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EXPERIMENTAL STUDY ON THE EFFECT OF DIFFERENT COARSE AGGREGATE SIZES ON THE STRENGTH OF CONCRETE

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ABSTRACT: The purpose of this research work is to compare the effect of coarse aggregate sizes on the strength of concrete. Materials for this study were (water, fine and coarse aggregates and cement). Acceptability criteria for tests on basic materials for concreting were ascertain such as; water according to BS 2690 standard, Fine and coarse aggregates according to BS 812:1975, part 1 to 4 standard and Cement according to BS 12:1991. The acceptability criteria for testing fresh and hardened concrete such as Workability test (slump test in accordance with BS 1881:1983, part 102) and Compressive strength test (cube test in accordance with BS 1881:1983. The specimen size for crushing strength was 150mm x 150mm x 150mm, cured and tested for 7, 14 and 28 days with concrete grade 20 of minimum compressive strength of 14 N/mm2 (mix ratio of 1:2:4). From the result gotten, the concrete strength of aggregate size of 20mm to 28mm after 28 days was higher than that of 13.2mm to 19mm and that of 3.35mm to 10 mm.

Keywords: Aggregate size, Concrete strength, compressive strength, Mix ratio, Slump test.

1. INTRODUCTION

The strength of concrete depends on many parameters, therefore, an in-depth understanding of appropriate mix ratios for optimum concrete strength is much required by engineers in this field of expertise. Compressive strength of concrete is influenced by age, type of material, and the process of curing, water cement ratio, size of aggregate, type of aggregate, and some other parameters [1, 2]. Emphasis is given to the parameters of the coarse aggregate size and its impact on the strength and workability of concrete. The compressive strength of the aggregate sizes of 3.35mm-10mm,13.2mm-19mm and 20mm-28mm is the main parameter to be examined, the test used to evaluate the compressive strength is non-destructive testing using destructive test on 7,14 and 28 days whichcwill be implemented on the samples and concrete cubes. Both tests are carried out based on the British Standard BS 1881 (1983). Ukala [3] studied the properties of concrete in terms of strength, slump and density by varying aggregate grades. Proportions of 12.7mm, 25.4mm, and 38.1mm and 50.8mm sizes of granite as coarse aggregates were varied in order to create diverse coarse aggregate grading and then combined with a constant fine aggregate gradation and a fixed water/cement (w/c) ratio of 0.7. The results showed that as the coarse aggregate was spread evenly across all four aggregate sizes the strength was maximum as compared to when the aggregates were concentrated towards the 50.8mm size. The workability was observed to be stiffer as more coarse aggregate sizes were introduced into the mix. Finally, the concrete density remained almost constant irrespective of the aggregate grading. Effects of aggregate sizes on the mechanical properties of lightweight concrete (LC) was investigated by Wei et al. [4]. The absence of medium-sized particles led to decreased in compaction of LC, thereby affecting the density and compressive strength of the concrete. Specimens having medium-sized lightweight aggregate (LAW) showed the highest compressive strength up to 95 MPa. The excessively lower size of expanded shale LWA undermined both the compaction, splitting tensile and flexural strength of LC, while a rational gradation of LWA was beneficial to the splitting tensile and flexural strength. Sneka et al. [5] employed different aggregate sizes in concrete work at constant mix of 1:1.5:3, with water cement ratio of 0.5 throughout the experiment. The mean concrete Compressive Strength and Split Tensile Strength increased with increasing aggregates size. Coarse aggregate sizes of 19, 25 and 37.5 mm gave average Flexural Strengths of 4.59, 4.38 and 3.98N/mm2. The effect of aggregate sizes on the compressive strength of concrete using two nominal mixes (1:2:4 and 1:3:6) was investigated by Ogundipe et al. [6]. Concrete cubes were produced with 6, 10, 12.5, 20 and 25 mm aggregates for the two nominal mixes and they were subjected to compressive strength test. The results indicated that the compressive strength increases with increasing aggregate size up to 12.5 mm, while the concrete produced using 20 