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Effects of Using 0.5, 0.55 and 0.6 Water Cement Ratio Separately With a Nigerian Grade 42.5R Portland Cement

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Abstract: This research paper is for the purpose of disseminating the results of an investigation into the effect of water cement ratio of 0.5, 0.55 and 0.6 separately while producing most commonly practiced concrete of cement, fine aggregate and coarse by 1:2:4 mixtures. This research study is limited to the use of newly grade 42.5R Portland cement that is being produced in Nigeria recently and of which is readily available. River sand was used as fine aggregate and coarse aggregates used separately were washed gravel, 19 mm and 12.5 mm granites. Nine different concrete mixtures were produced and it is important to note that the results of their slump tests deviated considerably from that of the compacting factor tests correspondingly while considering the degree of workability values. Conducting this research the potential impact derived is that only the use of 19 mm granite with water cement ratio of 0.5 and 0.55 achieved at 28 day flexural strength concrete grade of 4.92 N/mm^2 and 4.84 N/mm^2 respectively whilst are marginally greater than the standard specification value of 4.5 N/mm^2. The significance of this study is that while at when the flexural strength of concrete is satisfied the corresponding tensile strengths values which are 2.684 N/mm^2 and 2.590 N/mm^2 do not satisfy the required standard specification values which are respectively 3.355 N/mm^2 and 3.238 N/mm^2. The contribution to knowledge as regards to this research work is in the enlightenment benefit revealed upon the possible prevention of economic loss that can occur due to early rigid pavement failure for roads, petroleum filling station concrete pavements in cities and rural towns or yards for offices and factories due to design of poor concrete proportioning and the use of the new cement.

Keywords: Workability, Flexural, Compressive, Tensile, Strength, Economy

1. Introduction

In Nigeria, construction which involved development of rigid pavements for roads, playgrounds, domestic and factory yards were carried out of which grade 42.5R Portland cement that is relatively new is now most widely used along with 1:2:4 concrete mixtures. The manufacturing of Portland cement grade 42.5R is relatively new in Nigeria but its use is already comparatively high as it is mostly found easily in the open markets and on construction sites. This paper is limited to strength characterization of a Nigerian grade 42.5R Portland cement concrete using three selected coarse aggregates. Portland cement, aggregates and water are the most widely used materials in the production of basic concrete mix design although an admixture may be added for modification of its properties. The problem in the proportioning of concrete using mixtures of cement, fine, and coarse aggregate along with applied water cement ratio is how to get desirable concrete properties such as strength, durability and due economy for the intended structure. Portland cement is a finely-ground powder which, in the presence of water, has a chemical reaction along with hydration during and after setting and hardening forming a very strong and durable binding material. The bulk density of cement normally reflects the volume taken up by the cement plus any air trapped between the particles and the mass of the material whereas the relative density or specific gravity considered only the weight of the cement particles themselves. Cement relative density is considered in the region 3.11-3.15 and that of its bulk density of being general purpose is approximately 1000-1300 kg/m^3. Water that is meant for use in the production of Portland cement concrete must be drinkable and free from alkalis, acids, oil and organic matter. Addition of Portland cement with water is the paste and forms active ingredient of the concrete whilst aggregates including sand and stone are inert ingredients. The main aggregates in use for road pavements in combination with a Portland cement material are either natural rock materials, gravels and sands, or slag aggregates. Admixture may also be added to water before the production of the concrete.

Marotta [1] claimed that determining concrete quantities for a construction project requires volumetric calculations with addition of appropriate waste factor ranging from 3 to 8 percent. However, Hebhoub et al. [2] resolved that some of the factors which may affect the workability of concrete are the grading and shape of sand, the proportion of fine to coarse aggregates, and the characteristics of the aggregates. They have given useful information about concrete proportioning to achieve desired amount of concrete production and workability. Ukpata and Ephraim [3] investigated flexural and tensile strength properties of concrete using lateritic sand and quarry dust as fine aggregate and concluded that the proportion of lateritic sand content should be kept below 50% for structural works. Therefore, they have subjected their investigation to defined limitation of which a desired strength for road pavement may not be achieved. According to Ilangovana et al. [4] aggregates size distribution is one of the most important properties that influence several concrete characteristics that include workability, mechanical strength, durability and water absorption. Traditionally, concrete has been accepted to be a durable material but this view is no longer strongly held. Falade [5] claimed that inadequate design, care and supervision during construction and wrong choice of construction materials are among the reasons for concrete incapability to satisfy this requirement. Aggregates size distributions and water cement ratios are given considerations in this study in order to determine the strength and durability characteristics of the concretes produced and their worth.

