Optimization of Concrete Mix Design Using Combined Aggregates

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ABSTRACT

Result of grading test conducted on some samples of granite collected from some quarry sites in Ogun State was found to fall short of the requirements of BS 882:1990. Based on reviewed literature, the various sizes were combined in an obtained ratio so as to meet the requirements. Compressive strength test was then carried out on concrete cubes containing granites mixed in the combination ratio obtained from the study. The combination 19mm, 12.5mm and 9.5mm in the ratio of gives the highest compressive strength of 36.64N/mm2. This is therefore adjudged to be the optimal mix proportion of granites for producing concrete for building construction.

Keywords: Optimization, Concrete, Mix Design. Combined, Aggregates

iSTEAMS Proceedings Reference Format
Omopariola, S.S. & Jimoh, A.A. (2019): Optimization of Concrete Mix Design Using Combined Aggregates. Proceedings of the 16th iSTEAMS Multidisciplinary Research Nexus Conference, The Federal Polytechnic, Ilaro, Ogun State, Nigeria, 9th – 11th June, 2019. Pp 67-72-. www.isteams.net
- DOI Affix - https://doi.org/ 10.22624/AIMS/iSTEAMS-2019/V16N1P9

1. INTRODUCTION

Concrete has been said to be the most widely used construction material for infrastructures such as building, bridges, concrete roads, highways drainages; runway, sea ports and harbours etc. in Nigeria (Adewole., Olutoge, & Hamzat (2014). According to Mattawal (2013) poor concreting and low mix design as part of the critical factors responsible for the collapse of building in the country. Hitherto, in most construction companies in the country single aggregate sizes are used in mix proportioning for concreting works which does not conform to any grading curve envelope as set out in BS 882:1992. Alexander and Mindess (2010) defined mix proportioning as the process whereby the proportions of the different constituents in a concrete are selected, and the yield of the mix is determined. It was further stated that the yield is the volumetric quantity that can be delivered per batch of concrete and that aggregates play their most important role in governing these proportions to satisfy the requirements for the plastic mix.

Neville (2011) in his own definition stated that it is the process of choosing suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably strength, durability, and a required consistency. He added that the variation in the cost of material arises from the fact that cement is several times dearer than aggregate, so that, in selecting the mix proportions, it is desirable to avoid high cement content. 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. The paper added that while well graded aggregate may not result in the best combination that will produce a mixture that will typically be better than the gap graded aggregate produced in the industry in the 1970's and 1990's, combining aggregate grading is a good thing. Assessment of Compressive Strength of Concrete Based on Combination of Different Sizes of Aggregate" by Ahmed and Rahman 2015 considered combination of two different aggregates sizes. 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

2.0 METHODOLOGY

2.1 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.

The determination of the target mean strength was done using the formulae

fm = fk + Ks. ………………………………………………………………………………………………….(1)

Where fm = target mean strength, fk = characteristic strength = 25N/mm^2, k = constant = 1.64, s = standard deviation = 5. Hence fm = 25 + 1.64 x 5 == 33.2N/mm^2. The free water content was calculated from values obtained from Table in Appendix 1 for Slump values of 30 – 60.

Coarse aggregates used were crushed stones while river sand (uncrushed) was used as fine aggregate. Therefore the free water content was calculated using the formulae

$2/3 \times Wf + 1/3 \times Wc$…;;………………………………………………………………………………….(2)

Where: Wf = Free water content appropriate to type of fine aggregate, Wc = Free water content appropriate to type of coarse aggregate

The cement content was determined using equation 3

Cement content $= \frac{Free\ Water\ Content}{Water - Cement\ Ratio}$………………………………………………………………………..(3)

The total aggregate content was determined by obtaining the density of the fully compacted concrete from Appendix 2. Equation 4 was then used in calculating the value of total aggregate content.

Total Aggregate Content = D – C – W ………………………..……………………………………………… .(4)

Where D = The wet density of concrete (in kg/m^3), C = The cement content (in kg/m^3), W = The free – water content (in kg/m^3)

The fine aggregate content was determined by obtaining the value of the proportion of fines appropriate for the relevant size of aggregate from appendix 3. The proportion of fines was determined based on the proposed workability of the concrete mix, the maximum aggregate size, the grading of the fine aggregate determined by the percentage passing a 600µm sieve and the free water – cement ratio. The fine aggrgate content and coerse aggregate content was determined from equation 5 and 6 below.