mm aggregate had higher compressive strength than those produced using 25 mm aggregate. A synergistic combination of three sizes of coarse aggregates (10mm, 14mm, and 20mm) for concrete work was investigated by Ramonu et al. [7]. Each of the sizes were cast which served as the control. The three aggregate sizes were also combined based on percentage proportion and cast. For each combined sizes of coarse aggregates, 21 cubes (150×150mm) were cast to allow the compressive strength to be monitored at 7, 14 and 28 days. It was observed that the third test of the combined coarse aggregates which contained 30% 10mm, 20% 14mm and 50% 20mm had the highest compressive strength of 25N/mm^2. Obi [8] evaluated the effects of coarse aggregates sizes on concrete quality. It was observed that with proper mixing, the slump test results did not witness shear or collapse type of slump rather there were true slump in all cases of the test. The workability decreased with slight differences when the coarse aggregate size was increased. The increase in the coarse aggregates yielded appreciable increase in the compressive strength. Ekwulo and Eme [9] investigated four concrete specimens made from aggregate size of 9.5mm, 12.7mm, 19.1mm and graded aggregate specimen made from a combination of 9.5mm, 12.7mm and 19.1mm aggregates. A concrete mix of 1:1.5:3 with a constant water-cement ratio (w/c) of 0.6 was used and tested for slump. Concrete cubes were produced from same mix, cured and tested for compressive strength at 14 and 28 days. It was observed that workability (slump) of fresh concrete decreases with increase in aggregate size and that compressive strength increases with increase in aggregate size. It was also observed that grading aggregates using Cement Treated Aggregate gradation procedure does not necessarily increase compressive strength of concrete for rigid pavements. Salau and Busari [10] investigated the effect of different coarse aggregate sizes on the strength characteristics of laterized concrete. The workability of laterized concrete at constant mix ratio of 1:2:4 and water-cement ratio of 0.6 increased as coarse aggregate particle size increased, but decreased with increase in percentage of laterite content. For the two largest coarse aggregate particle sizes (19.5mm and 12.5mm), the workability of laterized concrete at 25% laterite content was almost the same compared to that of normal concrete but was low for 50% laterite content. The density of the hardened concrete (using all granite particle sizes inclusive) increased from 0% to 25% laterite content but later decreases from 25% to 50%. With mixing ratio of 1: 2: 4 and water cement ratio of 0.5, Musa and Saim [11] investigated the effect of concrete strength using coarse aggregate of 10mm, 20mm and fine aggregate 3mm. The results on the 28th day showed the comparison percentage of Cube Test 47.6%, Cylinder Compressive Test 40.5% and Schmidt Hammer Test 48.9%. The results revealed that concrete aggregate size of 20mm had 45.7% higher compressive strength than concrete aggregate size of 10mm. Ajamu and Ige [12] investigated the effect of varying coarse aggregate size on the flexural and compressive strengths of concrete beam. Concrete cubes and beams were produced in accordance with BS 1881-108 (1983) and ASTM C293 with varying aggregate sizes 9.0mm, 13.2mm, 19mm, 25.0mm and 37.5mm. The water cement ratio was kept at 0.65 with a mix proportion of 1:2:4. The specimen produced were all subjected to curing in water for 28days. Compressive strength of cubes was 21.26N/mm^2, 23.41N/mm^2, 23.66N/mm^2, and 24.31N/mm^2 for coarse aggregate sizes 13.2mm, 19mm, 25.0mm and 37.5mm. That of flexural strength of test beams were 4.93N/mm^2, 4.78N/mm^2, 4.53N/mm^2, 4.49N/mm^2 and 4.40N/mm^2. The objective of this study is to compare the compressive strength of concrete molded with different sizes of crushed stone (i.e. 3.35mm-10mm, 13.2mm-19mm and 20mm-28mm) to determine the difference in strength of the different sizes of crushed stones which were tested after 7days, 14 days and 28 days of crushing.

2. MATERIALS AND METHODS

2.1. Materials

Materials employed in the experimental process of this study are as follows: Fine Aggregate, Coarse Aggregate, Cement, Water, Mould, Slump Cone, Tamping Rod, Tamping Bar, Scooper, Trowel, Compressive Testing Machine, Head-Pan, base plate, weighing balance, brush, A set of sieve.

