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Effects of Coarse Aggregate Size on the Compressive Strength of Concrete

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Abstract

This study investigates the effect of aggregate size on the compressive strength of concrete. Two nominal mixes, that is, 1:2:4 and 1:3:6 were used in the study. 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 after curing for 7, 21, 28 and 56 days. It was found in the study that the strength development follows the same trend for both nominal mixes. Also, the results show that the compressive strength increases with increasing aggregate size up to 12.5 mm, while the concrete produced using 20 mm had greater compressive strength than those produced using 25 mm aggregate. This established the importance of ensuring that the right aggregate size is used in the production of concrete. Therefore, it is recommended that careful attention must be paid to the sizes of aggregates used in the production of concrete for structural purposes.

Keywords: Aggregate Size; Mixes; Effects; Concrete; Compressive Strength.

1. Introduction

Concrete is simply a blend of aggregates normally natural sand and gravel or crushed rock. The blend of aggregates is bound by a hydraulic binder like Portland cement and activated by water to form a dense semi homogeneous mass. Concrete is sometimes referred to as artificial rock, because of its general characteristics. Concrete is very strong in resisting compression and weak in tension. Therefore, reinforcement is introduced into concrete to absorb tension, where required. Aggregates, which are generally considered inert filler, account for 60 to 80 percent of the volume and 70 to 80 percent of the weight of concrete. Although, aggregate is considered inert filler, it is an important constituent that determines the concrete thermal and elastic properties and dimensional stability. There are two types of aggregates: coarse and fine aggregates. Coarse aggregates are characteristically greater than 4.75 mm (retained on a No. 4 sieve), while fine aggregate is less than 4.75 mm (passing through the No. 4 sieve). The aggregate compressive strength is considered an important factor in the selection of aggregate. Therefore, it is important to evaluate the effect of aggregate size on the strength of concrete.

Haque et al. [1] studied the effects of size distribution of both fine and coarse aggregate and maximum coarse aggregate size on concrete compressive strength. They observed that compressive strength of concrete increased with the increase of the fineness modulus of both fine and coarse aggregate. Also, they stated that compressive strength has no linear relationship with the combine fineness modulus of aggregate. Yaqub and Bukhari [2] investigated the effect of coarse aggregate size on compressive strength of high strength concrete and found that the compressive strength of

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concrete depends upon a number of factor such as, mix ratio, size, texture of coarse and fine aggregate, method of compaction, and curing period. They reported that the aggregate of sizes 10 and 5 mm gave higher strength than all other sizes (20, 25, and 37.5 mm) of aggregates. Also, Woode et al [3] conducted tests to determine the effect of different sizes of machine crushed gneisses used in Ghana for concrete production on the compressive strength of concrete. They considered coarse aggregate samples of maximum sizes of 10, 14 and 20 mm at constant water/cement ratio of 0.63. Their results showed that the smallest coarse aggregate size gave the highest compressive strength and lowest slump at constant water/cement ratio. This agrees with the findings of Hague et al [1] and Yaqub and Bukhari [2] for high strength concrete.

Furthermore, Vilane and Sabelo [4] carried out experiment to determine the effect of aggregate size on the compressive strength of concrete. The considered three aggregate sizes (9.5, 13.2 and 19.0 mm) and the control for constant mix of 1:2:4 with a water/cement ratio of 0.5. Their results showed that slump increased with increasing aggregate size. They reported that the mean compressive strengths for the 9.5, 13.2, and 19 mm were 15.34, 18.61 and 19.48 N/mm^2, respectively. They concluded that concrete workability (slump) was directly proportional to aggregate size and the mean concrete compressive strength increased with increasing aggregates size. This is contrary to the findings Hague et al [1], Yaqub and Bukhari [2] and Woode et al [3]. Pandurangan et al. [5] evaluated the influence of size and shape of locally available coarse aggregates on the strength and flow characteristics of self-compacting concrete (SCC). They used two grades of SCC mixes with 60% and 40% replacement of cement with flyash. Their results showed that the flowability and strength of the high volume flyash SCC concrete mix with 10 to 16 mm maximum size aggregate (MSA) is found to be better than low volume flyash SCC with 20 mm (MSA). Smaller aggregate sizes were found to be better in this case because of the peculiar nature of the self-compacting concrete.