The study in this research paper aims at investigating the characterization of concretes produced using grade 42.5R Portland cement along with three selected coarse aggregates separately with the same river sand regarding concrete strength developed for worthy highway pavement. Specifically the objectives of this research are to:

a. Define the specific chemical and metallic composition properties of the cement used together with the determination of its initial and final setting times;
b. Determine the particle size distribution for both the fine and coarse aggregates along with their fineness modulus, coefficient of uniformity and coefficient of curvature;
c. Define and compare different concretes made of the cement, river sand and granite or gravel with varying water-cement ratio of 0.5, 0.55 and 0.6 while using 1:2:4 mixture individually;
d. Determine and compare the workability of the fresh concretes prepared through the slump test and the compacting factor test and;
e. Carry out laboratory tests to destruction of hardened concrete specimens prepared in order to determine flexural, compressive and tensile strengths.

The main scope of work in this study therefore includes using 19 mm granite, 12.5 mm granite and washed gravel individually in the production of concretes for city and rural street pavement construction with strength comparison considerations where the materials are readily available. Significantly, this study provides information upon the use of grade 42.5R Portland cement alongside the local content resourceful reliability. The justification for this research work is in the enlightenment on the economy associated to the failure of concrete commonly produced locally in Nigeria for the construction of highway pavement for petroleum filling stations in cities and rural towns or office and factory yards.

2. Materials and Methodology

The design mix for the hardened concrete produced for this research work contained the following four ingredients which are water, cement, fine aggregate and coarse aggregate. The kind of water used is the drinkable water found in the concrete laboratory of the department of Civil and Environmental Engineering, University of Lagos. The type of cement used for this investigation is relatively new in the Nigerian markets and it is the grade 42.5R ordinary Portland cement Type I whose properties conformed to AASHTO M 85 [6] and also being produced in Nigeria. Type I Portland cement is suitable for general concrete construction and where no special properties are required. The cements were supplied in 50 kg per bag and were well protected from dampness by placing them on planks to avoid lumps in the laboratory. Each bag of cement opened was used within 30 minutes. The relative density or specific gravity of cement used was determined according to ASTM C 188 [7] whilst the bulk density was determined as its weight per unit volume. The fineness of the cement used was measured by determining the percent passing the 0.045 mm sieve in accordance to ASTM C 430 [8] procedure. The cement was subjected to initial and final setting time tests based on measurements by the Vicat apparatus according to ASTM C 191 [9]. In the process, the time when a penetration of 25 mm occurred was determined and recorded as the initial setting time while the final setting time was when the needle did not penetrate visibly into the paste. Atomic absorption spectrometer methodology with high performance of low detection limits and accuracy was adopted in the laboratory to carry out the cement chemical elements composition and metallic components using the absorption of optical radiation by free atoms in the gaseous state.

Ogun River sand from Lagos environs used was air dried in the laboratory for concrete production. The gradation test was performed on the sample that passed through sieve 9.5 mm and retained on 0.075 mm after agitation of nest of the sieves according to AASHTO T 27 [10]. In the process, a nest of sieves with apertures 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm and 0.075 mm were used for the fine sand grain-size classification. Also, 19 mm, 12.5 mm granites and the washed gravel, obtained from Abeokuta environs in Ogun State of Nigeria were separately air dried in laboratory for the purpose of sieve analysis tests and concrete production. In the process, a nest of sieves with apertures 25 mm, 19.0 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm and 0.15 mm were appropriately used for grain-size classification of samples for the purpose of aggregate gradation. The test on size and gradation of coarse aggregates was performed according to AASHTO T 27 [10].

