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Comparison of the Effect of Different Sizes of Aggregate (Granite) on the Compressive Strength of Concrete

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ABSTRACT
The need for more understanding of the behavior and response of constituent materials of concrete used in construction projects to loadings and imposed stresses cannot be overemphasized. This paper investigates the effect of different coarse aggregate sizes on the compressive strength of concrete using different sizes ranging from 0-5mm, 5-14mm, 14-20mm, 20-28mm, >28mm and a combination of all the sizes. A nominal mix ratio of 1:2:4 batched by weight with 0.60 water-cement ratio was used. Tests conducted on the aggregates include moisture content, specific gravity, bulk density, sieve analysis, porosity and void ratio. On the other hand, the workability test (slump test) and compressive strength tests were carried out on fresh concrete and hardened concrete respectively. A total of 54 concrete cubes (150mm x 150mm x 150mm) were cast and tested at 7days, 14days and 28days. The result showed that the compressive strength and density increased with days of curing. The aggregate size range 14-20mm gives the highest compressive strength but for optimal and economic reasons the combined aggregate is recommended for construction work.

Keywords: Aggregate size, Concrete, Compressive strength, Workability.

1 INTRODUCTION

The need for a more cost-effective, efficient, and affordable means of shelter is ever increasing in the world most especially with the advanced infrastructural development techniques and methods newly introduced. As such, individuals, corporate organisations, institutions, and the government at large are in dire need of accommodation for people and the smooth running of the organisation's activities to achieve the set goals. Therefore, for such shelter and infrastructural development needs to be realized, construction projects must be put in place with the accompanying need for a large volume of material used during the project execution.

Concrete is one of the major materials used during construction stages due to the availability and ease of operation of its constituent materials. Concrete is a composite material composed mainly of aggregates (fine and coarse) that are bound together by hydraulic binders such as cement in the presence of water to form a dense mass (Ogundipe et al, 2018). Often, additives and reinforcements are included in the mixture to achieve the desired physical and mechanical properties of the finished material (Li, 2011). Concrete mix is thoroughly agitated in mixers, poured into moulds or formwork, and compacted to form the desired shape once dried. The amount of concrete used worldwide, ton for ton is twice that for steel, wood, plastics and aluminum combined. The quality of a concrete mix is dependent on the properties of the materials used, the method of batching and mixing, and the method of construction (Neville, 1987).

It is well recognized that aggregates most especially coarse aggregate play an important role in the strength and quality of concrete used in construction. Coarse aggregate typically occupies over one-third of the volume of concrete (Gupta and Gupta, 2014), with research showing that changes in the quality of coarse aggregate can affect the strength and fracture properties of concrete produced (Kozul and Darwin, 1997). Also, a well-graded coarse aggregate mix (size and volume) helps in obtaining good quality concrete with good workability and adequate strength (Aminulai et al, 2019).

The need to understand the behaviour and response of concrete under general loading requires an understanding of the effects of aggregate type, aggregate size, and aggregate content. This understanding can only be gained through extensive testing and observation. This research reports the result obtained from the investigation of the effect of different coarse aggregate sizes on the compressive strength of normal concrete.

2 METHODOLOGY

This research investigates the effect of different coarse aggregate sizes on the compressive strength of normal concrete. The sizes ranging from 0-5mm, 5-14mm, 14-20mm, 20-28mm, >28mm and a combination of all the sizes were used in the work. A nominal mix ratio of 1:2:4 batched by weight with water-cement ratio of 0.60 was used (BS 1881: Part 108: 1983). The absolute volume method was adopted for the batching of the materials. The estimate is done using equations 1 and 2 while the material proportion is shown in Table 1.

$$V_w + V_c + V_s + V_{ca} + V_{air} = 1 \quad (1)$$

$$\frac{W_w}{1000SG_w} + \frac{W_c}{1000SG_c} + \frac{W_s}{1000SG_s} + \frac{W_{ca}}{1000SG_{ca}} + 2\% = 1m^3 \quad (2)$$

where,

W_w = weight of water (kg)

W_c = weight of cement (kg)

W_s= weight of sand (kg)

W_{ca} = weight of coarse aggregate (kg)

SG_w = Specific gravity of water = 1

SG_c = Specific gravity of cement = 3.15

SG_s = Specific gravity of sand

SG_{ca} = Specific gravity of coarse aggregate

TABLE 2.1: PROPORTIONING OF MATERIALS FOR CONCRETE

Aggregate sizes	Cement (kg)	Water (Kg)	Sand (kg)	Coarse aggregate (kg)
0 – 5mm	9.1	5.46	18.2	36.5
5 – 14mm	9.27	5.56	18.54	37.08
14 – 20mm	9.27	5.56	18.54	37.08
20- 28mm	9.81	5.89	19.62	39.25
> 28mm	9.44	5.66	18.88	37.76
All sizes	9.47	5.68	18.94	37.88

The tests conducted on the aggregates include: moisture content, specific gravity, bulk density, sieve analysis, porosity and void ratio as specified by the relevant codes and standards. On the other hand, slump test was carried out on fresh concrete while the compressive strength test was carried out on hardened concrete. The slump test was used to assess the workability of the fresh concrete.

