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Optimized Aggregates Gradations for Concrete Mix Designs for Resilient Building Construction

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Abstract

Building collapse is a common phenomenon all over the world. However, its dire consequences of loss of live and properties makes such incidences a worrisome situation. Choice of aggregate sizes, concrete mix ratio and cement types are some of the factors associated with cases of this menace. Consequently, this study considers these factors with a view to providing an optimized concrete-mix-design for different types of cement brands available in Yewa South Local Government area of Ogun State. Sieve analysis was carried out on the various sizes of granite (9.5mm, 12.5mm, 19mm and 25mm), appropriate combination ratio of the various granite sizes were determined and used in casting concrete cubes which were subjected to compressive strength tests. Optimal concrete strength for each aggregate size and combination of sizes were determined at 7days, 14days, 21days and 28days for each cement brand. Results reveals that the combination of granite of various sizes of 19mm, 12.5mm and 9.5mm in the ratio 1:0.5:0.32 for Dangote cement of grade 42.5N has the highest compressive strength of 36.64N/mm^2. While that of Larfage is 26.60N/mm^2 and that Purechem cement is 25.29N/mm^2.

1.0 INTRODUCTION

Merriam-webster Resilient building can be defined as its capability to withstand shock without permanent deformation or rupture, Dong, Andrew and Jonathan (2015), defined resilience as an objective of design, maintenance and restoration for buildings and infrastructure, the ability of building or infrastructure to absorb or avoid damage without suffering complete failure, noting that it is a central concept for assessing environment adaptations. While Jennings, Vugrin and Belasich (2013) stated that Infrastructure resilience has become a primary objective for homeland and national security organizations over the past decade. According to the Resilient Design Institute, resilient design is defined as “the intentional design of buildings, in response to vulnerabilities to disaster and disruption of normal life. Resilience is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance. It is the capacity to bounce back after a disturbance or interruption.

It is however lamentable that building collapse and the failure of other concrete structures is a common occurrence in Nigeria. Building collapse is a problem that has hitherto being of great concern to both professionals in the construction industry, the government and even the citizenry in Nigeria. The use of poor quality materials the poor, application and use of inferior materials, especially cement and concrete have been cited as one of the major causes for the spate of building collapse in Nigeria (Omopariola 2014, Mattawal, 2012), Concrete is one of the essential component materials in building construction and the use of poor quality concrete have been responsible for this undesirable occurrence. Concrete is a composite material for construction consisting of aggregates (both soft and coarse) and cement mixed with water. There are different sizes of aggregates as well different grades of cement.

Optimized gradation simply means combining available aggregates in the proper proportions so that void space is minimized (ACPA).According to Afeni (2016, the design of Portland cement concrete is influenced by the voids between the particles. Neville (2011) posited that while there is no ideal grading, it may be desirable or required to proportion the available materials in such a way that the grading of the combined aggregate is similar to a specific curve or lies between given limits. In www.commandalkonconnect.com, it was stated that for a given set of material, there is an optimum combination of materials that will result in the best concrete performance based on a single characteristics. An optimum size of aggregate gives a workable and dense concrete mix and improves the performance of concrete while the increase in fracture toughness with increasing aggregate size results in the increased resistance to propagating crack.

According to Omopariola (2018), personal on-site experience with some granite used for construction work reveals that they do not conform to the percentage passing the appropriate sieve sizes and grading limits specified in relevant codes and standards. Also In the year 2014, there were controversies surrounding the use of grade 32.5 cement. There were insinuations that its use which constitutes about 50% of cement usage in the country was responsible for the collapse of buildings in Nigeria.