The specific gravity of the fine aggregate used was determined according to AASHTO T 85 [11] specification. Also, the specific gravities of the three coarse aggregates used were determined separately according to AASHTO T 84 [12] specification. The bulk densities for the aggregates 19 mm granite, 12.5 mm granite, washed gravel and fine aggregates used were determined separately according to AASHTO T 19 [13] specification. The specific gravity value of water used in this study is 1 while its bulk density is 1000 kg/m^3. The specific gravity value of cement is 3.15 while the bulk density is 1100 kg/m^3. The specific gravity value of sand determined is 2.65 while the value of the bulk density of the sand determined for the concrete production is 1600 kg/m^3. The specific gravity values obtained for 19 mm, 12.5 mm granites and washed gravel are 2.7, 2.7 and 2.65 respectively while their respective bulk densities are 1560 kg/m^3, 1580 kg/m^3 and 1620 kg/m^3.

2.1. Proportioning of the Concrete Mixtures

Owing to the use of three types of aggregates which are 19.5 mm granite, 12.5 mm granite and washed gravel separately as well as three types of water cement ratio that are 0.5, 0.55 and 0.6 individually, nine batches of concrete were produced. The total volume of nine batches of concrete, Vcb produced in the laboratory with entrainment air of 2 percent and 7 percent wastage is equal to 2.358 cubic metres. Volume of the concrete constituents per batch determined is in Table 1. The proportions of water, cement, fine and coarse aggregates determination was based upon the absolute volume method in order to ascertain the proportion that will give satisfactory strength, durability and economy when used for highway pavement. In the process of the absolute volume method, the specific gravity and bulk density of each ingredient were given consideration while calculating each constituent that produced absolute volume of concrete per 50 kg cement bag in m^3. Subsequently, the volume obtained is converted into weight for the determination of the batching of the concrete constituents.

Table 1. *Volume of the concrete computation constituents per set of specimens.*

Label	Beam	Cube	Cylinder	Total
Strength Test	Flexural	Compressive	Tensile Splitting	
Size, mm	150 x 150 x 550	150 x 150 x 150	150 x 300	
Testing Days After Curing	7, 14, 21, 28, 56 & 91	7 & 28	7 & 28	
Number	6 x 3 = 18	2 x 3 = 6	2 x 3 = 6	
Concrete Volume V, m^3	0.223	0.010	0.016	0.249
Volume of concrete per set of specimens with entrainment air of 2 percent and 7 percent wastage, Vcpss = 0.262 m^3; [0.249(1-0.02+0.07)]				
Total volume of concrete for nine sets of specimens produced with entrainment air of 2 percent and 7 percent wastage Vct = 2.358 m^3				

In the process, the mixture to be used was firstly assumed in the proportion of part of cement α that its value is normally 1 to β part of fine aggregate and to ω part of coarse aggregate for a fixed water cement ratio w/c which is always less than 1. Also, the already determined bulk densities of cement, fine aggregate and coarse aggregate which are γ_c , γ_{fa} and γ_{ca} respectively were used along with their respective specific gravity S_c , S_{fa} and S_{ca} . It is worthy of note that the bulk density of water γ_w is 1 and that of its density S_w is also 1, Also, in the determination of the concrete production respective weights of constituents of water, cement, fine and coarse aggregates are defined as $W, C, F_a \ and \ C_a$ respectively.

For a unit weight of Portland cement, the volume of concrete V_{cb} produced is given by Equation 1. Table 2 gives expressions for the modalities of using Equation 1 for the possibilities of obtaining absolute volume concrete in m^3 per 50 kg bag of cement and absolute weight of concrete for batching of V_{cb} m^3 given consideration to bulk densities of the materials used. A useful template for the determination of absolute weight concrete for batching of V_{cb} m^3 is in Table 3 while employing Microsoft Excel Spreadsheet. Table 4 is showing the values of absolute concrete weight for batching of 0.262 m^3 in terms of each concrete material constituent for water cement ratio of 0.5 and 19 mm granite.

$$V_{cb} = \frac{W}{\gamma_w} + \frac{C}{\gamma_w \times S_c} + \frac{F_a}{\gamma_w \times S_{fa}} + \frac{C_a}{\gamma_w S_{ca}} \tag{1}$$

Table 2. *Expressions for the computation of the absolute volume and absolute weight of concrete per batch. 7.*

