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Influence of aggregate size and curing time on the compressive strength of concrete

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Abstract
This study explored the influence of aggregate size and curing time on the compressive strength of concrete. The coarse aggregates were sieved to a particle size of 19 mm, 13.2 mm, 9.5 mm, and 6.7 mm, while the fine aggregate was sieved to an average size of 2mm. Different concrete formulations of dimensions 100 mm x 100 mm x 100 mm were prepared using cement, fine aggregates, and coarse aggregates in a nominal mix ratio of 1:2:4 with a water-cement ratio of 0.6. Three cubes were cast for each aggregate size and cured for 7 days, 14 days, 21 days, and 28 days respectively. The compressive strength of the prepared concretes was measured. The experimental results demonstrated the dependence of compressive strength of concretes on the aggregate size and curing time. Results revealed at each curing time, the compressive strength of the concrete increased with increasing aggregate size up to 13.2 mm size and decreased with further increase in aggregate size (from 13.2 mm to 19 mm). The compressive strength of the concrete containing an aggregate of 13.2 mm size increased by about 46.84% as the curing time increased from 7 days to 28 days. With increasing curing time at different aggregate sizes, the compressive strength increased correspondingly. The average weight of the concrete samples decreased with increasing curing time.

Keywords: Compressive strength, coarse aggregate, concrete, interfacial transition, curing ages

1. Introduction

The role of coarse aggregate in concrete is central to its strength. While the topic has been under study for many years, an understanding of the effects of coarse aggregate has become increasingly more important with the introduction of high-strength concretes (since coarse aggregate plays a progressively more important role in concrete behavior, as strength increases). In normal-strength concrete, failure in compression almost exclusively involves de-bonding of the cement paste from the aggregate particles at what, for this report, will be called the matrix-aggregate interface. In contrast, in high-strength concrete, the aggregate particles, as well as the interface, undergo failure, clearly contributing to overall strength. As the strength of the cement-paste constituent of concrete increases, there is greater compatibility of stiffness and strength between the normally stiffer and stronger coarse aggregate and the surrounding mortar. Thus, micro-cracks tend to propagate through the aggregate particles (since, not only is the matrix-aggregate bond stronger than in concretes of lower strength, but the stresses due to a mismatch in elastic properties are decreased). Thus, aggregate strength becomes an important factor in high-strength concrete.

A study by Aginam *et al.* [1] on the compressive strength of concrete prepared from different aggregates of natural ravels and granite, established that the crushed granite gave a higher compressive strength than that of natural gravel prepared concrete. Bhikshma and Annie [2] in their study of high-grade concrete made of different volumes of fly ash revealed that the workability of the concrete is dependent on the size and volume of the fly ash. The results showed that the workability increased with increasing size and volume of fly ash from 10 mm to 20 mm, and from 20 vol. % to 59 vol.% respectively. Ahmad and Alghamd [3] is their study established that replacing 8% cement with silica fume led to an improvement of both compressive strength, modulus of elasticity, and steel-corrosion resistance of concrete in 3 % NaCl solution. The effect of replacing sand with laterite on the density, workability, and compressive strength of concrete prepared using aggregates of different particle sizes at various curing age was investigated by Salau and Busari [4]. The study revealed optimum properties after adding 25% laterite of aggregate size 12.5-19.5 mm at 28 days curing time. A study by Mohammad *et al.* [5] revealed that aggregate particle size has great effects on the ductility, fracture toughness, and impact energy of self-compacting concrete. The study established that the ductility, fracture toughness, and impact energy of self-compacting concrete showed increasing trends with increasing aggregate particle size. The elastic modulus, tensile; and compressive strengths behavior of concretes containing different aggregates of steel slag, dolomite, calcareous, and quartzitic limestone was investigated by Beshr *et al.* [6] The study established that the concrete prepared with steel slag gave the highest split tensile strength among the aggregates, though with very low compressive strength. The concrete containing calcareous limestone gave the best compressive strength among other aggregates, with corresponding lower elastic modulus. A study by Kwan *et al.* [7] revealed that by addition of recycled coarse aggregate to concrete, excellent ultrasonic pulse velocity and compressive strength with corresponding low water absorption and intrinsic permeability. Sudarshan *et al.* [8] in their study of the workability, permeability, and compressive strength of lean cement concrete prepared with marble aggregate revealed and increasing workability and compressive strength of the prepared concrete with increasing percentage addition of marble aggregate up to 80%. The study also revealed that by increasing the content of marble aggregate, the porosity of the concreted correspondingly leading to an increase in the permeability of the concrete. A study by Rathish and Krishna [9] established that by addition of fly ash, the durability and compressive strength of concrete can be significantly enhanced with an optimum value of 20MPa and 30MPa obtained by adding 30% fly ash aggregate of 12.5 mm and 10 mm-size respectively after 56 days. The sorptivity of the fly ash based concrete decreased correspondingly at increasing compressive strength of the concrete. The workability of the prepared concrete was increased with decreasing aggregate size. Ajamu and Ige (2015) studied the effect of aggregate size on the compressive and flexural strength of concrete beams. Their work highlighted the fact that coarse-aggregate size is directly proportional to the slump (workability) of fresh concrete with constant water-cement ratio. The compressive strength of concrete increased with an increase in coarse aggregate size. Coarse aggregate sizes 13.2 mm, 19 mm, 25 mm, and 37.5 mm gave average compressive strength of 21.26 N/mm^2, 23.41 N/mm^2, 23.66 N/mm^2 and 24.31N/mm^2 respectively. The flexural strength of a concrete beam was found to be inversely affected by the increase in coarse-aggregate size, while the compressive strength of concrete was inversely proportional to flexural strength (as coarse-aggregate size increased when subjected to the same condition (s)).