Fine Aggrgate Content = Total Aggrgate Content x proportion of fines………………………………...…..(5)

Coarse Aggrgate Content = Total Aggrgate Content - Fine Aggrgate Content…………………………….(6)

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 3.13 below obtained from Neville and Brooks (2010). It was asserted by Neville and Brooks that the combination thus obtained gives a parabolic curve for the percentage of materials passing a sieve size that represents an ideal grading.

$$P = \frac{d^x - 3.76^x}{D^x - 3.76^x} \times 100 \qquad (7)$$

The various percentages for each fraction is presented in Table 1.

Table 1: Cumulative Percentage Passing for the Various Sizes of Aggregates

Sieve size(inch)	**Sieve size(mm)**	**% Cumulative passing**			
		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

The expression from Neville and Brooks (2010) was used in conjunction with matrixes software Techcalc for the calculation to obtain the ratio for each coarse aggregate size combination. The combination ratio thus obtained were 1.0 : 0.95 : 0.52 : 0.21 respectively for 25mm, 19mm, 12.5mm and 9.5mm while 1.0 : 0.5 : 0.32 combination ratio was obtained for 19mm, 12.5mm and 9.5mm aggregate and combination ratio 1 : 0.19 for 12.5mm aggregates.

2.3 Concrete Cube Production

Fresh concrete were scooped into steel cubes moulds of size 150mm x 150mm x 150mm in 3 equal layers of approximate (50mm) and each layer compacted by tamping 25 times using a compacting rod to BS EN 12390-2:2009. The side of the mould was tamp with a hammer to remove trapped air in the concrete and allows compaction of the sample. The concrete was then levelled off using a concrete trowel to give a smooth surface flush with the top of the mould.

The concrete cubes were removed from the moulds between 16 to 24 hours, after which they were transferred into a curing tank for proper hydration. It was ensured that the cubes were fully submerged at all times.

2.4 Compressive Strength Test of Concrete Cubes

The cubes were tested at 7, 14, 21 & 28 days in accordance with BS EN 12390-2: 2009 / BS EN 12390-3:2009. The cubes were removed from the curing tank, dried and grit removed. The cubes were tested using a digital compression machine. The cubes were tested on the face perpendicular to the casting face. The compression machine exerts a constant progressing force on the cubes till they fail, the rate of loading is 0.6 ± 0.2 M/Pas ($N/mm^2/s$). The reading at failure which is the maximum compressive load of the concrete was then recorded. The compressive strength of the cubes were then calculated by using the formulae

3. RESULTS AND DISCUSSION

For the single size aggregates, the value of the 28 days compressive strength for 9.5mm aggregates (27.03 N/mm^2) is the least followed by that of 12 .5mm aggregates (20.37 N/mm^2) and then 25mm aggregates (31.99 N/mm^2). The value for 19.5mm aggregate(34.37 N/mm^2) is the highest. For the combined aggregates, 19.5mm combined aggregate consisting of 19.5mm, 12.5mm and 9.5mm in the combined ratio of 1.0: 0.95: 0.52: 0.21 has the highest 28 days strength of 36.64N/mm^2, While that of 25mm combined consisting of 25mm, 19.5mm, 12.5mm and 9.5mm aggregates in the combined ratio of 1: 0.5: 0.32 has compressive strength of 34.36 N/mm^2 and 12.5mm combined consisting of 12.5mm and 9.5mm aggregates in the combined ratio of 1: 0.19 has the least value of 31.26 N/mm^2. Observation reveals that there was improvement in the compressive strength of concrete when the aggregates were combined with that of lesser size. The compressive strength of 19.5mm combined aggregate consisting of 19.5mm, 12.5mm and 9.5mm in the combined ratio of 1.0: 0.95: 0.52: 0.21 with the highest 28 days strength of 36.64N/mm^2 can thus be said to be the optimal mix proportion of the various sizes of granites tested in this study.