Label	Water	Cement	Fine Aggregate	Coarse Aggregate
Assumed Ratio	w/c	α	β	ω
Bulk Density	γ_w	γ_c	γ_{fa}	γ_{ca}
Applied Ratio by Weight	w/c	α	$\frac{\beta\times\gamma_{fa}}{\gamma_c}$	$\frac{\omega\times\gamma_{ca}}{\gamma_c}$
Specific Gravity	S_w	S_c	S_{fa}	S_{ca}
Absolute concrete volume Vca, per 50 kg cement $V_{50kgcem}$ / bag, m^3	$\frac{w/c\times 50}{\gamma_w\times S_w}$	$\frac{\alpha\times\gamma_c\times 50}{\gamma_w\times\gamma_c\times S_c}$	$\frac{\beta\times\gamma_{fa}\times 50}{\gamma_w\times\gamma_c\times S_{fa}}$	$\frac{\omega\times\gamma_{ca}\times 50}{\gamma_w\times\gamma_c\times S_{ca}}$
Absolute concrete weight W_{cb} for Vcpss, m^3	$\frac{V_{cpss}\times 50\times w/c}{V_{ca}}$	$\frac{V_{cpss}\times 50}{V_{ca}}$	$\frac{V_{cpss}\times 50\times\beta}{V_{ca}}$	$\frac{V_{cpss}\times 50\times\omega}{V_{ca}}$

Table 3. *Modelling of absolute volume and absolute weight of concrete per batch.*

	B	C	D	E	F	G
3	Label	Water	Cement	Fine Aggregate	Coarse Aggregate	Sum
4	Assumed Ratio	0.5	1	1.375	2.821	
5	Bulk Density	1000	1100	1600	1560	
6	Applied Ratio by Weight	=C4	=D4	=E4*E5/D5	=F4*F5/D5	
7	Specific Gravity	1	3.15	2.65	2.65	
8	Absolute concrete volume per 50 kg cement bag, m^3	=C6*50/1000/C7	=D6*50/1000/D7	=E6*50/1000/E7	=F6*50/1000/F7	=SUM (C8:F8)
9	Absolute concrete weight for 0.262 m^3 volume	=D9*C6	=0.262/G8*50	=D9*E6	=D9*F6	=SUM (C9:F9)

Table 4. *Simulation of absolute volume and absolute weight of concrete per batch in relationship to Table 3.*

	B	C	D	E	F	G
3	Label	Water	Cement	Fine Aggregate	Coarse Aggregate	Sum
4	Assumed Ratio	0.500	1.000	1.375	2.821	
5	Bulk Density	1000.000	1100.000	1600.000	1560.000	
6	Applied Ratio by Weight	0.500	1.000	2.000	4.001	
7	Specific Gravity	1.000	3.150	2.650	2.650	
8	Absolute concrete volume per 50 kg cement bag, m^3	0.025	0.016	0.038	0.075	0.154
9	Absolute concrete weight for 0.262 m^3 volume	42.507	85.013	170.026	340. 052	637.598

2.2. Materials Batching and Concrete Specimens Production

Batching of the mixture started through measuring and pouring concrete constituents into the rotating mixer as proportioned in Table 5. The rotating mixer was charged with 10% of the required water followed by 50% of the coarse aggregate, then 100% of the fine aggregate and followed by 100% cement and then the remaining 50% of the coarse aggregate. 80% of water required was added to the rotating mixer and with a minimum total time of mixing time of 4 minutes before the mixture was let out from the rotating mixer. 10% of the water remaining was later pour into the rotating mixer and allowed to rotate for 30 seconds and the water together with the remaining constituent were poured out directly on top of the concrete mixture already on the platform.

Thorough hand mixing was done for uniform concrete colour and there after it paved way for placing of the concrete finally into the required moulds to produce specific specimens. The moulds for concrete casting were duly primed with grease as a lubricator for easy removal of the concrete specimens. Thereafter, concrete were placed in primed moulds to produce specimens based on standard specified layers and compaction to produce 18 numbers of 150 mm x 150 mm x 550 mm beams, 6 numbers of 150 mm x 150 mm x 150 mm cubes and 6 numbers of cylinders of 150 mm diameter with 300 mm height.

Demoulding of the specimens was carried out about 24 hours of casting and then cured. Curing of the specimens was done by placing them into clean water inside a tank having the average temperature of $23\pm1.7°C$ till the day of testing. The remaining 8 sets of specimens based on their concrete constituents were carried out similarly for batching, mixing, handling of the fresh concrete for making samples and curing but not on the same day because of the availability of specimen moulds and space inside the laboratory.