2.0 MATERIALS AND METHOD

2.1 Materials: The materials used in the study consists of Ordinary Portland cement, fine aggregate, coarse aggregate, and water. Details of the materials properties and the tests performed are described below

2.1.1 Cement: Three different brands of ordinary Portland cement were used in the production of the concrete for this research work. The different cement brands are Dangote Cement produced by Dangote cement Plc, Ibese, Purechem cement produced by Purechem cement Plc, Onigbedu and Larfage Cement produced by Larfage Cement Plc, Ewekoro . While Dangote Cement is grade 42.5N/mm^2, pure chem and Larfage cements are both of grade 32.5N/mm^2. All the cement brands conformed to the requirement of BS 12:1996

2.1.2 Fine aggregate: The fine aggregate used for this research was well graded sharp sand which passes through 4.75 mm and retained on 2.36 mm sieve. It was free from silt, impurities and organic matter and conforms to the requirement of BS 882:.1992

2.1.3 Coarse aggregate: The coarse aggregate used was a combination of four different single size aggregates (granite) of sizes 25mm, 19 mm, 12.5mm and 9.5mm obtained at Omoologede Quarry, in Abeokuta.

2.1.5 Water: The water used was a potable pipe borne water, free from oil.

2.2 Methods

2.2.1. Test on Properties of Materials

2.2.1.1. Sieve Analysis of Fine and Coarse Aggregate

Sieve Analysis of both the fine and coarse aggregates were carried out in accordance with the specifications in BS 812: 1985.

2.2.1.2. Test on Properties of Cement

The following tests were carried out on the three different cement brands to determine their properties:

(i) Specific gravity test in accordance with BS in accordance with BS EN 196 – 3 - 2005

(ii) Normal consistency tests in accordance with BS EN 196 – 3 - 2005

(iii) Initial and final setting time in accordance with BS EN 196 – 3 - 2005

(iv) Soundness test in accordance with BS EN 196 – 3 - 2005

2.2.2 Determination of Combination Ratio for the Combined Aggregates

The combination ratio for coarse aggregate fractions to give maximum density and minimum voids was determined using equation 1 obtained from Neville and Brooks, (2010). It was further stated that the combination obtained from equation 1 gives a parabolic curve for the percentage of materials passing a sieve size that represents an ideal grading.

$$P = \frac{(d^x - 3.76^x)}{(D^x - 3.7^x)} x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where P the cumulative percentage passing for the d - sieve sizes, d sieve size in millimeters, D nominal maximum size of aggregate in millimeters and x 0.8 for crushed aggregates and 0.5 for rounded aggregates.

The various percentages for each fraction is presented in Table 1. The results obtained for each sieve size in equation (1) was equated to the value of the percentage passing the sieve size for the samples collected from the various quarry sites to obtain the ratio of aggregates that conform to BS 812:1992,. The results thus obtained are presented in Tables 2.

2.2.3. Mix design

There are different methods of mix design, but the DOE mix design method was used for the proportioning of the various constituent materials for concrete for producing cubes to be tested for in this research work. The method involves specification of mix parameters such as target mean strength, water-cement ratio and concrete density. The characteristic strength considered in this study was 25N/mm^2 commonly specified for building constructions, while a water-cement ratio of 0.5 was adopted

2.3.4. Testing the Concrete

Tests on fresh concrete and the preparation of specimens for tests on hardened concrete was carried out immediately after the completion of the mixing process in accordance with BS 1881 (1983). The required operations were carried out during a period of not more than thirty minutes from the time of the addition of water to the cement. Tests carried out on wet concrete includes: Slump Test in accordance with BS EN 12350-2:2000, Compaction Factor Test in accordance with BS1881:103:1983 while that of hardened concrete include: Compressive strength in accordance with BS1881:116:1983. The concrete cubes were cast in accordance with BS EN 12390-2:2009.