2.2. Methods

River sand is one of the fine aggregates used for this project work and it was obtained from Ikot Ekong in Mkpat enin L.G.A, Akwa Ibom State, Nigeria. It was clean, sharp and free from clay and other organic matter. Crushed stones which are the largest amount of aggregate used in concrete and are the mineral aggregates. It was obtained from Akamkpa quarry site in Cross River State, Nigeria. Portland cement is manufactured by heating in a kiln mixture of a calcareous and a siliceous, usually argillaceous material. Portland limestone cement was used. The Superset brand of Portland limestone cement of the 42.5N grade produced in Akamkpa was the cement used for this project work and it was well protected from dampness. Workability tests are designed to measure the ease with which concrete can be compacted. To achieve this, concrete was compacted into the mold in three appropriately equal layers with a 16mm diameter tamping rod giving 35 tamps per layer. Top surface was struck off and finished with trowel. The mould was then lifted off vertically and the concrete was allowed to slump.

2.2.1. Acceptability criteria for testing hardened concrete

i. Strength Test: Strength tests are designed to measure the potential strength of concrete when cured and tested in a standard manner. The primary reason for strength test is to maintain control over the batching and mixing of the concrete, thereby checking compliance with specified requirements.
ii. Laboratory Test: Laboratory test in retarder and ordinary Portland cement for the purpose of characterization and determination of their strength when mixed with other constituent was carried out in terms of compressive strength test and slump test respectively.
iii. Curing of Cubes: Mould size of 15cm x15cm was used to cast cubes for compressive strength test. The cubes were cast and tested at the ages of 7, 14 and 28 days after curing.

2.2.2. Preparation of cubes

The Batching of concrete was done by weighing the different constituent materials base on the adopted mix ratio of 1:2:4. The materials were then mixed before adding the prescribed quantity of water and mixed further to produce fresh concrete. Water cement ratio of 0.4 was adopted. The fleshly mixed concrete was then cast into the mould after mixing for slump test to determine the workability of a fleshly mixed concrete. The concrete poured into the cube mould was compacted in three layers using the tamping rod. The surface of the cubes was made as smooth as practicable by the use of trowel, and the specimen was kept in the mould for 24 hours before demolding it and for it to be ready for curing.

2.2.3. The slump and compressive tests

Before mixing the concrete for the cubes, a trial mix casting was carried out to determine the slump. Slump test is very useful in detecting variations in the uniformity of a mix of a given normal proportions. It is a method used all over the world on day to day, hour to hour variations in the materials being fed into the mixer or manual mixing. The apparatus consisted of a conical mould of 100mm in diameter at the top and 200mm at the bottom and 300mm height and 16mm diameter tamping rod 600mm long and rounded at the end. The inside of the mould was cleaned before each test and the mould placed on a hard surface. The mould was placed in it three layers of concrete of approximately equal depth. Each layer was tamped with 35 strokes using the rounded end of the tamping rod. After the top layer has been tamped, the surface of the concrete was struck off level with the top of the mould using a trowel. The slump is the difference between the highest of the concrete and the height after the removal of the conical mould. After the measurement was taken the concrete that was used in determining slump was thoroughly mix with the fresh concrete before casting into the mould and the surface levelled using a trowel and it was kept for 24 hours in the laboratory before de-moulding and then the cubes were immerged in water for the require curing age. A total of 18 cubes was made. Testing of the hardened cubes was carried out after 7, 14 and 28 days respectively using a Universal compressive testing machine. The cubes were then placed between the hardened steel bearing plates of the Universal compression machine and the load was applied at the rate of 15N/mm^2 per minutes as specified in BS 1881. The Sample was wiped off from grit and place centrally with load applied steadily to destruction and the highest load reached was determined. This was used to compute the compressive strength and the ratio of the highest load to the cross-sectional area of the samples used for each test and the averages results were adopted as the compressive strength. The slump test experimental process is shown in Figure 1.

Figure 1. Slump test Experiment.

2.2.4. Sieve analysis

The aim of this analysis was to determine the particle size distribution of an aggregate sample. The aggregates were sieved through a set of sieve, the material retained on different sieve is determined. The percentage of material retained on any sieve is given by Equation 1.

$$PN = \underline{Mn} \times 100 \quad (1)$$

Where Mn is the mass of soil retained on each sieve and M is the total mass of sample retained as the commutative.