Table 5. *Absolute weight of concrete constituents per batch.*

Water Cement Ratio	Ingredients	19 mm Granite Weight, Kg	12.5 mm Granite Weight, Kg	Washed Gravel Weight, Kg
0.5	Water	42.507	43.095	42.440
	Cement	85.013	86.190	84.880
	Fine Aggregate	170.027	172.381	169.760
	Coarse Aggregate	340.112	344.785	339.515
0.55	Water	46.635	46.638	46.015
	Cement	84.791	84.796	83.664
	Fine Aggregate	169.583	169.591	167.328
	Coarse Aggregate	339.224	339.205	334.649
0.6	Water	50.065	50.067	49.409
	Cement	83.441	83.445	82.349
	Fine Aggregate	166.882	166.891	164.698
	Coarse Aggregate	333.822	333.804	329.390

2.3. The Slump and the Compacting Factor Tests

The slump and the compacting factor tests were carried out 10 minutes of finishing concrete mixture. The slump test was carried out in accordance to AASHTO T 119 [14]. Sump test is useful for defining high and medium workability together with the consistency of the fresh concrete. The compacting factor test was also carried out according to BS 1881 [15]. The compacting factor test is useful for medium and low workability of fresh concrete along with its compact ability. The compacting factor value was calculated by dividing the partially compacted concrete weight by that of the fully compacted concrete of which the value is always less than 1. It is pertinent to note that the higher the value of the compacting factor the more workable is the mix and the lesser the hardened concrete strength. The compacting factor test is useful for defining low workability of the fresh concrete mixture.

2.4. Compression Strength Test

Figure 1. *Compression strength test machine.*

The 150 mm x 150 mm x 150 mm concrete cubes were tested at 7 and 28 days after being removed from the clear water curing tank and dried for few hours in accordance to BS EN 12390-3 [16]. The cubes are tested using a calibrated compression machine inside the laboratory as in Figure 1 under the care of competent personnel. Each cube tested has the face perpendicular to the casting face and the machine exerts a constant compressive progressing force on the cube till it fails at a loading rate of 0.6 ± 0.2 $N/mm^2/s$. The maximum compressive strength of the concrete is based upon the reading at failure.

2.5. Flexural Strength Test

A third point loading with effective span l of 450 mm was achieved on the simply supported specimen as shown in Figure 2 to pave way for flexural strength test according to ASTM C 78 [17].

Figure 2. *Flexural strength test machine.*

The load was applied continuously and without shock at a rate of 200 m/s and the flexural strength, R or modulus of rupture was then calculated using the following formula.

$$R = \frac{PL}{bd^2} \tag{2}$$

P = maximum load, N
L = span length, m
b = specimen width, mm
d = specimen depth, mm

2.6. Tensile Splitting Strength Test

Each hardened concrete cylinder specimen of 150 mm diameter by 300 mm high was subjected to a compressive load for testing at a constant rate of 400 N/s along the vertical diameter until failure occurred in accordance to ASTM C 496 [18] as shown in Figure 3.

Figure 3. *Tensile splitting strength test.*

Calculating the splitting tensile strength of the hardened specimen tested is as follows:

$$T = \frac{2P}{\pi l d} \quad (3)$$

Where:

T = splitting tensile strength, MPa

P = maximum applied load indicated by the testing machine, N

l = length, m

d = diameter, m

3. Results and Discussions

The results upon the tests carried out on cement, fine aggregate, coarse aggregates, fresh concrete and hardened concrete are presented in this section. Comparisons are discussed regarding the standard specification of the cement requirements, the three types of coarse aggregates used for concrete production individually, tests upon fresh and hardened concrete produced.