A total of 54 concrete cubes measuring 150mm x 150mm x 150mm were cast, cured by complete immersion in water and tested for their compressive strengths at 7days, 14days and 28days (BS 1881: Part 111: 1983).

2.1 MATERIALS USED

The materials described below were used during the research work.

2.1.1 ORDINARY PORTLAND CEMENT (OPC)

Ordinary commercial Portland cement was used throughout this research work. OPC being the most widely recommended material of its kind and largely available in Nigeria acts as a hydraulic binder that sets and hardens by chemical interaction with water. The cement was produced from industrial decomposition of calcium carbonate with the addition of other constituents such as aluminium oxide, silicon oxide, and other granular material in a calculated proportion conforming to BS EN 197-1 (2011) code specification.

Typical example of this ordinary Portland cement is the Dangote Portland cement. It was purchased from a local market in Minna and taken to the laboratory in a sealed 50kg bag. The cement was protected from dampness to avoid lumps.

2.1.2 AGGREGATE USED

The Fine aggregate (natural sand) used was collected from a local source in Minna, Niger State, Nigeria which was clean, sharp, free from clay and organic matter and also well graded according to the requirements set by ASTMC 1992, standard specification of aggregates for conventional concrete. This fine aggregate is an aggregate whose size is not larger than 5mm, passing the No 4 ASTM sieve and predominantly retained on the No 200 (75µ) sieve. The sand used was air-dried in the Civil Engineering laboratory for 72 hours to reduce excess moisture present before use for the concrete production as prescribed in PD 6682-1:2009+A1 (2013).

The coarse aggregate was also obtained from a local dealer in Gidan Kwano along the Minna-Bida

Road and was found to have conformed to PD 6682-1:2009+A1 (2013) as it was retained on BS sieve 5mm. It was passed through sets of sieves to screen the particle sizes to obtain the different aggregate sizes needed for this work.

2.1.3 WATER

Potable tap water was obtained from the Civil Engineering Laboratory in Federal University of Technology, Minna, Gidan Kwano campus which was suitable for use throughout this experiment. The water used was clean, free from algae, spirogyra and other biological substances. To obtain a satisfactory result, the water used had to be clean and free from harmful amounts of acids, alkalis and organic materials. This was adequately ensured as specified in BS EN 1008 (2002) specifications.

2.2 EXPERIMENTAL INVESTIGATIONS

Preliminary tests were carried out on the fine and coarse aggregate to determine their physical properties. Also, the property of fresh concrete (via slump test), as well as property of the hardened concrete (compressive strength test), was carried out. The preliminary tests carried out include specific gravity, bulk density, sieve analysis, moisture content, void ratio and porosity.

i. Specific gravity, (G_s): This is the ratio of mass of a unit volume of a material to the mass of the same volume of water at the same temperatures. The test was carried out according to BS EN 1097-6 (2000) and then the result was tabulated and specific gravity computed using equation 3 below.

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (3)$$

where,
M_1 = Weight of empty can (g)
M_2 = Weight of can + sample (g)
M_3 = Weight of can + sample + water (g)
M_4= Weight of can + water (g)

ii. Bulk density: This is a measure of the weight of the soil per unit volume, usually given on an oven-dried (110°C) basis. Bulk density can also be considered to be a measure of how dense or closely packed a sample is. It is determined by measuring the mass of dry samples per unit volume (g/cm^3). The bulk density of a sample depends on the structure of the sample beds, how tightly they are packed, the number of spaces (pores), and its composition. Bulk density could either be compacted or un-compacted (loose) bulk density. The test was carried out on the fine and coarse aggregates following BS EN 1097-3 (1998) guidelines. The bulk density, compacted and loose, is calculated using equations 4 and 5 respectively:

$$Compacted\ Bulk\ Density = \frac{M_3 - M_1}{V} \quad (4)$$

$$Loose\ Bulk\ Density = \frac{M_2 - M_1}{V} \quad (5)$$

where,
M_1 = Weight of mould (g)
M_2 = Weight of mould + un compacted sample (g)
M_3 = Weight of mould + compacted sample (g)
V = Volume of mould

iii. Particle size distribution (sieve analysis): This is the process of dividing a sample of aggregates into fractions of the same particular size to determine the grading or size distribution of the aggregates (Neville, 1990). In other words, it can simply be described as the process of dividing a sample of aggregates into fractions of different particle sizes. The test was carried out according to BS EN 933-1 (2012).