2.2.5. Procedure for coarse aggregate

The laboratory test procedures for performing a sieve analysis presented here as ASTM. Standard test method particle size distribution of sample

i. Take the required quantity of the coarse aggregate, sieve it through a 4.75mm sieve. Take the sieve sample and weight.
ii. Determine the initial mass of the sample. Then a stock of the aggregate is assembled. The sieves approximately double that of the next finer. The top sieve must possess openings that are large enough so that the entire sample will fall through the pan.
iii. The sample was then sieve using a mechanical sieving machine. While sieving through each sieve, the sieve agitated such that the sample rolls in irregular motion over the sieve.
iv. The mass of samples in each of the sieve was weigh using a weighing balance. The percentages finer (N) by weight, which is also known as percentage passing in each of the sieve has being plotted.

2.2.6. Procedure for fine aggregate

A Given mass of fine aggregate was measured and washed. This was done so as to remove the clay, silt and dust contained in the sample. The sample being washed became less turbid and a bit transparent. It was then spread outside to dry for about 24 hours and it was put into a set of sieves arranged in decreasing apertures indicated on the chart. The sample retained on each of the sieve was weighed and the results obtained were recorded. The percentage passing through each sieve was computed and plotted against the sieve of aperture sizes to obtain a curve as the particle size distribution curve.

3. RESULTS AND DISCUSSION

The test conducted includes sieve analysis, compressive strength test and slump test. Results obtained from the sieve analysis for fine aggregate sizes and coarse aggregate are presented in Table 1 and 2. The results presented in Table 1 and 2 are further represented in graphical form as shown in Figure 2 and 3.

Table 1. Results of sieve analysis test for fine aggregate.

Sieve sizes (mm)	Weight Retained (kg)	Percentage Retained	Cumulative percentage Retained	Cumulative Percentage Passing
3.35	0.046	3.07	3.07	96.93
1.7	0.108	7.20	10.27	89.73
0.85	0.256	17.07	27.33	72.67
0.425	0.502	33.47	60.80	39.20
0.3	0.296	19.73	80.53	19.47
0.212	0.202	13.47	94.00	6.00

0.075	0.058	3.87	97.87	2.13
PAN	0.03	2.00	99.87	0.13

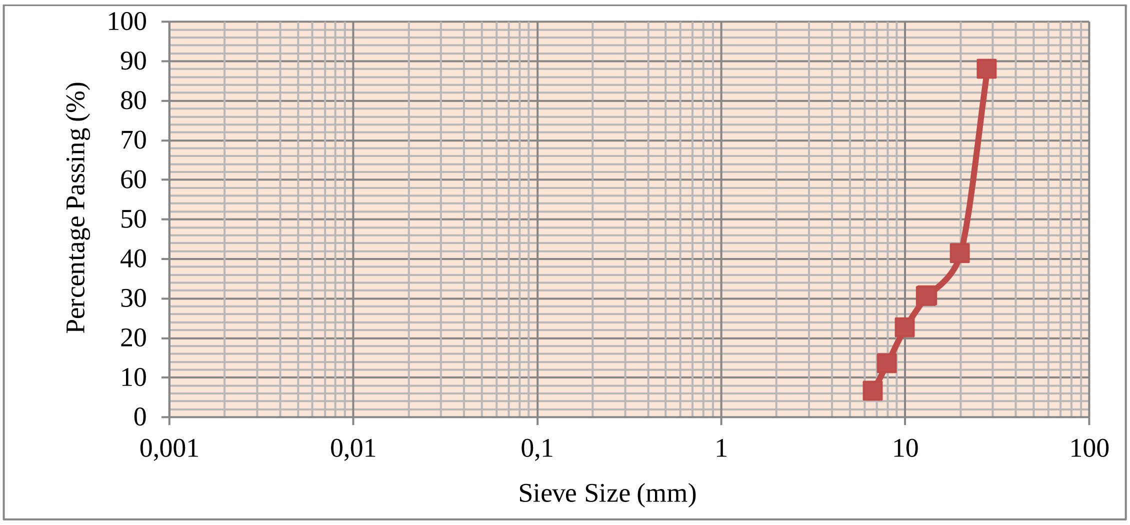

Figure 2. Particle size distribution for fine aggregate.

