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Flexural Strength and Water Absorption of Concrete made from Uniform Size and Graded Coarse Aggregates

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ABSTRACT: *Concrete flexural strength and water absorption play critical role in pavement cracking and deterioration. Loss of flexural strength of concrete is largely responsible for the failure of concrete pavement and other concrete structures. Flexural strength is an input in empirical-mechanistic design of pavement and should be considered while choosing aggregates for concrete production. The use of uniform size aggregates or aggregates containing different sizes in making concrete for rigid pavement and other concrete structures necessitated this research. The study investigated four sets of concrete samples made from aggregates of uniform sizes of 9.5mm, 12.7mm, 19.1mm and samples made from a combination of 9.5mm, 12.7mm and 19.1mm aggregates using the Cement Treated Aggregate gradation procedure. A concrete mix of 1:1.5:3 with a constant water-cement ratio (w/c) of 0.6 was used. Concrete flexural beams were produced, cured and flexural strength test carried out at 14 and 28 days. Water absorption test was also carried on a set of beams at 28 days. The result showed that the concrete made from aggregate sizes of 9.5mm, 12.7mm and 19.1mm recorded average flexural strengths of 2.96N/mm^2, 3.20N/mm^2 and 3.29N/mm^2 at 14 days; and 3.20N/mm^2, 3.35N/mm^2 and 3.40N/mm^2 at 28 days respectively. However, the combined (graded) aggregates recorded the least flexural strength of 2.45N/mm^{2}and 3.12N/mm^2 at 14 and 28 days respectively. Also, concrete made from aggregate sizes of 9.5mm, 12.7mm and 19.1mm recorded average water absorption of 5.5%. 4.95% and 3.4% respectively, while concrete made from the graded aggregates recorded average water absorption of 2.1% at 28 days. It was concluded that that flexural strength of concrete made from uniform size aggregates increases with increase in aggregate size and that aggregates graded using the Cement Treated Aggregate gradation procedure resulted in concrete of lower flexural strength relative to those produced using uniform size aggregates. It was also conclude that concrete made from graded aggregates improved water absorption relative to concrete made from uniform size aggregates.*

Keywords: *Flexural, Strength, Water Absorption, Uniform Aggregates, Graded Aggregates.*

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I. INTRODUCTION

Flexural Strength (Modulus of Rupture) of concrete is the theoretical maximum tensile stress reached in the bottom fibre of a test beam during a flexural strength test [1]. It is one of the important parameters for computing deflection in reinforced concrete structures [2]. Flexural strength is an input in the design of rigid pavements. Maintenance of rigid pavements is more effective if the prevailing conditions and residual strength and or deterioration rate of the strength could be monitored as the pavement is being affected by traffic and weather. Concrete is composed of aggregates (fine and coarse), cement and water with aggregates taking about three-quarter of the concrete volume and the coarse aggregates taking between 50 and 60 percent of the concrete mix depending on the mix proportion. [3]. Many researchers [3, 4, 5, 6, 7] have carried out studies on the strength characteristics of concrete produced using different aggregate materials.

There is much controversy concerning the effects of coarse aggregate size on concrete flexural strength. Kaplan [8] studied the effects of the properties of coarse aggregates on the flexural and compressive strength of high-strength and normal-strength concrete. Walker *et al.* [9] studied the effects of coarse aggregate size on the properties of normal-strength concrete. Their work demonstrates that an increase in aggregate size from 10mm to 64mm results in a decrease in the compressive strength of concrete by as much as 10 percent; however, aggregate size seems to have negligible effects on flexural strength. The study also shows that the flexural-to-compressive strength ratio remains at approximately 12 percent for concrete with compressive strengths between 35 MPa and 46 MPa. Ajamu *et all*[1] studied the effect of coarse aggregate size on the compressive strength and flexural strength of concrete beam and reported that flexural strength of concrete beam is inversely affected by the increase in coarse aggregate size. Also, there exist empirical relationships between flexural strength and compressive strength of plain concrete as presented in Table 1. The result of this empirical relationship indicates that the flexural strength of plain concrete is affected by its compressive strength.

Table 1: Recommended empirical relationships between flexural strength and compressive strength of plain concrete [10].