Arum and Olotuah [6] stated that aggregate size, shape and surface texture could indirectly affect strength because they affect the workability of the concrete. They said this would occur because more water would be required in mixtures made unworkable by big aggregate sizes, thus resulting in concrete with lower strength. Arslan and Kamas [7] investigated the effect of varying size of the aggregates on the compressive strength of concrete cubes at 28 days. They created three-dimensional concrete models by idealizing the material properties such as modulus of elasticity and mass density that they obtained experimentally. The used piezoelectric ceramic patches (PZT) in the core of the concrete cube models with aggregates in fine, medium, and coarse sizes and the harmonic analyses were simulated in commercial software, ABAQUS using the multi-physics finite element method (MP-FEA). They used electromechanical impedance spectroscopy (EMIS) results as well as mechanical impedance spectroscopy (MIS) results to highlight the relative changes in the impedance results depending on the aggregate sizes. Their EMIS and MIS results gave varying trendlines due to the varying modulus of elasticity and the densities. Also, they found the concrete models with 19 mm aggregates to be the most durable followed by 38 and 76 mm. They observed from the MIS results at 0-2000 Hz intervals, that the first peak was observed for models with 19 mm aggregates. Krishna et al. [8] investigated the effect of different sizes of coarse aggregate (i.e., 20; 16; 12.5 and 10 mm) on the properties of Self compacting concrete (SCC.). They considered M30 grade concrete and a total of eight mixes were prepared. They concluded that fresh properties of SCC reduced with increase in size of aggregates and that the compressive strength, split tensile strength and flexural strength of SCC were maximum at 20 mm aggregate. They stated that the increase in strength was directly proportional to the size of aggregate.

Ahmed and Rahman [9] studied the effect of size of locally available aggregate on the variation of compressive strength and determined the mix ratio at which higher strength could be obtained. They considered six different sizes of coarse aggregates (19, 12.5, 9.5, 4.75, 2.36 and 1.18 mm), mixtures of local sand and Sylhet sand (1:1) with fineness modulus of 1.93 and ordinary Portland cement was used as binding material. Also, they made different blends of coarse aggregates like 2.5 and 9.5; 9.5 and 4.75; 19, 12.5, 9.5 and 4.75; 12.5, 4.75, 2.36 and 1.18 mm) and four nominal mixes (1:1.5:3 (mix 1); 1:1.25:2.5(mix 2); 1:1:2(mix 3) and 1:0.75:1.5(mix 4)) with constant water-cement ratio of 0.45. They found that combination of aggregate sizes 19, 12.5, 9.5 and 4.75 mm showed higher strength in mix ratios 1, 2 and 3 after 7, 14 and 28 days curing period, while in mix ratio 4 the maximum strength was obtained for combination of aggregate sizes 12.5 and 9.5 mm. Furthermore, Ajamu and Ige [10] examined the potential impact of coarse aggregate type and mixing procedures on the properties of concrete. They used gravel and crushed granite and three mixing methods - mixing on bare ground, on concrete platform, and the use of mixing machine- in the study. They considered 1:3:6 mix ratio with water-cement ratio of 0.65. They reported that for the granite concrete, the compaction factor for mixing on concrete platform and using mixing machine was 0.93 while that of concrete mixed on bare ground was 0.91, while the corresponding results for gravel concrete were 0.94 and 0.92, respectively. Also, they stated that the compressive strength at 28 days of concrete made with granite on bare ground was 26.49 N/mm^2, those of concrete mixed on concrete platform and mixing machine were 29.33 and 29.60 N/mm^2, respectively. The corresponding values for gravel concrete were 10.13, 13.56 and 15.11 N/mm^2. They concluded that to achieve a high compressive strength, density and workability of concrete mix, machine mixing method should be adopted and granite material should always be used for the concrete production. Their study showed that the performance of the aggregates could be related to the properties of the aggregates used.

