively at normal concrete as well as superplasticized concretes using superplasticizer dosage of 1.0% by cement content weight. The compressive mix design strength results obtained satisfied concrete specification for grades C35 and C40. However, moist cured specimens mix design strength of 62 N/mm² and 69 N/mm²at 90 days were achieved respectively at superplasticizer dosage of 1.25% and1.5% cement content by weight. The results correspondingly satisfied specified grade of concrete C45 and C50.

Also as shown in Table 10, moist cured specimens flexural mix design strength 5.3 N/mm² at 28-day was achieved at superplasticizer dosage of 1.25% cement content by weight. The flexural mix design strength obtained satisfied specified concrete grades C35 and C40. It could also be seen in Table 10 of which moist cured specimens flexural mix design strength 5.4 N/mm² at 90-day moist cured was achieved for normal concrete. The result obtained satisfied concrete specified grades C35, C40 and C45. However, moist cured specimens flexural mix design strength 6.1 N/mm² N/mm²at 90-day was achieved at superplasticizer dosage of 1.0% cement content which satisfied specified grade of concrete C35, C40, C45 and C50.

As shown in Table 11, moist cured specimens tensile mix design strength 4.5 N/mm² at 28-day moist cured was achieved at superplasticizer dosage of 1.0% cement content by weight. The result satisfied specified concrete grades C35 and C40. It is also shown in Table 11 of which moist cured specimens' tensile mix design strength of 5.0 N/mm² and 5.1 N/mm²at 90 days were achieved respectively at normal concrete as well as at using superplasticizer dosage of 1.0% cement content by weight. The results obtained satisfied concrete specified grades C35 C40 and C45. However, moist cured specimens tensile mix design strength of 6.5 N/mm² at 90-day moist cured was achieved at superplasticizer dosage of 1.5% cement content by weight correspondingly in order satisfied specified grade of concrete C50.

Table 9: Comparison of the moist cured specimens compressive mix design strengths at 28-day and 90-day

Specified grade of concrete.	Required average compressive strength. N/mm²	Compressive mix design strength at 28-day moist cured. N/mm²	Compressive mix design strength at 90-day moist cured. N/mm²
C35	44	46 N/mm² by Normal concrete; 48 N/mm² @ 1% Superplasticizer dosage	52 N/mm² by Normal concrete; 53 N/mm² @ 1.0% Superplasticizer dosage
C40	50	55 N/mm² @ 1.25% Superplasticizer dosage	52 N/mm² by Normal concrete; 53 N/mm² @ 1.0% Superplasticizer dosage
C45	55	55 N/mm² @ 1.25% Superplasticizer dosage	62 N/mm² @ 1.25% Superplasticizer dosage
C50	65	Not Applicable	69 N/mm² @ 1.5% Superplasticizer dosage

Table 10: Comparison of the moist cured specimens flexural mix design strengths at 28-day and 90-day

Specified grade of concrete	Required average flexural strength N/mm²	Flexural mix design strength at 28-day moist cured. N/mm²	Flexural mix design strength at 90-day moist cured. N/mm²
C35	4.9	4.93 N/mm² by normal concrete; 5.02 N/mm² @ 1.0% Superplasticizer dosage	5.4 N/mm² by normal concrete; 6.06 N/mm² @ 1.0% Superplasticizer dosage
C40	5.2	5.31 N/mm² @ 1.25% Superplasticizer dosage	5.4 N/mm² by normal concrete; 6.06 N/mm² @ 1.0% Superplasticizer dosage
C45	5.4	5.71 N/mm² @ 1.25% Superplasticizer dosage	5.4 N/mm² @ 0% by normal concrete; 6.06 N/mm² @ 1.0% Superplasticizer dosage
C50	5.9	Not Applicable	6.06 N/mm² @ 1.0% Superplasticizer dosage

Table 11: Comparison of the moist cured specimens flexural mix design strengths at 28-day and 90-day

Specified grade of concrete	Required average tensile strength N/mm²	Tensile mix design strength at 28-day moist cured. N/mm²	Tensile mix design strength at 90-day moist cured. N/mm²
C35	4.0	4.40 N/mm² by normal concrete; 4.5 N/mm² @ 1.0% Superplasticizer dosage	5.0 N/mm² by normal concrete; 5.1 N/mm² @ 1.0% Superplasticizer dosage
C40	4.5	4.5 N/mm² @ 1.0% Superplasticizer dosage	5.0 N/mm² by normal concrete; 5.1 N/mm² @ 1.0% Superplasticizer dosage
C45	5.0	5.2 N/mm² @ 1.25% Superplasticizer dosage	5.1 N/mm² @ 1.0% Superplasticizer dosage
C50	5.5	Not Applicable	6.5 N/mm² @ 1.5% Superplasticizer dosage

IV. CONCLUSIONS AND RECOMMENDATIONS

Granite material of 12.5 mm nominal maximum size aggregate gradation has been used somewhat with other constituents of concrete for purpose of producing rigid pavement material. The other concrete constituents included clear water, Master Rheobuild 850 superplasticizer, 42.5 N Portland cement, and river sand as fine aggregate.