Code	Country	Relationship
IS: 456-2000	India	$f_r = 0.7\sqrt{f_c}$
ACI	USA	$f_r = 0.62\sqrt{f'_c}$
NZS-3101	New Zealand	$f_r = 0.60\sqrt{f'_c}$
EC-02	Europe	$f_r = 0.201\ f_c$
BS 8110	Britain	$f_r = 0.60\sqrt{f'_c}$

Where, f_r = modulus of rupture (flexural strength) at 28 days in N/mm^2

f_c = cube compressive strength at 28 days in N/mm^2

f'_c = cylinder compressive strength at 28 days in N/mm^2

Studies by Vilane and Sabelo [11] investigated compressive strength of concrete made from 9.5mm, 13.2mm and 19.0mm aggregates. Results indicate that compressive strength of concrete increased with increase in aggregate size. Rozalija and Darwin [12] studied the effect of Aggregate type, size and content on concrete strength and fracture energy. The result indicates that compressive strength of both normal and high strength concrete is little affected by aggregate size.

One of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. For low quality concrete, water enters pores in the cement paste and even in the aggregate and when excess water in concrete evaporates, it leaves voids inside the concrete element. Incomplete compaction and presence of voids in concrete may result in high water absorption leading to concrete of low strength. By proper selection of ingredients and mix proportioning, and following good construction practices almost impervious concrete can be obtained. Several research has been carried out on concrete water absorption but little or no attention has been given to the effect of aggregate size on concrete water absorption.

Aggregates for use as pavement material must meet specifications in terms of gradation [13]. The use of uniform size or graded (combined) aggregates for construction of rigid pavements is a common practice in most developing countries. The correlations between flexural strength and compressive strength of concrete, result of studies on the effect of aggregate size on compressive strength of concrete and the arbitrary use of uniform size and combined aggregates for rigid pavement construction necessitated this study. This study attempts to investigate the flexural strength and water absorption of concrete made from uniform size and graded (combined) coarse aggregates.

II. MATERIALS AND METHODOLOGY

2.1 Materials and Apparatus

The selected materials used in this study are locally available and currently used in making concrete in Nigeria, namely: Ordinary Portland Cement, fine river sand as fine, 9.5mm river sand as coarse aggregate, 12.7mm crushed stone (granite chippings) as coarse aggregate, 19.1mm crushed stone (granite chippings) as coarse aggregate and water. The crushed stone was sourced from a quarry site at Akampka, in Cross Rivers State, Nigeria and in the desired sizes. The equipment that were used in the study were: 150mm x 150mm x 600mm steel moulds, tags sieves, retainers, brush, weighing instrument, trowel, spanners, electric table vibrator, electric concrete mixer, slump test cone, curing tank and Universal Testing Machine (UTM).

2.2 Methodology

2.2.1 Sieve Analysis

The aggregates (fine and coarse) were sieved to various sizes in accordance with BS 812:103 [14].

2.2.2 Experimental Design

The study involved laboratory tests on four concrete beam specimens (150mmx 150mm x 600mm) prepared using aggregate sizes of 9.5mm, 12.7mm, 19.1mm and graded aggregates consisting of a combination of 9.5mm, 12.7mm and 19.1mm coarse aggregates marked "B". There were nine (9) replications for each specimen, six(6) for flexural strength test and the other three(3) for water absorption test using a constant mix ratio. A total of thirty six (36) beam specimens were prepared.

2.2.3 Grading of mixed Aggregates

The combined aggregates were sieved and graded in accordance with the Cement Treated Aggregate Procedure [15, 16]. The aggregate gradation/sieve analysis is as presented in Table 2.

Table 2: Aggregate Gradation/Sieve Analysis

Weight of Sample taken for sieving 1000g					
Sieve No B.S.S	Sieve size (mm)	Weight Retained (gm)	Percent retained (%)	Percent passing (%)	Gradation requirement
1.5in	37.5O	0	0	100	100
$^{3}/_{4}{}^{in}$	19.00	230.0	23.0	77.0	70-100
No. 10	2.00	311.5	31.15	45.85	45-70
No.40	0.425	331.4	33.14	12.71	10-40
No.200	0.075	102.6	10.26	2.45	0-20
Passing 200	-	24.5	12.36	0	-

2.2.4 Concrete Batching and Mixing Proportion

The proportion of fine aggregates, coarse aggregates and cement were estimated by determining the total volume of concrete required to cast nine (9) specimens for flexural strength and water absorption tests, the weight of cement, fine aggregate, coarse aggregate and water required per mix using a mix proportion of 1:1.5:3 and water-cement (w/c) ratio of 0.6. In the case of the graded aggregates, the entire combination of the various sizes was used as the coarse aggregate portion of the entire concrete mix. The fine aggregates, coarse aggregates and cement were thoroughly mixed together with the electric concrete mixer, after which the required water estimated at 0.6 water-cement ratio (w/c) was added. The entire constituents were mixed until an even paste was obtained and tested for slump.