Table 2. Results of sieve analysis test for coarse aggregate.

Sieve sizes (mm)	Weight Retained (kg)	Percentage Retained	Cumulative percentage Retained	Cumulative Percentage Passing
28	0.18	12.00	12.00	88.00
20	0.7	46.67	58.67	41.33
13.2	0.16	10.67	69.33	30.67
13	0.002	0.13	69.47	30.53
10	0.12	8.00	77.47	22.53
8	0.134	8.93	86.40	13.60
6.7	0.106	7.07	93.47	6.53
3.35	0.09	6.00	99.47	0.53

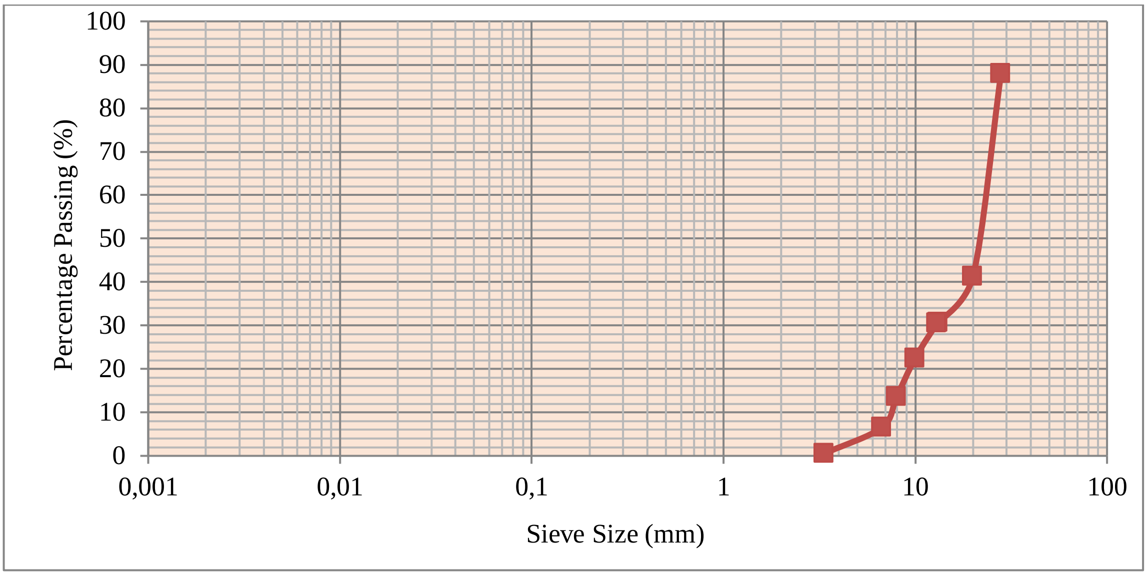

Figure 3. Particle size distribution for coarse aggregate.

Results obtained from the compressive strength test for different coarse aggregate sizes (3.35mm-10mm, 13.2mm-19mm and 20mm-28mm) are presented in Table 3-5. The results presented in Table 3-5 are further represented in graphically as shown in Figure 4-6. Summary of results for compressive strength for different coarse aggregate sizes is presented in Table 6 and graphically illustrated in Figure 7. Results obtained from slump test experiment is presented in Table 7.

Table 3. Results of compressive strength for 3.35mm-10mm coarse aggregate.

AGGREGATE SIZES = 3.35-10mm; AREA OF CUBE = 22500mm^2					
Age (Days)	Cube Description	Weight Before Curing (Kg)	Weight After Curing (Kg)	Load (Kn)	Compr. Strength (N/Mm^2)
7	M	7.89	8.00	378.15	14.16
	N	8.27	8.27	258.92	
14	O	7.78	7.78	388.96	17.47
	P	7.88	7.96	397.15	
28	Q	7.87	8.00	357.04	18.64
	R	8.01	8.12	481.79	