V. CONCLUSIONS

1. Concrete raw constituents used in this study are of local contents materials in Nigeria that complied satisfactorily with relevant standard specification requirements and which have been successful utilized to produce normal concrete and superplasticized concretes.
2. The proportioning of the concretes produced is by the parameters of aggregate-cement ratio of 5 and fine-coarse aggregates ratio 40/60. Also, other parameters are 0.4 water cement ratio for normal concrete and 0.3 water cementitious materials ratio for the other three types of superplasticized concretes.
3. The workability of the fresh concrete produced was defined by slump value and compaction factor. The slump values varied from 0 for the normal concrete to 45 mm for concrete with superplasticizer of 1.5% by weight of cement. Similarly, compacting value varied from 0.78 mm for the normal concrete to 0.80 mm for the concrete with superplasticizer of 1.5% by weight of cement.
4. The flexural mix design value obtained from the normal concrete produced varied from 4.1 N/mm² at 7 days moist curing to 5.4 N/mm² for 120 days moist curing. The flexural mix design value also obtained from the superplasticized concrete produced varied from 7 days moist curing to 120 days moist curing respectively from 4.24 N/mm² with superplasticizer of 1.0% by weight of cement to 6.9 N/mm² with superplasticizer of 1.5% by weight of cement.
5. The compressive mix design value obtained from the normal concrete produced varied from 44.2 N/mm² at 7 days moist curing to 52.7 N/mm² for 120 days moist curing. While the compressive mix design value obtained from the superplasticized concrete produced varied from 7 days moist curing to 120 days moist curing respectively from 45 N/mm² with superplasticizer of 1.0% by weight of cement to 69 N/mm² with superplasticizer of 1.5% by weight of cement.
6. The tensile mix design value obtained from the normal concrete produced varied from 4.1 N/mm² at 7 days moist curing to 4.9 N/mm² for 120 days moist curing. While the tensile mix design value obtained from the superplasticized concrete produced varied from 7 days moist curing to 120 days moist curing respectively from 4.2 N/mm² with superplasticizer of 1.0% by weight of cement to 6.5 N/mm² with superplasticizer of 1.5% by weight of cement.

RECOMMENDATIONS

Highway rigid pavement with flexural required average flexural strength of 5.2 N/mm² corresponding to specified grade of concrete C40 can be produced successfully in Nigeria using locally sourced materials as exhibited in this study to prevent premature failure of Nigerian roads.

Although Type B3 concrete mix with superplasticizer of 1.5% by weight of cement has 5.7 N/mm² as the flexural mix design strength it is Type B2 concrete mix with superplasticizer of 1.25% by weight of cement with 5.3 N/mm² that is recommended for being economical.

Although granite of 12.5 mm nominal maximum size aggregate is employed in this study other sizes of granites could as well be subjected to similar experimental investigations.

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REFERENCES

[1] ASTM D 448. Classification for sizes of aggregate for Road and Bridge Construction. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2015: Vol. 04.03

[2] ASTM C 125. Terminology relating to concrete and concrete aggregates. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2015: Vol. 04.02

[3] Buertey JIT, Atsrim F, Ofei, WS. An Examination of the Physiomechanical Properties of Rock Lump and Aggregates in Three Leading Quarry Sites near Accra. Am. J. Civ. Eng. (2016): 4(6):264-275

[4] Bhattacharjee M, Rahman MA. Effect of Aggregate Properties on the Crushing Strength of Concrete, International Journal of Materials Science and Applications. 2015: 4(5):343-349.

[5] Oduroh PK, Mahboub KC. and Anderson RM. Flat and elongated

aggregates in Super pave regime. Journal of Materials in Civil Engineering. 2000: 12: 124-130.
[6] ASTM C 150. Potential compound composition. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2015
[7] ACI 211.1. Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete. American Concrete Institute, 38800 Country Club Dr 48331 Farmington Hills, Michigan. 2009
[8] Mamlouk MM. and Zaniewski JP. "Materials for Civil and Construction Engineers", Pearson Education, Inc., Upper Saddle River, New Jersey. 2006
[9] Akiije I. Effects of CONPLAST SP 430 Superplasticizer Using Four Nigerian Produced Cements Individually In Concrete Production for Highway Pavement. Journal of Multidisciplinary Engineering Science and Technology. 2017: 4(6)
[10] AASHTO M 85. Standard Specification for Portland cement. American Association of State Highway and Transportation Officials, Washington, D.C. 2018
[11] ASTM D6023. Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low-Strength Material (CLSM). American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2016
[12] ASTM C 188. Standard Test Method for Density of Hydraulic Cement, density, hydraulic cement, specific gravity. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2015
[13] ASTM C 191. Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2013
[14] AASHTO T 27. Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates. American Association of State Highway and Transportation Officials, Washington, D.C. 2014
[15] AASHTO T 85. Standard Specification for Portland cement (Chemical and Physical)", American Association of State Highway and Transportation Officials, Washington, D.C. 2009
[16] AASHTO T 19. Standard Method of Test for Bulk Density ('Unit Weight') and Voids in Aggregate. American Association of State Highway and Transportation Officials, Washington, D.C. 2014
[17] AASHTO T 119. Standard Method of Test for Slump of Hydraulic Cement Concrete," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2013
[18] ASTM C192. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2016
[19] ASTM C 78. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)", American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2016
[20] BS EN 12390: Testing Hardened Concrete - Making & Curing Specimens for Strength Tests", British Standards Institution, London. 2009
[21] ASTM C 496. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, cylindrical concrete specimens, splitting tension, tensile strength," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2011
[22] ASTM C33 / C33M. Standard Specification for Concrete Aggregates", American Society for Testing and Materials," 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2016
[23] ASTM C 430 (2008): "Standard Test Method for Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve", American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2008
[24] AASHTO T 84: "Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate", American Association of State Highway and Transportation Officials, Washington, D.C. 2013
[25] ASTM D4791, (2014): "Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959
[26] BS 1881: "Testing concrete," British Standards Institution, London.2011
[27] Wright, P. H. and Ashford, N. J.: "Transportation Engineering Planning and Design." John Wiley and Sons, Inc., New York. 1998
[28] ASTM C 33. Specification for concrete aggregates. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 2018