Guades et al [11] worked on the behavior of the geopolymer concrete under compressive loading with particular attention on the effect of the size of aggregate. They used rounded coarse aggregates. Three ranges of gravel sizes were adopted in the study: M1 (12.5 – 25 mm); M2 (25 – 37.5 mm); and M3 (37.5 – 50 mm). Compressive tests were carried out on a $100 \times 200\ mm$ cylindrical specimen using a compression testing machine. The specimens were cured at an ambient temperature and in oven at 60°C. They reported that generally the compressive strength decreases with increasing mean size of the coarse aggregates. They explained the phenomenon with two notable reasons. First, bigger size aggregates generate wider aggregate-paste interface. Second, internal bleeding occurs when water gets trapped on the underside of the bigger sized aggregate. This resulting in the formation of voids when the trapped water evaporates, thus causing decrease in the strength of the concrete. They observed that the mean particle size of 18.75 mm provides the highest value of the compressive strength for specimen cured in an ambient temperature. Also, they observed that oven-cured specimen had higher compressive strength values than ambient cured specimens. Abdullahi [12] investigated the effect of aggregate type on compressive strength of concrete. He employed three types of coarse aggregates: quartzite, granite, and river gravel with sand from borrow pit and a nominal mix with water-cement ratio of 0.6. His test results showed that concrete made from river gravel has the highest workability followed by crushed quartzite and crushed granite aggregates. Highest compressive strength at all ages was noted with concrete made from quartzite aggregate followed by river gravel and then granite aggregate. He concluded that aggregate type has effect on the compressive strength of normal concrete. Neetu and Rabbani [13] evaluated the effect of aggregate size on the compressive strength of concrete. Their study involved three treatments, which were aggregate of sizes 10, 12 and 15 mm. They used nominal mix of 1:2:4 with a water/cement ratio of 0.5 throughout the experiment. Their results reflected that slump increased with increasing aggregate size. The concrete made from the 10, 12 and 15 mm aggregate sizes had slumps of 10, 15 and 20 mm, respectively. The mean compressive strength for the 10, 12, and 15 mm were 13, 15 and 20 N/mm^2, respectively. They concluded that concrete workability was directly proportional to aggregate size and the concrete compressive strength increased with increasing aggregates size.

Also, Ajamu and Ige [14] evaluated the effect of varying coarse aggregate size on the flexural and compressive strengths of concrete. They considered 9.0, 13.2, 19, 25.0 and 37.5 mm aggregate sizes and nominal mix 1:2:4 with water cement ratio of 0.65. Their specimens were subjected to curing in water for 28 days and tested to determine the compressive strength and flexural strength using Universal Testing Machine. They reported compressive strength of 21.26, 23.41, 23.66, and 24.31 N/mm^2 for concrete having coarse aggregate sizes 13.2, 19, 25.0 and 37.5 mm, respectively, while the flexural strength were 4.93, 4.78, 4.53, 4.49, 4.40 N/mm^2 respectively. They concluded that the coarse aggregate size is directly proportional to the workability of a fresh concrete and the compressive strength of a concrete increases with increase in coarse aggregate size. Their finding in this regard is in line with researchers that found that increasing aggregate size leads to corresponding increase in compressive strength. They stated that the flexural strength of concrete beam is inversely affected by the increase in coarse aggregate. Karagüler and Yatağan [15] studied the effect of the aggregate grain size on the shrinkage and reported that the shrinkage decreased while the maximum grain size was bigger than 9 mm. They explained that coarse aggregate restrains the development of the crack. The larger grains restrain the inner strains and prevent the change of the micro-cracks to the macro-cracks. This implies that the concrete with the coarse aggregate size greater than 9mm would have higher compressive strength. Salau and Busari [16] investigated the effect of coarse aggregate sizes on the strength characteristics of laterized concrete. They studied 19.5, 12.5, 9.5, 5.0 and 2.36 mm coarse aggregates obtained from Ojodu-Berger in Lagos State while the sharp river sand was used as a fine aggregate. Their results showed that workability, density and compressive strength at constant water-cement ratio increase with the increase in the coarse aggregate particle size and also with curing age. Lastly, Musa and bin Saim [17] conducted a study to determine the effect of using coarse aggregate of sizes 10, 20 and fine aggregate (sand mining) 3 mm, randomly purchased from suppliers on concrete strength. They prepared concrete samples from each aggregate using mix ratio of 1:2:4 and water cement ratio of 0.5. Their results showed the concrete aggregate size of 20 mm has 45.7% higher compressive strength than the concrete aggregate size of 10 mm.