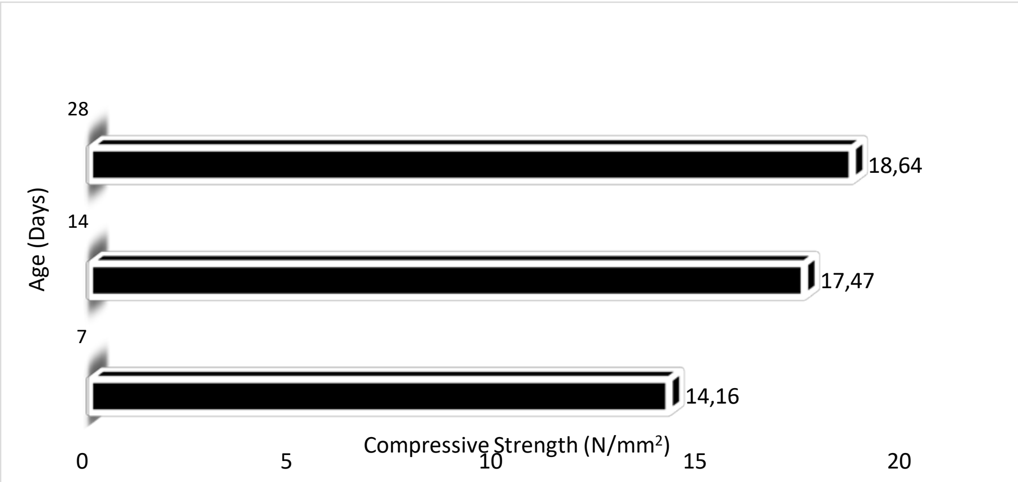

Figure 4. Compressive strength of 3.35-10mm coarse aggregate.

Table 4. Results of compressive strength for 13.2mm-19mm coarse aggregate.

AGGREGATESIZES = 13.2-19mm;AREAOFCUBE = 22500mm^2					
Age (Days)	Cube description	Weight before curing (Kg)	Weight after curing (Kg)	Load (Kn)	Compr. Strength (N/Mm^2)
7	A	8.19	8.24	418.32	19.37
	B	8.54	8.58	453.33	
14	E	8.49	8.55	498.88	24.11
	F	8.39	8.46	585.88	
28	I	8.36	8.46	368.99	24.55
	J	8.58	8.65	735.76	

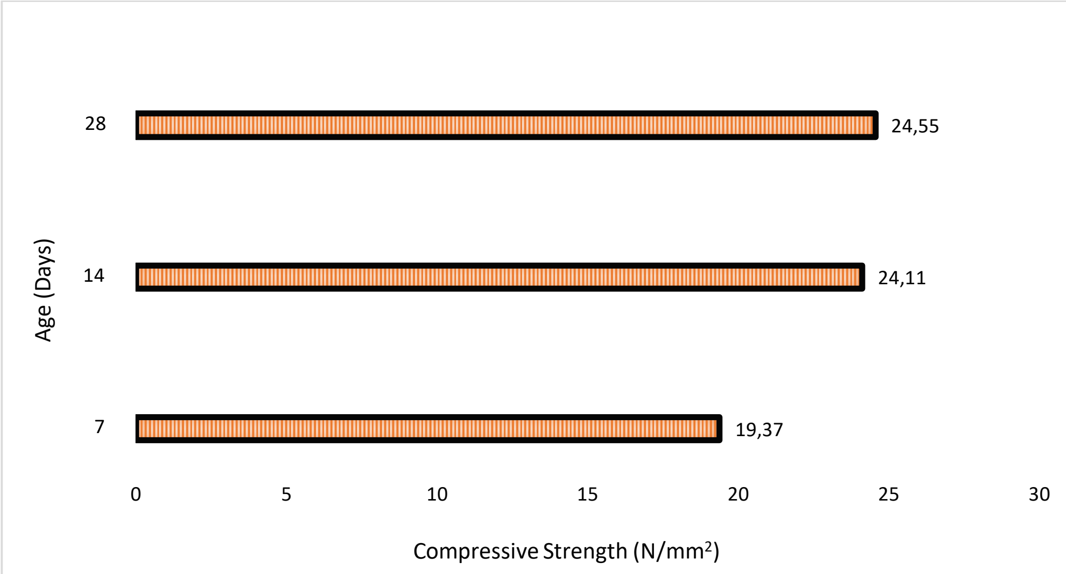

Figure 5. Compressive strength of 13.2-19mm coarse aggregate.