2. Experimental procedure

2.1 Materials sourcing and preparation

For this experimental study, the coarse and fine aggregates were sourced from gneiss rock deposits and pits respectively at Ibadan, Oyo State, Nigeria. The coarse aggregates were sieved using a mechanical sieve to obtain aggregates of 6.7mm, 9.5mm, 13.2mm, and 19mm sizes as presented in Fig. 1, while the sand was sieved to obtain sand of 2 mm average size as presented in Fig. 2. Other materials such as Portland cement of specific gravity 3.15, 32.5 Grade (Nigerian Industrial Standards (NIS)), and potable water (BS 3148, 1980 standard) were obtained from Dangote group of company, Lagos, Nigeria, and Civil Engineering Laboratory, University of Ibadan, Nigeria, respectively.

Fig 1: Granite aggregates of different particle sizes (a) 19 mm, (b) 13.2 mm, (c) 9.5 mm, and (d) 6.7 mm

Fig 2: Fine aggregate of 2mm average particle size

2.2 Concrete formulation

Different concrete formulations of dimensions 100 mm x 100 mm x 100 mm were prepared using cement, fine aggregates, and coarse aggregates in a nominal mix ratio of 1:2:4 with a water-cement ratio of 0.6. Three cubes were cast for each aggregate size and cured for 7 days, 14 days, 21 days, and 28 days respectively. The compressive strength test was conducted using a compressive testing machine and the values calculated using equation 1. The samples were remolded 24 hours after casting and cured in water until their various testing ages. The concrete cubes were removed from the curing tanks in each category of aggregate-size specimen cast at respective curing days and allowed to drain off moisture from the surface for few minutes; they were then weighed using a weighing balance. The cubes were then put in the compression machine, and an increasing compressive load was applied to the specimen until a failure occurred, to obtain the maximum compression load. The compressive strength test was conducted on three samples of each of the aggregate size and the average value was taken.