III. CASTING AND TESTING OF SAMPLES

3.1 Casting and Curing

Four concrete specimens were made from the uniform size and graded (combined) aggregates - six (6) flexural test beams and three (3) water absorption test beams were cast for each specimen making a total of thirty six (36) test samples. The beams were cast by filling each mould in small layers and compacting each layer using the electric vibrator before the next layer was poured. They were left in the mould for 24 hours to set at laboratory temperature, after which they were demoulded and transferred into a curing tank that contained clean water.

3.2 Flexural Strength Test

Three (3) 150mm x 150mm x 600mm concrete beams were tested at 14days while the other three (3) were tested at 28 days for flexural strength using the third-point loading procedure. The value of the load at which the test beams failed was recorded and used to calculate the flexural strength at each curing age. The flexural strength was calculated using the formula in equation 1.

$$f_r = \frac{Pl}{bd^2} \quad (1)$$

Where,

f_r = Modulus of rupture in N/mm^2

P = Failure load in N

b = Beam width in mm

d = Beam depth in mm

3.3 Water Absorption Test

The 150mm x 150mm x 600 mm height beams after casting were cured in water for 28days. These specimens were then oven dried for 24 hours at the temperature110°C until the mass became constant and weighed again.

This weight was noted as the dry weight W_1 of the beam. After that the specimen was kept in hot water at 85°c for 3.5 hours. Then this weight was noted as the wet weight W_2 of the beam. The concrete water absorption was calculated using the formula in equation 2.

$$\% \ Water \quad Absorption \quad = \frac{(W_2 - W_1)}{W_2} x\, 100 \qquad (2)$$

Where,

W_1 = Oven dry weight of cylinder in grams

W_2 = Weight after 3.5 hours

IV. RESULTS AND DISCUSSIONS

The results of flexural strength and water absorption test for the uniform size and graded aggregates are as summarized in Table 3:

Aggregate Size (mm)	Flexural Strength N/mm²				Water Absorption (%)
	14 days		28 days		
	Failure Load (N)	Modulus of Rupture f_c	Failure Load (N)	Modulus of Rupture f_c	28 days
9.5	17,100	3.04	19,100	3.40	5.5
	16,800	2.98	18,000	3.20	5.7
	16,100	2.86	16,900	3.00	5.3
	Mean	***2.96***	***Mean***	***3.20***	***5.5***
12.7	15,800	2.80	21,100	3.72	4.95
	18,600	3.30	18,500	3.28	4.80
	19,700	3.50	19,700	3.50	5.10
	Mean	***3.20***	***Mean***	***3.35***	***4.95***
19.1	19,400	3.44	19,900	3.54	3.6
	18,600	3.31	18,700	3.32	3.0
	17,600	3.12	19,100	3.40	3.6
	Mean	***3.29***	***Mean***	***3.40***	***3.4***
GRADED AGGREGATES (B)	13,300	2.37	16,200	2.88	2.1
	14,000	2.48	18,600	3.30	1.9
	14,100	2.50	17,900	3.18	2.3
	Mean	***2.45***	***Mean***	***3.12***	***2.1***

4.1 Flexural Strength

The effect aggregate size on flexural strength of concrete is shown in Figure 1. The result shows that flexural strength of the concrete made from various aggregate sizes increased with age. At 14days, the uniform size aggregates of 9.5mm, 12.7mm, 19.1mm recorded average flexural strengths of 2.96N/mm^2, 3.20N/mm^2 and 3.29N/mm^2 respectively, and 3.2N/mm^2, 3.35N/mm^2 and 3.42N/mm^2 respectively at 28 days. The graded aggregates "B" recorded lower average flexural strength of 2.45N/mm^2 and 3.12N/mm^2 at 14 and 28 days respectively. This result indicates that flexural strength of concrete made from uniform size aggregates increases with increase in aggregate size as against the graded aggregates. One of the causes could be that the graded aggregates contains combination of the other three aggregates sizes at varying percentages hence could not provide adequate strength when compared to the strength provided by the uniform size aggregates.