iv. Moisture content (Mc): This is defined as the water in excess of the saturated dry condition of the aggregates. Moisture content is used in a wide range of scientific and technical areas and its exressed as a ratio, which can range from zero (completely dry) to the value of the materials' porosity at saturation. It can be given on volumetric or mass (gravimetric) basis. The test was done as described in BS EN 1097-5 (2008) and the result computed as follows (equation 6):

$$Mc = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \quad (6)$$

where,
M_1 = Weight of empty can (g)
M_2 = Weight of can + sample (g)
M_3 = Weight of can + dry sample (g)

v. Void ratio (e): This is the ratio of the volume of void in a mixture to the volume of solids. For a well-graded material, it is required that the pore spaces created by the larger particles are occupied by a considerable amount of fine. Pore spaces are generally removed by adequate compaction. In the case of the concrete mix, the pore spaces created by coarse aggregates are properly filled with sand/cement paste (mortar). The void ratio (e) can be obtained for a sample of known bulk density and specific gravity as shown in equation 7 below.

$$Void\ ratio\ (e) = 1 - \frac{(Uncompacted\ BD)}{SG\ x\ unit\ weight\ of\ H2O} \quad (7)$$

vi. Porosity: This is a measure of the void spaces in a material, and is measured as a fraction between 0 – 1; or as a percentage between 0 – 100%. The porosity, permeability and absorption of aggregates influence the bond and the cement paste, the resistance of concrete to freezing and thawing as well as chemical stability, resistance to abrasion and specific gravity (Neville and Brooks, 2011). Aggregate with lower porosity will tend to produce higher durable concrete. The value of porosity can be calculated from the bulk density and particle density of the sample as shown in equation 8.

$$\%\ Porosity = 1 - \frac{un\text{-}compacted\ bulk\ density}{compacted\ bulk\ density} \times 100 \quad (8)$$

The slump test was done on the fresh concrete to determine its workability following the guidelines in BS EN 12350-2 (2009) while the compressive strength test was done on the hardened concrete in accordance to BS EN 12390-2 (2009) and BS EN 12390-3 (2009).

3 RESULTS AND DISCUSSION

In this presentation, the results obtained from the physical properties of materials were recorded as well as tests conducted on fresh concrete and hardened concrete.

3.1 PROPERTIES OF AGGREGATES

The particle size distribution curves of the fine and coarse aggregates are presented in Figure 1. It showed that the aggregates are all well-graded. This shows that the aggregates require less amount of cement and water, therefore, making them more economical in the production of higher strength concrete with lower shrinkage and greater durability (Shetty, 2012).

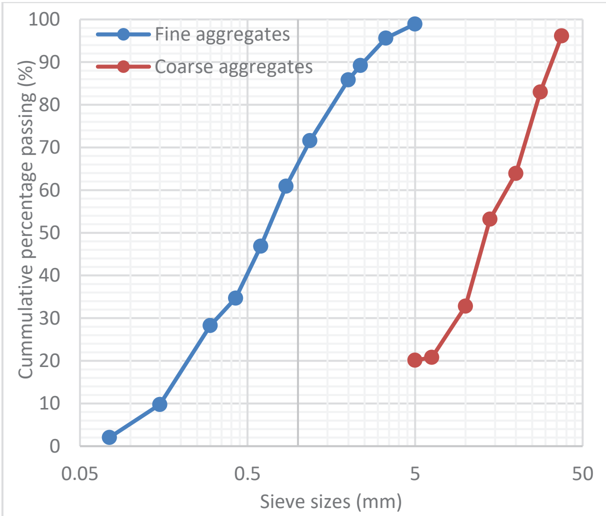

Figure 1: Particle size distribution of fine and coarse aggregates

The results of the physical properties of the aggregates are presented in Table 1 below.

The specific gravity of the fine aggregate is 2.60 which showed that it is within the standard range of 2.6 – 2.7 while those of the coarse aggregate ranges between 2.42 - 2.84 showing that three of the sizes were out of the standard range of 2.6 – 3.0 (Neville, 2010).