$$\text{Compressive strength} = \frac{P \, x \, 10^3}{A}$$

Where, P equals the crushing load and A equals the area of the cube

3. Results and discussion

The effect of aggregate size and curing time on the compressive strength of the developed concrete samples is presented in Table 1 and Figs. 3-6. Table 1 and Figs. 3-6 revealed that the compressive strength and weight of the concrete samples produced are quite dependent on the aggregate size and curing time. The experimental results indicated that at each curing time, the compressive strength of the concrete increased with increasing aggregate size up to 13.2 mm size. Further increase in aggregate size from 13.2 mm to 19 mm led to decrease in compressive strength of the concrete. At curing time of 7, 14, 21, and 28 days, maximum compressive strength of 10.12 MPa, 10.33 MPa, 12.23 MPa, and 14.86 Mpa respectively were recorded. Figs. 3-6 showed that with increasing curing time at a different aggregate size, the compressive strength increased correspondingly. Fig. 6 showed that the compressive strength of the concrete containing aggregate of 19 mm size, the compressive strength increased from 8.43 MPa to 12.36 MPa as the curing time increases from 7 days to 28 days. For the concretes containing 9.5 mm and 6.7 mm sizes, the compressive strength values increased from 6.44 MPa to 14.34 MPa, and from 6.18 MPa to 11.01 MPa, as the curing time increased from 7 days to 28 days respectively. Table 1 showed that the weight of the concrete produced decreased with increasing curing time.

Table 1: Effects of aggregate size and curing time on the compressive strength of the developed concrete samples

Curing time (days)	Aggregate size (mm)	Average weight (kg)	Average maximum load (kN)	Average compressive strength (MPa)
7	19.0	2.71	84.27	8.43
	13.2	2.76	101.23	10.12
	9.5	2.78	64.37	6.44
	6.7	2.31	61.78	6.18
14	19.0	2.61	98.03	9.80
	13.2	2.62	103.33	10.33
	9.5	2.45	83.40	8.34
	6.7	2.36	78.13	7.81
21	19.0	2.64	114.1	11.41
	13.2	2.60	122.27	12.23
	9.5	2.44	92.77	9.28
	6.7	2.42	85.50	8.55
28	19.0	2.60	123.60	12.36
	13.2	2.53	148.57	14.86
	9.5	2.56	143.77	14.34
	6.7	2.35	110.1	11.01

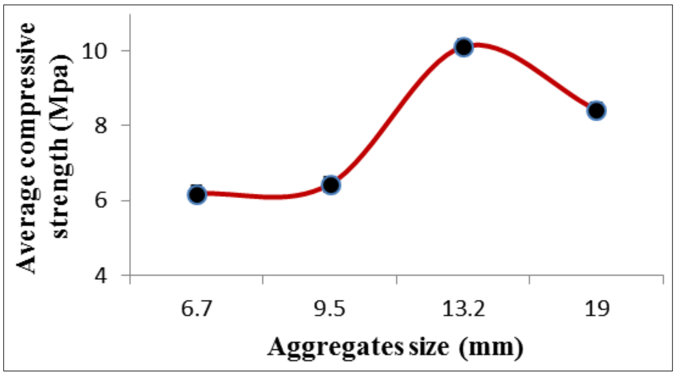

Fig 3: Effect of aggregate size on the compressive strength of concrete cured for 7 days

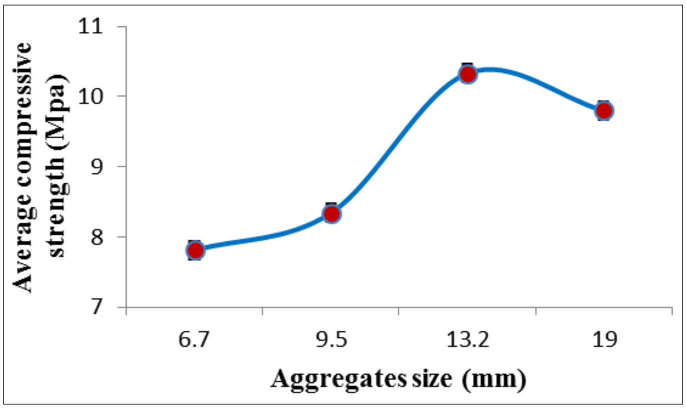

Fig 4: Effect of aggregate size on the compressive strength of concrete cured for 14 days