3.0 Results and Discussion

3.1 Grading Test and Determination of Combination Ratio of Coarse Aggregates

Table 1: Ideal Combined grading for coarse aggregates of nominal maximum sizes of 25mm, 19.5mm, 12.5mm and 9.5mm

Sieve Sizes (mm)	Cumulative percentages passing for nominal maximum size of 25mm, 19.5mm, 12.5mm and 9.5mm			
	37.5 – 25mm	25 – 19mm	19 – 12.5mm	12.5 – 9.5mm
37.5	100	_	_	_
31	86	_	_	_
25	67	100	_	_
19	50	75	100	
12.5	30	49	61	100
9.5	21	31	41	68
6.3	10	14	19	32
4.75	3	6	8	13

Table 2: Cumulative Percentage Passing for the Various Sizes of Aggregates

Sieve	Sieve	% Cumulative passing

size(inch)	size(mm)	38.1 - 25mm	25 - 19mm	19 – 12.5mm	12.5 – 9.5mm
1½	38.1	100	_	_	_
1¼	31.8	96	_	_	_
1	25.4	55	100	_	_
¾	19.0	6	58	100	_
½	12.5	0	8	99	100
⅜	9.5	0	0	30	99
¼	6.3	0	0	18	40
3/16	4.76	0	0	6	5
No7	2.36	0	0	0	0

From the result of the grading test conducted, it was in line with the findings of Omopariola (2018) that single size granites do not conform to the percentage passing the appropriate sieve sizes and grading limits specified in relevant codes and standards. Therefore the single size granites were combined in line with the procedure spelt out in Neville and Brooks 2010 and using TechCalc software. The combination ratio for 25mm, 19mm, 12.5mm and 9.5mm aggregates are: 1.0 : 0.95 : 0.52 0.21; while the combination ratio for 19mm, 12.5mm and 9.5mm are 1.0 : 0.5 : 0.32 and that of 12.5mm and 9.5mm are 1: 0.19 respectively.

3.2 Mix Design Parameters

Table 3: Mix Design Parameters for all granite samples and for all brands/grades of cement

Stage items	9.5mm Single Size Aggregates	12.5mm Single Size Aggregates	12.5mm Combined Aggregates	19mm Single Size Aggregates	19mm Combined Aggregates	25mm Single Size Aggregates	25mm Combined Aggregates
Characteristic Strength (N/mm^2)	25	25	25	25	25	25	25
Standard Deviation	5	5	5	5	5	5	5
Margin 1.64 x ∂ (N/mm^2)	8	8	8	8	8	8	8
Target mean	33	33	33	33	33	33	33

strength							
Water – Cement ratio	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Slump Value (mm)	30 – 60	30 – 60	30 – 60	30 – 60	30 – 60	30 – 60	30 – 60
Free Water Content	188	183.6	183.6	170	170	151.7	151.7
Cement Content (kg/m)	377	367	367	340	340	303	303
Relative Density of Coarse Aggregates (SSD State)	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Concrete Density	2450	2460	2460	2470	2470	2490	2490
Total Aggregate Content	1855	1909	1909	1960	1960	2035	2035
Grading of Fine Aggregate (Percentage passing 600µm Sieve %)	23	23	23	23	23	23	23
Proportion of Fine Aggregate	57	56	56	47	47	39	39
Fine Aggregate Content	1074	1067	1067	921	921	794	794
Coarse Aggregate Content	811	842	842	1039	1039	1241	1241

3.3 Result of tests of Properties of Cement

Table 4: Results of tests of Properties of Cement

Cement Brand/Grade	Specific Gravity	Normal Consistency	Initial Setting Time	Final Setting Time

		(%)	(Minutes)	(Hours)
Dangote (42.5N/mm^2)	3.02	26	75	4.5
Lafarge (32.5N/mm^2)	3.01	25	90	5.25
Purechem (32.5N/mm^2)	2.92	25	135	6.75

The results of Specific gravity tests obtained for both Dangote and Larfage are very close to the range of values of within 3.026 and 3.138 obtained by Burtler, (2015) but that of Purechem cement is a little bit at variance. The normal consistency of all the brands /grades of cement as seen in Table 4 falls within the range of 26% and 33% stated in Neville and Brooks (2011). The initial setting time for Dangote cement of 74minutes is greater than the required time of 60minutes for grade 42.5 cement, while the final setting time was 4hours 30minutes is lesser than the specified 10hours as specified in . The initial setting times for Larfage cement (grade 32.5) was 90minutes and for Purechem cement (grade 32.5) was 135minutes. All these values are greater than the 75 minutes specified for grade 32.5 cements. Also the final setting times of 5hours 15 minutes and 6hours 45minutes for Larfage and Purechem cements respectively are lesser than the specified 10hours. All the three cement samples tested positive for the soundness test as none of them exhibits any significant expansion after boiling the moulded samples for about 3½ hours.

