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Effect of Coarse Aggregate Sizes on the Compressive Strength of Concrete using Response Surface Methodology

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Abstract

This paper examined the effect of coarse aggregate sizes on the compressive strength of concrete using response surface methodology. It has become imperative to carry out this study to ascertain which aggregate size, will produce the optimum compressive strength, which may guide engineers when using it in the construction industry. Regression equations relating the compressive strength of concrete using various aggregate sizes with both the curing duration, fine aggregate, cement and water/cement ratios were developed. The adequacy of the model was checked using the coefficient of determination (R^2). The results showed that the 9.5 mm aggregate sized concrete had 35 N/mm^2 as compressive strength for 28 days curing duration, while the 12.5 mm aggregate sized concrete had 24 N/mm^2 as compressive strength for 28 days curing duration and the 19 mm aggregate sized concrete's compressive strength was 23 N/mm^2 when cured for 28 days. The compressive strength of 9.5 mm aggregate sized concrete had an increase of 1.46% and 1.52% over the 12.5 mm and 19 mm aggregate sized concrete's compressive strength. The low coefficient of determination (R^2) of 0.1270 for 9.5 mm aggregate sized concrete, R^2 of 0.1322 for 12.5 mm aggregate sized concrete and R^2 of 0.1243 for 19 mm aggregate sized concrete shows that the linear model could not predict the compressive strengths of the different aggregate sized concrete efficiently.

1. Introduction

Concrete is made up of cement, water, fine and coarse aggregates [1]. Coarse aggregates which may be natural or artificial are aggregate sizes that cannot pass 4.75mm sieve while fine aggregate are aggregate that can pass through the 4.75 mm sieve [2]. The size of aggregate normally used in concrete varies from 37.5 mm to 0.15 mm [3]. The coarse aggregates can be classified as a mixture component of various sizes of stone or rock particles, which is in contact with each other. They can either be gravel, crushed stone or a combination of both, such as quartz, sandstone and quartzite in addition to blast furnace slag, or recycled concrete fragments [3]. Aggregates are classified in terms of density as: Heavy weight, normal and lightweight aggregates [4]. Heavyweight aggregate includes magnetite, iron shot, lead shot. Example of normal aggregate are sand, gravel, granite and also blast furnace slag, broken brick. Lightweight include pumice expanded slate, shale, and fuel ash [4].

For a properly engineered mix design, an in-depth knowledge of the properties of cement, aggregates and water is critical to understanding the behavior of concrete [5]. These includes the water/cement ratio, degree of compaction, ratio of cement to aggregates, bond between mortar and aggregates, grading of aggregates, physio-mechanical and mineralogical properties of aggregates [6]. Aggregates are a very significant constituent in concrete since they give body to the concrete, reduce shrinkage and affect economy. It constitutes more than 70% of the composition of concrete therefore aggregate contribute more to the compressive strength of concrete [6]. It is imperative that a constituent with such a high proportion would affect the strength of concrete [7]. Other studies have shown that aggregates provide volume stability and durability of the resulting concrete [8]. Some physical properties like specific gravity, bulk density and absorption and moisture content affect in great deal, the properties of the resulting concrete from such an aggregate [4]. An aggregate with a high porosity tends to produce less durable concrete than an aggregate of low porosity [9]. Many authors claim that uniformly distributed mixtures produce better workability than gap-graded mixtures [10, 1], although higher slumps could be achieved with gap-graded mixtures.

The scarcity or excess of any size fraction could result in poor workability and durability of concrete [12]. The amounts of coarse and fine aggregate must be in balance. Both coarse aggregate and fine aggregate should be uniformly graded. If fine aggregate is too coarse it will produce bleeding, segregation and harshness, but if it is too fine, the demand for water will be increased [12]. Consequently, the shape factor of aggregate also affects concrete.

According to [13] there are two other characteristics which were termed as roundness and angularity. Angularity is related to the sharpness of the edges and corners of a particle, while roundness attempts to describe the outline of the particle, which may be measured in terms of "convexity. Cubical or spherical particles require less paste and less water for workability [12]. Flaky and elongated particles negatively affect workability, producing very harsh mixtures.

It has become imperative for engineers to be interested in the compressive strength of concretes subjected to the different sizes of aggregate in other to know which aggregate size will be suitable in achieving the optimum compressive strength when used in various structural applications.

2. Methodology

This study used a quantitative experimental research design method to carry out this work. The experimental design is concerned about the investigation of the effect of coarse aggregate sizes on the compressive strength of concrete. The material used in the study comprises coarse aggregate sizes of 9.5 mm, 12.5 mm and 19 mm. Also, Portland cement, fine aggregate and water were used. The tools used consisted of steel moulds (100 mm x 100 mm x 100mm size), shovel and head pans.

Ninety-two (92) cubes of 100 mm x 100 mm x 100 mm were made with two cubes for each mix. However, the concrete was cast and cured between 7 days and 28 days respectively using w/c of 0.57 which conforms to the minimum standard of [14] for concrete making.