The literature review shows there is no general agreement about the effect of aggregate size on the compressive strength. Some researchers stated that the compressive strength increases with increasing aggregate size, while others found that the smaller aggregate size gives better compressive strength. Therefore, a research in this area will be worthwhile. The aim of this study is to determine the effect of different aggregates sizes used for construction work in Nigeria on the compressive strength of concrete.

2. Materials and Methods

2.1. Materials

The materials used for this research study are aggregates (coarse and fine), ordinary Portland cement and water.

Coarse aggregate: The coarse aggregates used for the study is from granitic rock. The single sized aggregates used are 6, 10, 12.5, 20, and 25 mm. They were sourced from Kopek quarry construction company located at Ise Ekiti, Ekiti state, Nigeria. The particle size distributions of the aggregates determined in accordance with British Standard [18] is shown in Figure 1.

Fine aggregates: The fine aggregate used in the study is river sand. It is free of clay and organic materials. The particle size distribution is shown in Figure 1.

Cement: The cement used was Ordinary Portland cement of 32.5 Grade. It meets all the requirements for cement as indicated by the manufacturer (Dangote Cement, Nigeria).

Water: The water fit for drinking (potable) was used for the study.

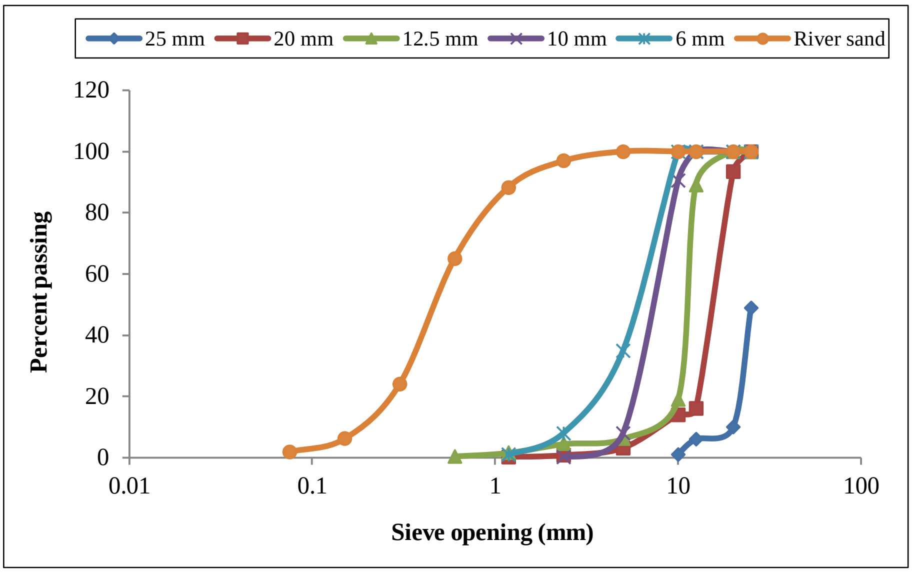

Figure 1. Particle size distribution curves of the aggregates

2.2. Method

2.2.1. Preparation of the Concrete

Two nominal mixes: 1:2:4 and 1:3:6 were used in the study. The batching of the concrete was done by weight. The water-cement ratio of 0.55 was used. The aggregates and water were properly mixed to coat the surface of all the aggregate particles with cement paste. A total of 120 concrete cubes, each of dimension 150×150×150 mm were produced. The concrete cubes were cured at 7, 21, 28, and 56 days in water at room temperature and the compressive strengths were determined. Typical concrete cubes are shown in Figure 2.