3.4 Result of tests of Workability Test of Wet Concrete

Table 5: Results of Slump Tests of Wet Concrete for all sizes of aggregates for All Brands of Cement

Aggregate size	9.5mm Single Size	12.5mm Single Size	19.5mm Single Size	25mm Single Size	12.5mm combined	19.5mm combined	25mm combined
Dangote (42.5N/mm^2)	30	30	45	35	30	45	50
Lafarge (32.5N/mm^2)	35	30	50	45	55	40	50
Purechem 32.5N/mm^2)	75	45	45	50	50	50	50

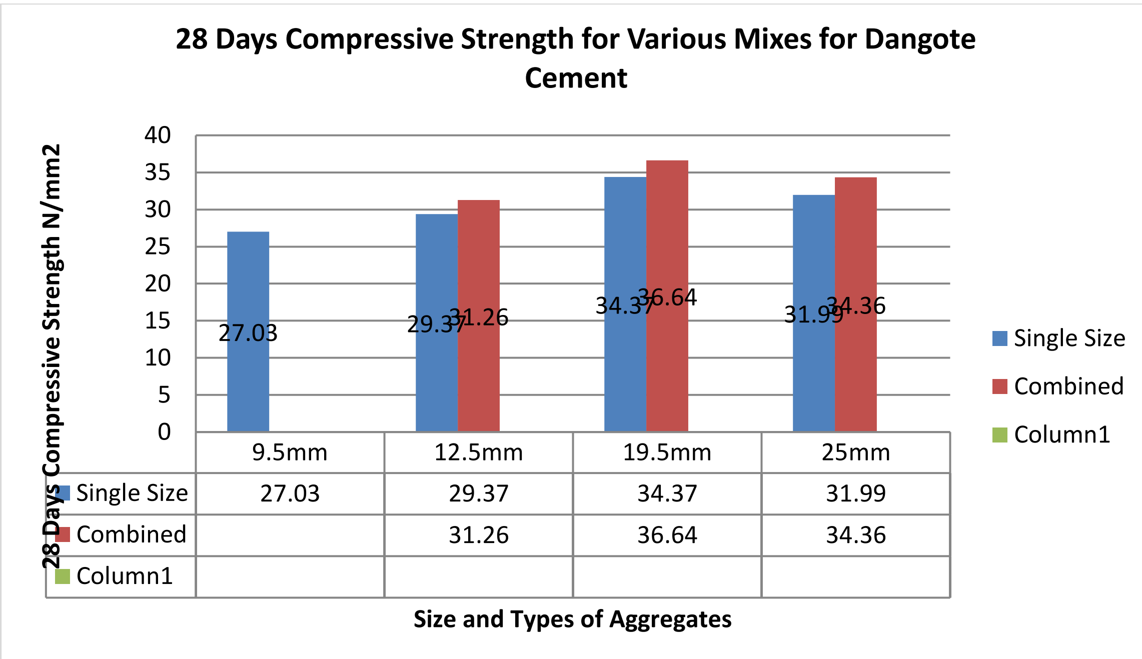
From tables 5 it can be seen that the result of the slump tests for all the various sizes and grades of cement falls within the range of the designed value of 30 – 60mm except that of 9.5mm aggregates for Purechem which is slightly above the designed value of 30 – 60mm. All the slump values for all mix proportions are within the range stipulated in the above literatures and code of standard. This implies that all the mix proportions have acceptable workability and as such there is the assurance of obtaining a quality concrete.