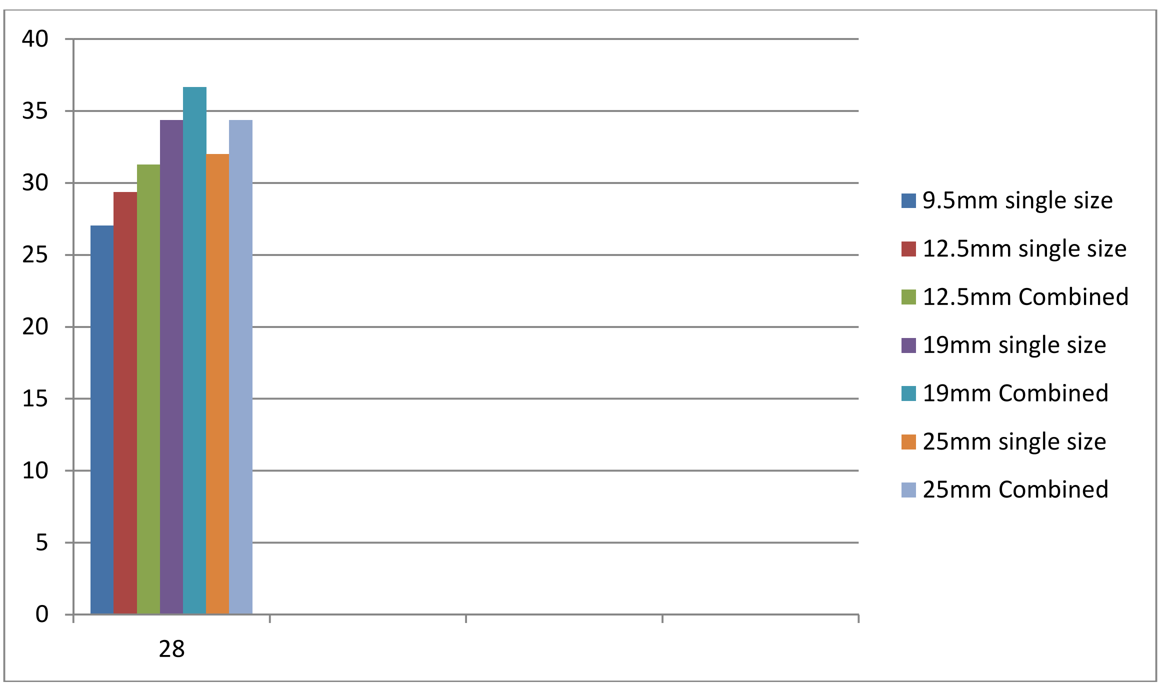

Figure 1: 28 Days Compressive Strength for Various Mixes

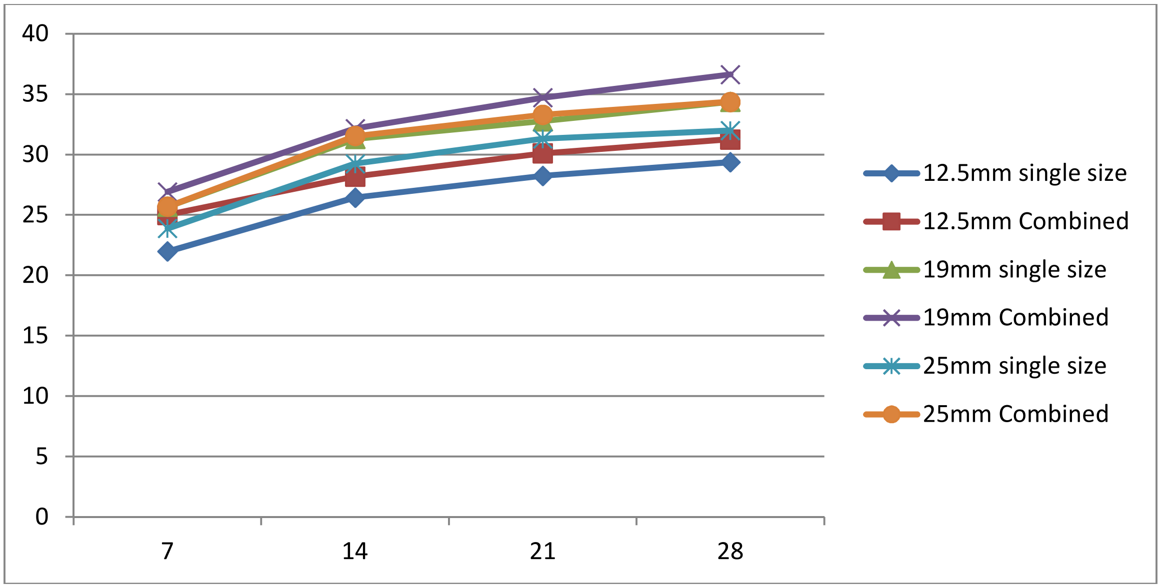

Figure 1: 7Days, 14Days 21Days and 28Days Compressive Strength for Various Mixes

4. CONCLUSION AND RECOMMENDATION

Based on the results obtained from the study, it can be concluded that the combination 19mm, 12.5mm and 9.5mm in the ratio of gives the highest compressive strength of 36.64N/mm2. It is therefore recommended that grading test be carried out on all samples of granites to be used in producing concrete meant for building construction to ensure its conformity to standard. Where it fails to meet the required standard, appropriate combination ratio of various sizes of granites should be determined and used for the purpose

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