Figure 2. Typical concrete cubes for compressive strength test

2.2.2. Compressive Strength Test

The test was carried out in accordance with British Standard [19]. The compressive strength of each specimen was calculated by dividing maximum load carried by the specimen during the test, that is, the load at failure by the cross-sectional area of the specimen as shown in Equation 1.

$$\text{Compressive strength (N/mm}^2\text{)} = P/A \qquad (1)$$

Where, P is the load at Failure and A, the cross-sectional area of the concrete cube.

3. Results and Discussion

The compressive strength results of the concrete produced with 6, 10, 12.5, 20 and 25 mm single-sized aggregates for nominal mix ratio 1:2:4 is shown in Figure 3, while that of nominal mix 1:3:6 is shown in Figure 4. The results show a clear picture of how aggregate size affects the compressive strength of the concrete. The first observation from the results is that the compressive strength increases with age and for all the tests the highest compressive strength was recorded at 56 days. This implies that strength development continues beyond the 28 days that the concrete is believed to have attained full strength.

Figure 3 shows that for the nominal mix 1:2:4, the concrete produced with 20 mm aggregate has the highest compressive strength followed by the concrete with 25, 12.5, 10 and 6 mm, respectively. Also Figure 4 shows that concrete samples from the nominal mix 1:3:6 follow the same trend as nominal mix 1:2:4.

As shown in Figures 3 and 4 for both nominal mixes, the compressive strength increases with increasing aggregate size and all the concretes produced from the aggregate sizes follow the same trend except that produced using 12.5 mm aggregate size, which has compressive strength falling between 20 and 25 mm from 28 days of curing.

Although, the results showed that the compressive strengths increase with increasing aggregate size, concrete produced using 20 mm single sized aggregates had the highest compressive strength. This implies that there is optimum size, in this case 20 mm, which will give the best results. The results indicate that using very big aggregate sizes in normal concrete will not produce the desired result and this is because of the difficulty in compacting the concrete to a dense state and the greater voids that will be created in the mix. Also, this could also be attributed to the reason given by Arum and Olotuah [6] that big aggregate sizes make the concrete mix unworkable, thus requiring that the mixtures be made workable by adding more water, resulting in concrete with lower strength. Again, as stated by Guades et al [11], big aggregate size leads to wider aggregate-paste interface providing opportunity for water to get trapped and leaving voids in the concrete after evaporation.

The percentage increase in the 56 day compressive strength of the concrete produced with 10, 12.5, 20 and 25 mm aggregates relative to the 6 mm aggregates for nominal mix 1:2:4 is shown in Table 1, while Table 2 shows that of nominal mix 1:3:6. Table 1 shows that the percent increase for nominal mix 1:2:4 ranges from 102.2 to 207.7%, while that of nominal mix 1:3:6 ranges from 70.2 to 185.5 with the concrete produced with 20 mm aggregate size having the largest percentage as mentioned earlier.

The study indicates that a serious attention must be paid to the aggregate size used in the production of concrete for structural purposes.