3.1. Properties of the Employed 42.5R Cement

Table 6. *Compositions of a Nigerian produced 42.5R cement.*

Parameters		Type 42.5R	Specification Requirements	Remarks
Chemical Composition %	SiO_2	19.160	18.7-22.0	Complied
	Al_2O_3	4.920	4.7-6.3	Complied
	Fe_2O_3	0.750	1.6-4.4	Not complied
	CaO	64.250	60.6-66.3	Complied
	MgO	2.170	0.7-4.2	Complied
	SO_3	1.020	1.8-4.6	Not complied
	Na_2O	0.400	0.11-1.20	Complied
	K_2O	0.350	0.11-1.20	Complied
	$Ca(OH)_2$	0.410	-	Complied
	BaO	-	-	Complied
	PbO	-	-	Complied
	MnO	-	-	Complied
	Moisture	-	-	Complied
	Fibre	-	-	Complied
Potential Compound Composition %	C_3S	78.83	40-63	Not complied
	C_2S	4.45	9-31	Not complied
	C_3A	11.77	6-14	Complied
	C_4AF	2.28	5-13	Not complied

The results of this research upon chemical and potential compound compositions while using 42.5R cement in the concrete production are presented in Table 6. CaO and SiO_2 that represent more than 80% of chemical composition satisfied the standard specification requirements. Although C_3S is of higher percent than the specification requirements for compound composition potential, it is worthy of note that it is an advantage for higher early strength for the Portland cement concrete produced. Other required cement quality parameters such as initial setting time, final setting time, fineness, specific gravity, bulk density, insoluble residue and loss of ignition do complied with the standard specification requirements as shown in Table 7.

Table 7. *Other parameters of a Nigerian produced cement.*

Parameters	Type 42.5R	Specification Requirements	Remarks
Initial Setting Time, minutes	113	45 minimum	Complied
Final Setting Time, minutes	212	375 maximum	Complied
Fineness, Residue %	21.76	10 maximum	Not complied
Specific Gravity γ_G	3.15	3.15	Complied
Bulk Density, γ_b kg/m^3	1100	1000-1300	Complied
Insoluble Residue, IR	99.560	99.95-99.97	Not complied
Loss of Ignition, LOI	0.005	0.04-0.05	Complied

3.2. Properties of the Aggregates N/mm^2

Figure 4 is showing the particle size distribution of fine aggregate used within the total range of sizes as well graded for it is exhibiting a line of constant slope. The fineness modulus of the fine aggregate used in this study is 2.70 of which it could be graded as medium sand for having the size between fine and coarser material based upon the specification limits value of 2.3 to 3.1 in conformity with ASTM specification. The coefficient of uniformity C_U and the coefficient of curvature C_C of the sand are 2.67 and 1.04 respectively of which the material is a clean and poorly graded sand SP. The bulk density of the sand used for the concrete is 1600 kg/m^3 while its specific gravity value is 2.65.

The fineness modulus of 19 mm granite, 12.5 mm granite and washed gravel are 7.38, 6.31 and 6.9 respectively. The coefficient of uniformity C_U and the coefficient of curvature C_C of the 19 mm granite are 2 and 1.13 respectively as shown in Figure 5. Also, the coefficient of uniformity C_U and the coefficient of curvature C_C of the 12.5 mm granite are 2.94 and 1.76 respectively. Similarly, the coefficient of uniformity C_U and the coefficient of curvature C_C of the washed gravel are 2.90 and 1.06 respectively. It is obvious from the results of the 19 mm and 12.5 mm together with the washed gravel are poorly graded and clean materials. The bulk densities of 19 mm, 12.5 mm granites and washed gravel are 1560 kg/m^3, 1580 kg/m^3 and 1620 kg/m^3 respectively. The specific gravity values obtained for 19 mm, 12.5 mm granites and washed gravel are 2.65, 2.65 and 2.6 respectively. The results of the 19 mm, 12.5 mm granites and washed gravel show that they are normal aggregates for the bulk densities lie between 2400 to 2700 kg/m^3 and specific gravities lie between 2.01 to 3.