The loose bulk density indicates the volume that the aggregates will occupy in the concrete mix. The results fot the loose and compacted bulk densities for fine aggregate are presented in Table 1. The bulk density of fine aggregate is 1552.6kg/m^3 which falls within the standard limit of 1300 – 1800 kg/m^3 (Neville, 2010). Also, the coarse aggregates have bulk densities ranging from 1491kg/m^3 – 1608kg/m^3

showing conformity with the standard limit of 1500 – 1700 kg/m³ (Neville, 2010).

The moisture contents obtained for the fine and coarse aggregates shown in Table 1 are within the limit specified by Neville (2010). Also, the percentage of porosity obtained for most of the aggregates is within the specified range of 1% - 15% (Neville, 2010).

The void ratios have a greater effect on the durability of concrete. For quality grade concrete, it is often required that the void spaces created by coarse aggregates be filled with mortar to improve hardness and strength development and minimize honey-combing. In consonance with this, the results obtained, shown in Table 1 fall within (0-50) the percentage specified by Neville (1987).

TABLE 2: SUMMARY OF THE PROPERTIES OF FINE AND COARSE AGGREGATE USED IN THE STUDY

Properties	**Fine Aggregate**	**0-5mm**	**5-14mm**	**14-20mm**	**20-28mm**	**>28mm**	**All sizes**
Moisture Content (%)	0.20	0.25	0.37	0.11	0.06	0.14	0.15
Specific Gravity	2.60	2.42	2.52	2.52	2.84	2.62	2.64
Bulk Density (Loose) (kg/m³)	1552.64	1529.24	1494.15	1491.23	1608.19	1576.03	1551.78
Bulk Density (compacted) (kg/m³)	1584.80	1687.14	1526.32	1540.94	1675.44	1581.88	1639.57
Void Ratio	0.40	0.37	0.41	0.41	0.43	0.40	0.31
Porosity (%)	2.03	9.36	2.11	3.23	4.01	0.37	3.10

3.2 Workability Test Result (Slump Test)

Slump is used to determine the workability of a mix of a given proportion. The slump test primarily measures the consistency of concrete. Table 2. shows the result of the slump test with mix ratio of 1:2:4 . The degree of workability obtained from the slump test result ranges from low to medium (25mm -100mm) which is the recommended slump value according to (Neville, 1987).

TABLE 3: SLUMP TEST RESULT OF CONCRETE OF DIFFERENT SIZES OF COARSE AGGREGATE

Aggregate sizes (mm)	Water/cement ratio	Mix ratio	Slump (mm)	Degree of workability
0-5	0.6	1:2:4	26	Low
5-14	0.6	1:2:4	28	Low
14-20	0.6	1:2:4	36	Medium
20-28	0.6	1:2:4	55	Medium
>28	0.6	1:2:4	45	Medium
All sizes	0.6	1:2:4	29	Low

3.3 Compressive Strength Test Result

The results of the compressive strength of the concrete cube produced for different sizes of aggregate are presented in Figure 2. It can be seen generally that the compressive strength increases with an increase in the curing days. Also, the aggregate size range 14 – 20mm has the highest compressive strength at 28 days of curing. This is due to the relatively closed packing of the aggregate and the good bond between the cement paste matrix and the aggregates. Furthermore, the compressive strengths of the concrete increased with increase in the sizes of aggregates with the combination of all the different sizes having a very good strength at 28 days.

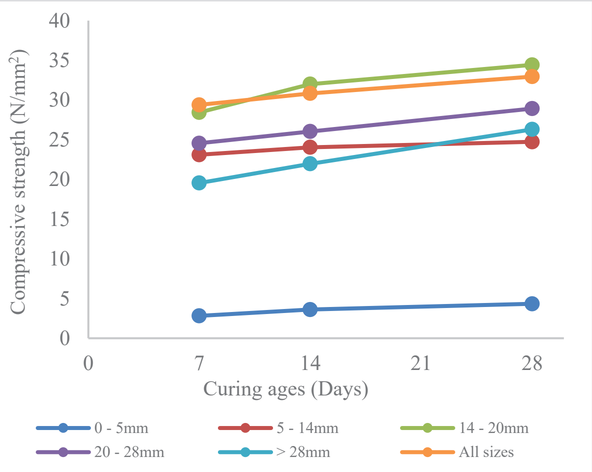

Figure 2: Compressive Strength Graph of concrete produced with different sizes of aggregate

4 CONCLUSION

The study investigates the effects of different sizes of aggregates on the compressive strength of concrete. It was discovered that the concrete strength increases with the increase in the aggregate size range up to a range (14 – 20mm) that the increment is almost not effective. However, for optimal and economic reasons, the aggregates with all the sizes mixed is recommended for use in concrete for structural use as it gives a very reasonable strength.

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