Table 6: Results of Tests of Compaction Factor of Wet Concrete for all sizes of aggregates for All Brands of Cement

Aggregate size	9.5mm Single Size	12.5mm Single Size	19.5mm Single Size	25mm Single Size	12.5mm combined	19.5mm combined	25mm combined
Dangote (42.5N/mm^2)	30	30	45	35	30	45	50
Lafarge (32.5N/mm^2)	35	30	50	45	55	40	50
Purechem 32.5N/mm^2)	75	45	45	50	50	50	50

According to Neville and Brooks, (2010), compaction factor of 0.78 is considered as very low, 0.85 as low, 0.92 is medium while 0.95 is considered as high. The value of the compaction factor for all mix proportions for all brands/grade of concrete are in the range of 92% or 0.92 implying a medium value. That means that the results obtained are okay for all mix proportions for all brands/grade of concrete are in the range of 92% or 0.92

3.5 Result of Compressive Strength Test of Hardened Concrete



	9.5mm	12.5mm	19.5mm	25mm
Single Size	27.03	29.37	34.37	31.99
Combined		31.26	36.64	34.36
Column1				

Figure 1: 28 Days Compressive Strength for Various Mixes for Dangote Cement

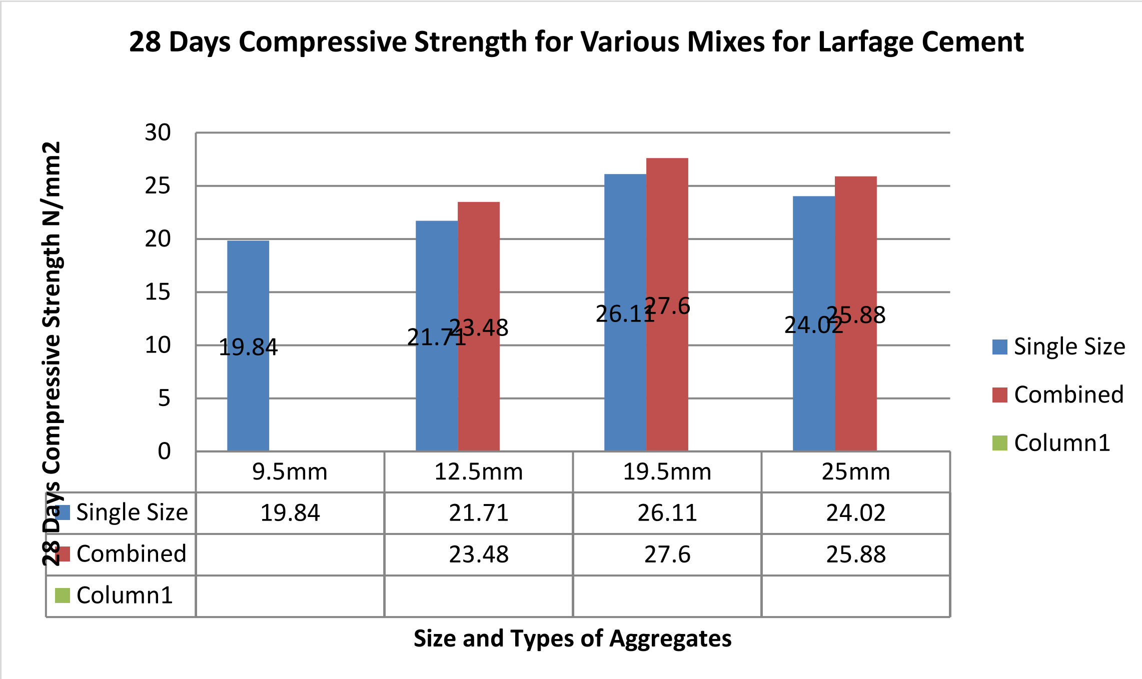


Figure 2: 28 Days Compressive Strength for Various Mixes for Larfage Cement

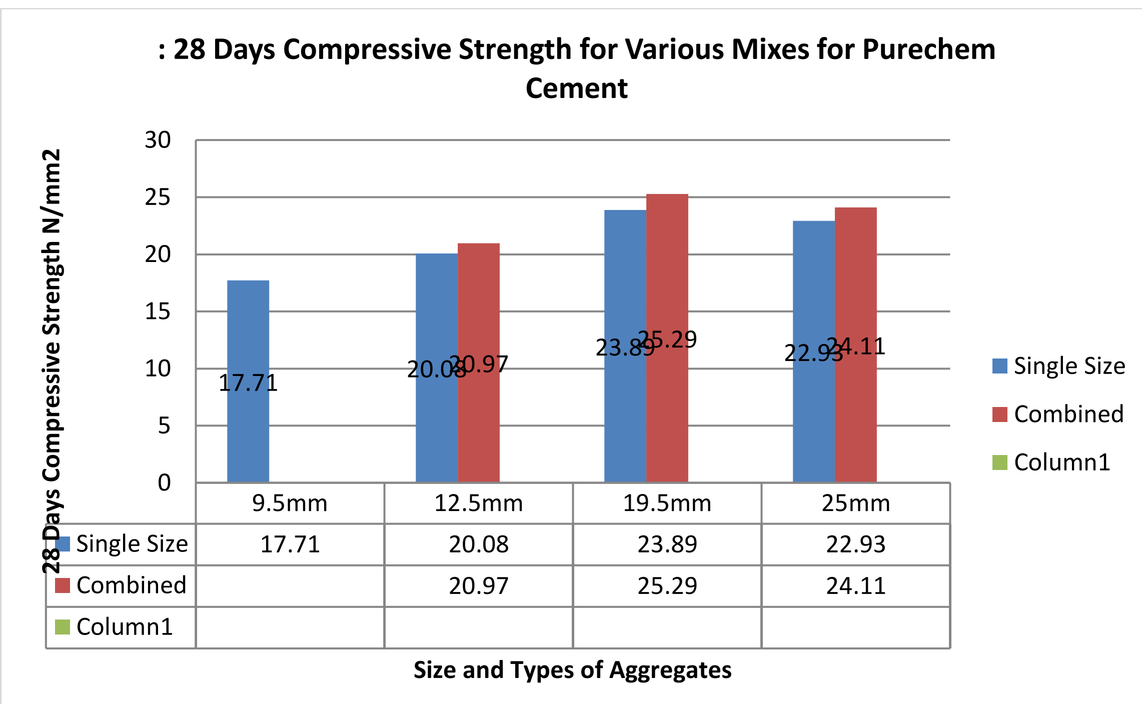


Figure 3: 28 Days Compressive Strength for Various Mixes for Purechem Cement

From figures 1 – 3, it can be observed that there was increase in strength when the granite samples were combined with that of lower sizes consistently for all the brands/grades of cement. Also for all the brands/grades of cement, the combination of 19mm, 12.5mm and 9.5mm has the optimum compressive strength of 26.29N/mm^2, 27.6N/mm^2 and 