Table 5. Results of compressive strength for 20mm-28mm coarse aggregate.

AGGREGATE SIZES = 20-28mm;				**AREA OF CUBE = 22500mm^2**	
Age (Days)	Cube Description	Weight Before Curing (Kg)	Weight After Curing (Kg)	Load (Kn)	Compr. Strenght (N/Mm^2)
7	C	8.47	8.51	344.40	18.31
	D	8.41	8.46	479.33	
14	G	8.54	8.59	633.20	23.68
	H	8.44	8.59	432.29	
28	K	8.37	8.45	588.14	25.25
	L	8.53	8.61	547.90	

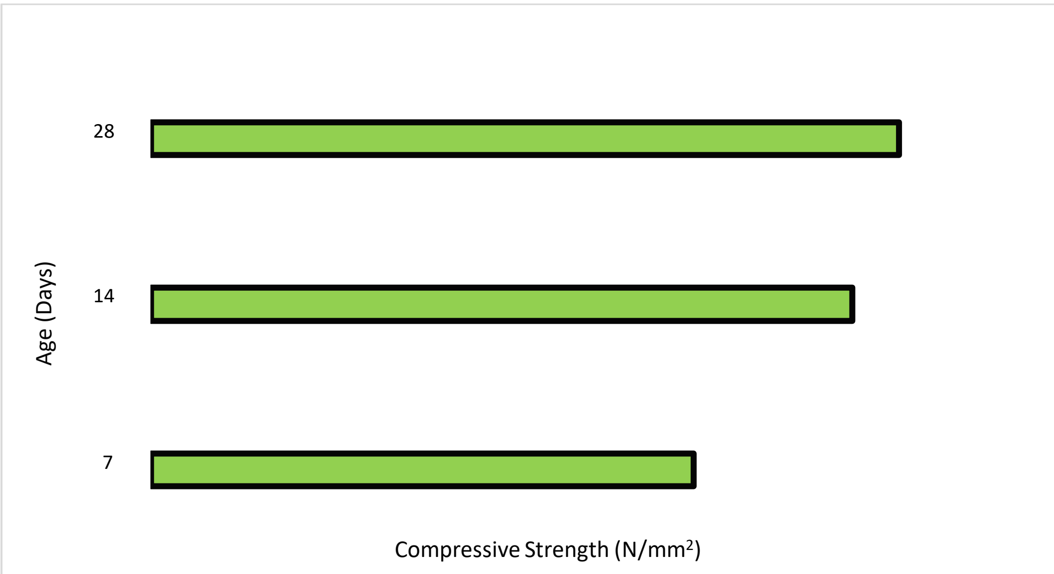

Figure 6. Compressive strength of 20-28mm coarse aggregate.

Table 6. Summary of compressive strength for different coarse aggregate sizes.

Age (Days)	Compressive strength for difference coarse aggregate sizes		
	20-28mm	**13.2-19mm**	**3.35 - 10mm**
7	18.31	19.37	14.16
14	23.68	24.11	17.47
28	25.25	24.55	18.64