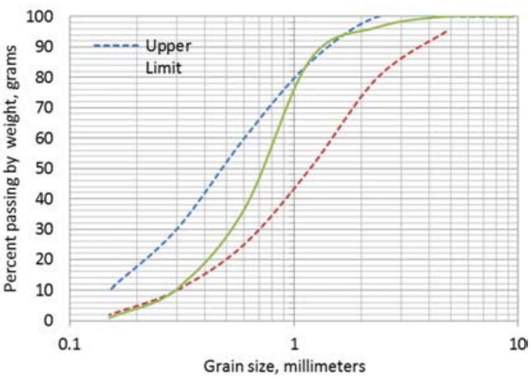

Figure 4. *The fine aggregate grain size distribution curve.*

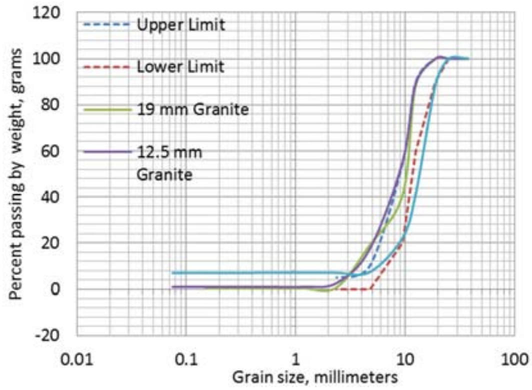

Figure 5. *The coarse aggregate grain size distribution curves.*

3.3. Properties of the Fresh Concrete Produced

Based upon the values obtained from slump tests and compacting factor tests as shown in Table 8, it is obvious that slump test results contradicted the compacting factor test results. This is because where the compacting factor test gave the results to be plastic state and of medium degree of workability (0.88-0.91), slump test claimed it to be of stiff state with very low degree of workability (0-22) while considering using water cement ratio of 0.50. Obviously relying upon slump test result values according to this study has shown that it could lead to collapse of structures.

Table 8. *Fresh concrete slump and compacting factor values obtained.*

Water Cement Ratio	**Slump Values, mm**		
	19 mm	**12.5 mm**	**Gravel**
0.50	0	21	22
0.55	10	23	24
0.60	15	22	20
Water Cement Ratio	Compacting Factor Values		
	19 mm	12.5 mm	Gravel
0.50	0.88	0.89	0.91
0.55	0.91	0.93	0.88
0.60	0.98	0.99	0.95

3.4. Properties of the Cast Hardened Concrete Specimens

Beams, cubes and cylinders are the specimens produced were used to determine flexural, compressive and tensile strengths and the results are respectively presented in Tables 9-13.

3.5. Flexural, Compressive and Tensile Strengths of the Concrete Specimens

Flexural strength of concrete beam specimen results while using 0.5, 0.55 and 0.6 water cement ratios individually for coarse aggregates of 19 mm, 12.5 mm and washed gravel with same type of fine sand are in Tables 7-9. It could be seen that at 28 days of water curing only concrete produced using 19 mm granite with water cement ratio 0.5 and 0.55 mm satisfied flexural and compressive strength standard specification requirements in a highway concrete construction work. However, flexural strength values of 4.92 N/mm^2 and N/mm^2 respectively marginally satisfied the standard specified value of 4.5 N/mm^2. Similarly, compressive strength values of 33.55 N/mm^2 and 32.38 N/mm^2 respectively also slightly satisfied the standard specified value of 30 N/mm^2. Considering tensile splitting test upon values that satisfy flexural and compressive strength, it could be seen that the corresponding values obtained are 2.684 N/mm^2 and 2.590 N/mm^2 respectively. However, based upon the fact that the expected tensile strength value should be about 10% of the corresponding compressive strength which are 3.355 N/mm^2 and 3.238 N/mm^2 is showing that the concrete produced does not satisfy the required standard specification requirement for tensile strength.

Table 9. *Flexural strength of the concrete specimens using 0.5 water cement ratio.*

Label	**19 mm Granite**	**12.5 mm Granite**	**Washed Gravel**
Days	**N/mm^2**	**N/mm^2**	**N/mm^2**
7	4.14	3.24	3.07
14	4.33	3.46	3.41
21	4.63	3.68	3.58
28	4.92	4.10	3.82
56	5.57	4.47	4.03
91	5.59	4.79	4.20

Table 10. *Flexural strength of the concrete Specimens using 0.55 water cement ratio.*

Label	**19 mm Granite**	**12.5 mm Granite**	**Washed Gravel**
Days	**N/mm^2**	**N/mm^2**	**N/mm^2**
7	3.88	3.42	2.93
14	4.10	3.73	3.22
21	4.52	4.27	3.28
28	4.84	4.44	3.61
56	5.45	4.46	3.91
91	5.45	4.72	4.15

Table 11. *Flexural strength of the concrete specimens using 0.6 water cement ratio.*