36.64N/mm^2 for Purechem, Lafarge and Dangote cement respectively. However, Dangote cement of grade 42.5N/mm^2 has the highest strength for all the single sizes and combined sizes, this is followed by Lafarge of grade 32.5N/mm^2, while Purechem also of grade 32.5N/mm^2 has the least compressive strength for all the single sizes and combined sizes.

4.0 Conclusion and Recommendations

4.1 **Conclusion:** From the result of this research it is established that the properties of various grades of cement for the research work conforms to necessary requirements in BS EN 197-1:2000. It can also be stated that the present practice of making use of single aggregate sizes in most construction companies does not give an optimum compressive strength and as such, the desired quality and expected performance of concrete is not attained. The workability test (slump test and compaction factor test) of fresh concrete used were in accordance with BS EN 206-1:2000 and BS 1881: 103: 1983. Conclussively the compressive strength of the cubes was higher when the single sized coarse aggregates were combined with lower sizes of aggregates and the coarse aggregate size combination that gives the optimum compressive strength is the combination of 19mm aggregates with lower sizes (12.5mm and 9.5mm).

4.2 **Recommendations:** Based on the findings from the study, it is recommended that Contractors should be mandated to carry out grading test of aggregates along other tests specified by the Engineer and determine the appropriate combination ratio to obtain an optimum compressive strength of concrete.

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