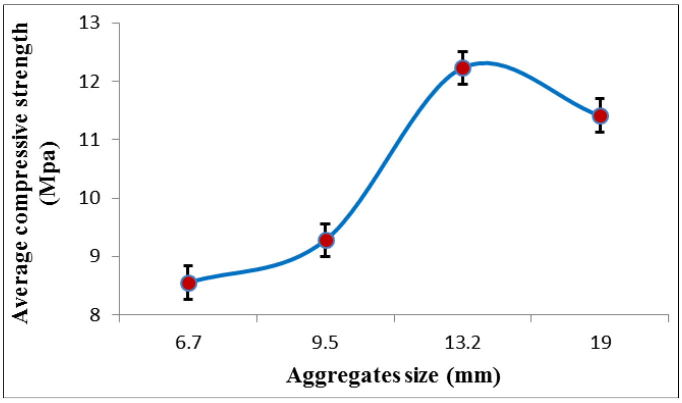

Fig 5: Effect of aggregate size on the compressive strength of concrete cured for 21 days

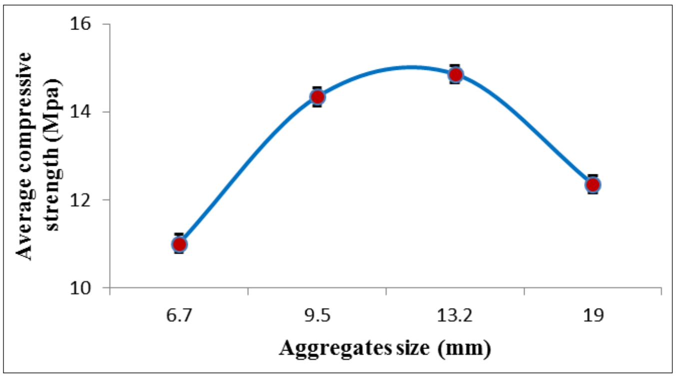

Fig 6: Effect of aggregate size on the compressive strength of concrete cured for 28 days

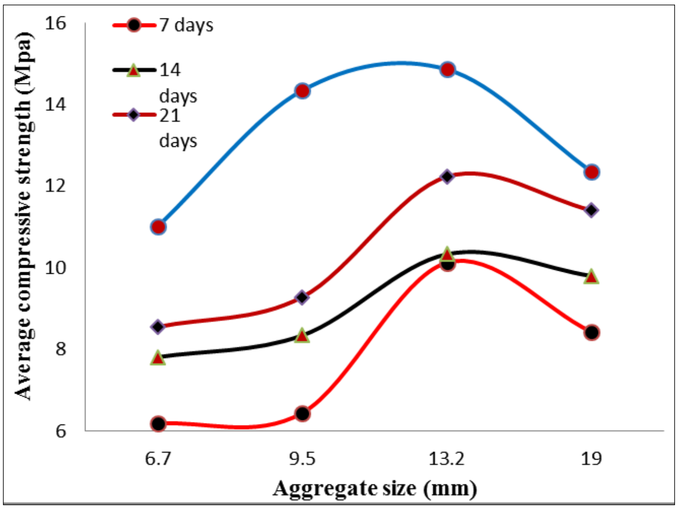

Fig 6: Effect of aggregate size and curing time on the compressive strength of concrete

4. Conclusion

This study explored the influence of aggregate size and curing time on the compressive strength of concrete. The experimental results demonstrated the dependence of compressive strength of concretes on the aggregate size and curing time. From the experimental results the following conclusions were drawn:

a. At each curing time, the compressive strength of the concrete increased with increasing aggregate size up to 13.2 mm size. Further increase in aggregate size from 13.2 mm to 19 mm led to a decrease in the compressive strength of the concrete.

b. At curing time of 7, 14, 21, and 28 days, maximum compressive strength values of 10.12 MPa, 10.33 MPa, 12.23 MPa, and 14.86 Mpa respectively were recorded.

c. With increasing curing time at a different aggregate size, the compressive strength increased correspondingly.

d. The compressive strength of the concrete containing an aggregate of 19 mm size, the compressive strength increased from 8.43 MPa to 12.36 MPa as the curing time increases from 7 days to 28 days.

e. For the concretes containing 9.5 mm and 6.7 mm sizes, the compressive strength values increased from 6.44 MPa to 14.34 MPa, and from 6.18 MPa to 11.01 MPa, as the curing time increased from 7 days to 28 days respectively.

f. The weight of the concrete produced decreased with increasing curing time.

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