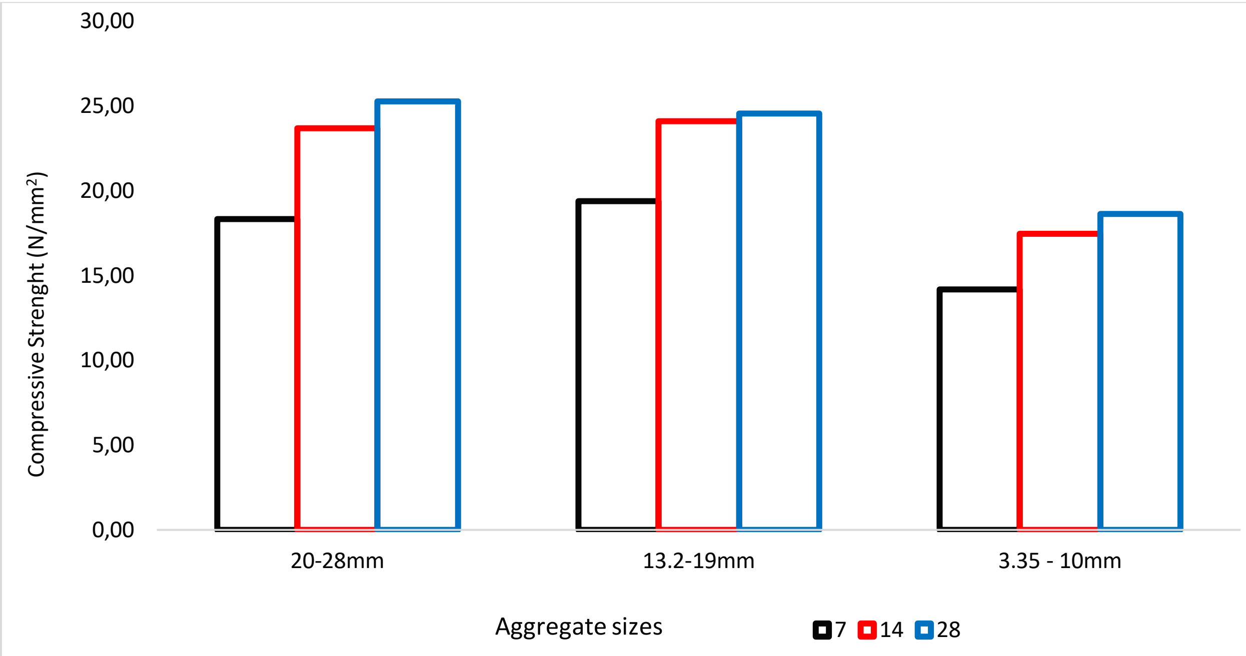

Figure 7. Compressive strength of different sizes of coarse aggregates.

Table 7. Results obtained from slump test experiment.

Sample No.	Mix ratio	W/C	Slump height (mm)	Slump type (mm)
3.35mm-10mm	1:2:4	0.4	10.00	True
13.2mm-19mm	1:2:4	0.4	13.50	True
20mm-28mm	1:2:4	0.4	20.00	True

Results obtained from the laboratory experiment which are shown in Table 6 and graphically in Figure 7, reveals that concrete made with coarse aggregates of sizes ranging from 20mm-28mm (i.e retained on 20mm to that retained on 28mm) had a higher compressive strength as compared to the other two size range. The strength also decreases with aggregate size range of 13.2mm-19mm while those with the range of 3.35mm-10mm showed the least compressive strength. This is in agreement with the findings of Ogundipe et al. [6]. Also in respect to weight of the concrete before and after curing, the concrete with the higher aggregate size range (i.e, 20mm to 28mm and 13.2 mm to 19mm) have a slightly more weight than those produced using the smaller aggregate size range (i.e, 3.35mm to 10mm). This in turn affects the rigidity of concrete and load required to crush them. What this means is that, they can withstand more pressure and thus carry more load. This has also been revealed by the experiment as can be seen in Tables 3, 4 and 5 that concrete made with higher coarse aggregate sizes require more crushing load. It is therefore safe to say, a higher coarse aggregate size will produce a richer concrete.

4. CONCLUSION

In conclusion, results from the experiment revealed that the bigger the coarse aggregate size, the higher the compressive strength produced. It also showed that the strength of concrete increased with the curing days and finally, that with a higher coarse aggregate size, concrete cubes were observed to have more weight than those produced with lesser coarse aggregate size. It was observed that crushed stone is very strong and tough, yet, it has good surface texture that enhanced proper bonding between aggregate and cement paste. Therefore, while evaluating aggregate sizes for optimum concrete strength, the following suggestions should be considered:

i. For construction of foundations, aggregate of larger sizes should be used since it has higher compressive strength.
ii. Proper compaction of the concrete cubes must be ensured, as compaction during the experimental process was observed to improve the strength of concrete.
iii. The workability of concrete is very important since it plays a vital role in the compressive strength of concrete, as such, concrete should be workable enough to achieve the expected strength.

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