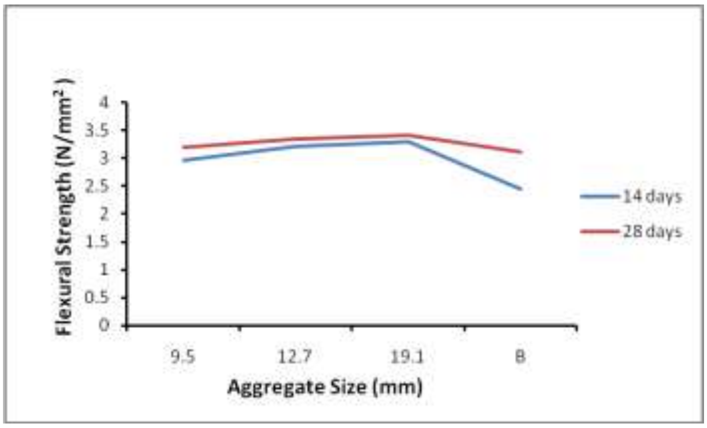

Figure 1: Variation of flexural strength with aggregate Size and gradation

4.2. Water Absorption

The result of water absorption of concrete made from uniform size and graded aggregates are shown in Fig. 2. Result shows that water absorption of concrete samples made from uniform size aggregates decreases as the aggregate size increases with the 9.5mm, 12.7mm and 19.1mm aggregates recording average water absorption of 5.5%, 4.85 and 3.4% respectively. However, concrete made from graded ggregates recorded the least water absorption of 2.1%. The decrease in water absorption with increase in aggregate size could be related to increased density of the concrete samples which contributed its flexural strength. This results also indicates that concrete samples made from the graded aggregates relative to those made from the 9.5mm, 12.7mm and 19.1mm aggregate resulted in a decrease in water absorption by 61.82%, 56.7%% and 38.23% respectively. This is because the smaller size aggregate in the graded aggregates filled the voids created by the larger particles as compared to the uniform size aggregates with relatively larger voids.

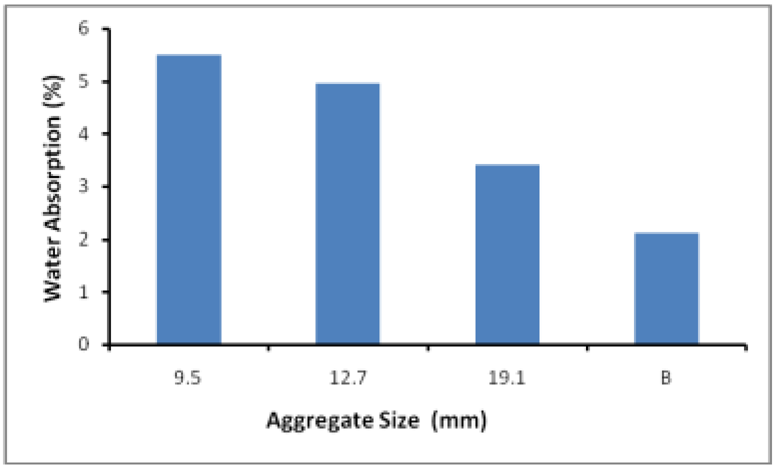

Figure 2: Variation of water absorption with aggregate size and gradation

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the study, the following conclusions have been drawn:

1. The aggregate size and gradation affect flexural strength (modulus of rupture) and water absorption of concrete.
2. Flexural strength of concrete made from uniform size aggregates increases with increase in aggregate size.
3. Concrete made from aggregates graded using the Cement Treated Aggregate gradation procedure does not improve the flexural strength of concrete relative to concrete made from uniform size aggregates.
4. Concrete made from graded aggregates using the Cement Treated Aggregate gradation procedure showed lower water absorption as compared to concrete made from uniform size aggregates.

5.2 Recommendation

i. Further research should be carry out to investigate and compare results of flexural strength and water absorption of concrete made from uniform size aggregates and grade aggregates adopting procedure such as the Coarseness Factor, Power Curve, Individual Retained chart and Tarantula Curve methods.

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