Label	**19 mm Granite**	**12.5 mm Granite**	**Washed Gravel**
Days	**N/mm^2**	**N/mm^2**	**N/mm^2**
7	3.01	3.06	2.86
14	3.16	3.14	2.94
21	4.18	3.70	3.19
28	4.24	3.99	3.35
56	4.93	4.11	3.80
91	5.04	4.62	3.98

Table 12. *Compressive strength of the concrete specimens using different water cement ratios.*

0.50 w/c	**19 mm Granite**	**12.5 mm Granite**	**Washed Gravel**
Days	**N/mm^2**	**N/mm^2**	**N/mm^2**
7	23.76	16.23	13.01
28	33.55	27.29	20.22
0.55 w/c	19 mm Granite	12.5 mm Granite	Washed Gravel
Days	N/mm^2	N/mm^2	N/mm^2
7	20.89	14.53	11.89
28	32.38	23.27	18.02
0.6 w/c	19 mm Granite	12.5 mm Granite	Washed Gravel
Days	N/mm^2	N/mm^2	N/mm^2
7	12.57	12.99	11.32
28	24.88	21.99	15.57

Table 13. *Tensile strength of the concrete specimens using different water cement ratios.*

0.50 w/c	**19 mm Granite**	**12.5 mm Granite**	**Washed Gravel**
Days	**N/mm^2**	**N/mm^2**	**N/mm^2**
7	1.901	1.162	1.041
28	2.684	1.862	1.618
0.55 w/c	19 mm Granite	12.5 mm Granite	Washed Gravel
Days	N/mm^2	N/mm^2	N/mm^2
7	1.671	1.298	0.951
28	2.590	2.183	1.442
0.6 w/c	19 mm Granite	12.5 mm Granite	Washed Gravel
Days	N/mm^2	N/mm^2	N/mm^2
7	1.006	1.039	0.906
28	1.990	1.759	1.246

4. Conclusions and Recommendations

Specimens of concrete for testing flexural, compressive and tensile strengths were developed using clean and clear water, a Nigerian produced 42.5R Portland cement, one type of river sand and three types of coarse aggregates separately. In the course of the concrete production process, water cement ratio of 0.5, 0.55 and 0.6 were used separately.

4.1. Conclusions

The following are the conclusions proffered based upon laboratory experiments in this study.

a. The 42.5R Portland cement produced Nigeria compared satisfactorily at very good level with ASTM, AASHTO and British relevant standard specification requirements upon its chemical and potential compound compositions. Parameters of the Portland cement such as initial and final setting times, fineness, specific gravity, bulk density, insoluble residue and loss of ignition also compared favourably well with the relevant specification standards.
b. The river sand used as fine aggregate is a clean and poorly graded material SP according to standard and is satisfactorily good in the production of concrete for construction. Also, the 19 mm and 12.5 mm granites together with the washed gravel used are poorly graded clean coarse aggregate materials according to related

standards and are useful all useful materials in concrete production for highway structures.

c. Compacting factor test is more suitable for the measurement of workability requirements of the concrete produced in this study than slump test. This is because the fresh concrete described as plastic state with medium degree of workability by compacting factor test is described as stiff state with very low degree of workability by slump test.
d. Only concrete produced using 19 mm granites at 0.5 and 0.55 water cement ratio individually slightly satisfied required strength of at 28 days curing for flexural and compressive strengths. However, tensile strength at same concrete has values of 2.684 N/mm^2 and 2.590 N/mm^2 respectively which is not satisfying the expected 10% of the corresponding compressive strength which are to be values of 3.355 N/mm^2 and 3.238 N/mm^2.

4.2. Recommendations

The following are the recommendations proffered based upon laboratory experiments in this study.

a. Table 2 is a useful paradigm of using expressions for the computations of the absolute volume and weight of a batch for concrete production. While the absolute volume methodology is useful at the construction site the weight approach is useful in the laboratory.
b. Table 3 is a useful modelling module that forms a template through the use of Microsoft Excel spreadsheet for actualization of the volume and weight values of a batch for concrete production.
c. Water, 42.5R Portland cement, fine and coarse aggregates used are useful material for the production of concrete but the use of 1:2:4 and water cement ratios 0.5, 0.55 and 0.6 should be discouraged while producing sustainable rigid pavement. This will surely prevent premature failure of public and private highway pavements.

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