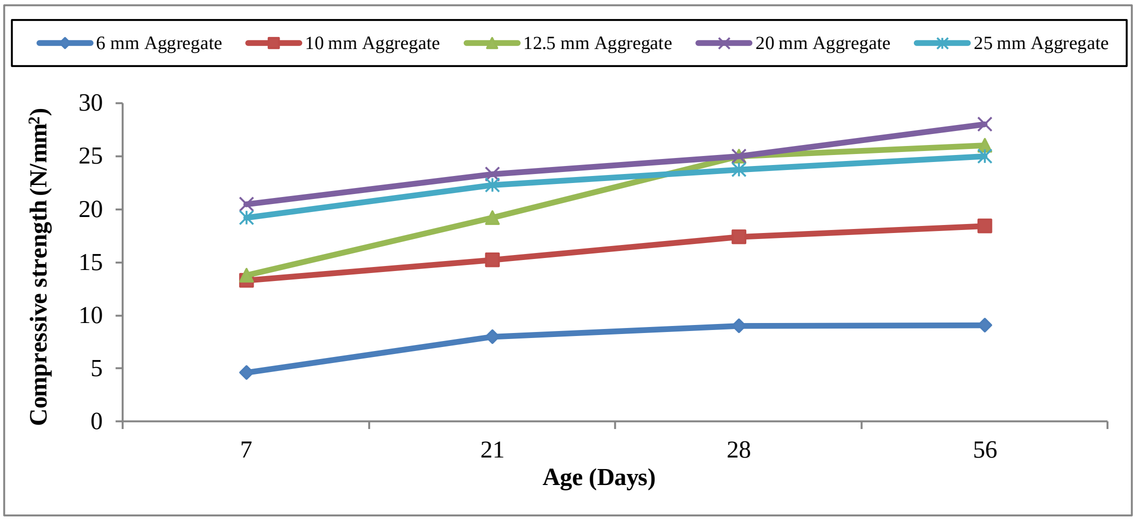

Figure 3. Compressive strength of the concrete produced using different aggregate sizes with age for nominal mix 1:2:4

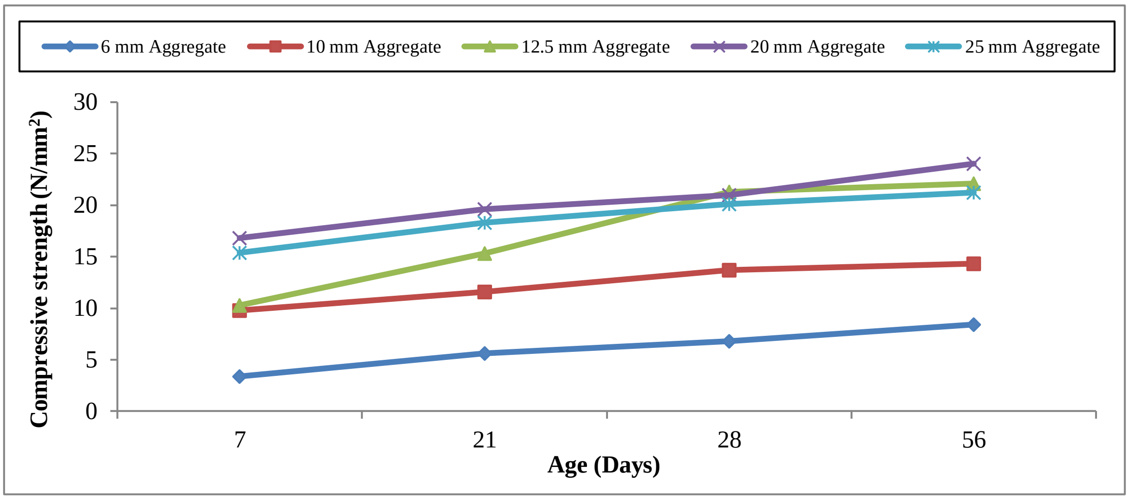

Figure 4. Compressive strength of the concrete produced using different aggregate sizes with age for nominal mix 1:3:6

Table 1. Percentage increase in the compressive strength of concrete produced with 10, 12.5, 20 and 25 mm relative to 6 mm for 1:2:4

Aggregate Size (mm)	56 –day Compressive Strength (N/mm^2)	Percentage increase relative to concrete with 6mm aggregate
6	9.1	-
10	18.4	102.2
12.5	26	185.7
20	28	207.7
25	25	174.7

Table 2. Percentage increase in the compressive strength of concrete produced with 10, 12.5, 20 and 25 mm relative to 6 mm for 1:3:6

Aggregate Size (mm)	56 –day Compressive Strength (N/mm^2)	Percentage increase relative to concrete with 6mm aggregate
6	8.4	-
10	14.3	70.2
12.5	22.1	163.1
20	24	185.7
25	21.2	152.4

4. Conclusion

The study investigates the effects of the size of aggregate on the compressive strength of concrete. It was found that strength development takes place beyond the 28-day used for specifications. Also, the study shows that as the size of aggregate used in concrete increases, the compressive strength also increases. However, it was found that there is a particular aggregate size that will give the best performance and using aggregate size greater than it will not give the desired result. The present study shows that the concrete produced with the 20 mm aggregate size has the highest compressive strength.

Based on findings of this research study, it is therefore recommended that careful attention must be paid to the sizes of aggregates used in the production of concrete for structural purposes.

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