Data were sourced from the compressive strength test carried out in the laboratory.

The regression equations relating the compressive strength of the 9.5 mm, 12.5 mm and 19 mm concrete were developed using a commercial statistical package, Design-Expert Software 7.0.0. (Stat-Ease Inc., Minneapoli, USA). Response Surface Methodology (RSM) using the Central Composite Design (CCD) was applied to study the response on the independent variables (curing duration, cement, coarse and fine aggregate, w/c ratio in the concrete). The regression coefficient of the linear model was determined using data obtained from the central composite design employed for the optimization of the independent variables as shown in Equation (1)

$$y_i = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{ii>j}^{n} \sum_{j}^{n} b_{ij}\, x_i x_j + e \quad (1)$$

$where;$

$y_i =$ $predicted\ response\ (\ compressive\ strength\ of\ 9.5mm, 12.5mm\ and\ 19mm\ concrete)$

$b_0, b_i\, b_{ii}\ \ b_{ij}\ = coefficients$

$n = number\ of\ independent\ variables$

$x_i, x_j =\ actual\ factors$

$e = error\ term$

The adequacy of the model was checked using the coefficient of determination R^2.

3. Results and Discussion

Regression equations relating the compressive strength of concrete using various aggregate sizes with both the curing duration, fine aggregate, cement and water/cement ratios were developed. Table 1 shows the factorial design and compressive strengths of the concrete using the various sizes of aggregate.

The 9.5 mm aggregate concrete had the best value of 25 N/mm^2, 34 N/mm^2 and 35 N/mm^2 compressive strengths at 7 days, 18 days and 28 days of curing as shown in Figure 1. The 12.5 mm aggregate concrete had compressive strength of 23 N/mm^2, 23 N/mm^2 and 24 N/mm^2 when cured for 7 days, 18 days and 28 days duration as shown in Figure 1. The 19 mm aggregate concrete had compressive strengths of 22 N/mm^2, 23 N/mm^2 and 23 N/mm^2 when cured for 7 days, 18 days and 28 days duration as shown in Figure 1.

These show a progressive decrease in compressive strengths of the concrete as the aggregate sizes increased. It may be attributed to more water and cement requirement for small-size aggregates, when compared to larger aggregate sizes, due to an increase in total aggregate surface area [15]. This was also collaborated by [16] in their studies, which showed that there is a direct correlation between the changes in coarse aggregates size to changes in the strength and fracture properties of concrete. In Table 2, the linear model for 9.5 mm aggregate concrete showed a R^2 value of 0.1270, which indicates that 12.7% of the systematic variations in the compressive strength of the concrete is accounted for by the independent variables (cement, fine aggregate, coarse aggregate, w/c ratios and curing duration). More so, Table 2 shows the result of the linear model for the 12.5 mm aggregate concrete. The R^2 of 0.1322 reveals that 13.22% of the systematic variations in the compressive strength of the 12.5 mm aggregate concrete are accounted for by the independent variables (cement, fine aggregate, coarse aggregate, w/c ratios and curing duration). Furthermore, the 19 mm aggregate concrete in Table 2 shows a R^2 of 0.1243. These reveal that 12.43% of the 19 mm aggregate concrete are accounted for the independent variables (cement, fine aggregate, coarse aggregate, w/c ratios and curing duration).

Table 1: Factorial design and response value for the different sizes of aggregate

Experiment	Independent Variable					Compressive strength of 9.5 mm concrete (N/mm²)	Compressive strength of 12.5 mm concrete (N/mm²)	Compressive strength of 19 mm Concrete
	Cement (kg)	w/c ratios	Fine aggregate (kg)	Coarse aggregate (kg)	Curing duration (days)			(N/mm²)
1	0.9	0.475	0.9	3.3	18	33	28	28
2	0.8	0.475	0.9	3.3	7	15	19	10
3	0.8	0.5	0.925	3.3	7	8	24	26
4	0.8	0.475	0.9	3.4	18	14	20	23
5	0.8	0.475	0.925	3.4	7	21	22	24
6	0.9	0.475	0.925	3.3	7	18	18	32
7	0.8	0.475	0.925	3.2	28	28	10	15
8	0.7	0.475	0.925	3.3	7	22	20	28
9	0.9	0.475	0.925	3.4	18	30	17	24
10	0.8	0.5	0.925	3.2	18	21	20	11
11	0.8	0.45	0.925	3.3	28	24	18	21
12	0.9	0.475	0.925	3.3	28	24	23	18
13	0.8	0.475	0.925	3.2	7	25	23	22
14	0.8	0.475	0.95	3.3	7	15	16	20
15	0.8	0.45	0.925	3.2	18	20	10	20
16	0.8	0.45	0.9	3.3	18	22	16	17
17	0.7	0.5	0.925	3.3	18	7	13	12
18	0.9	0.45	0.925	3.3	18	26	14	21
19	0.7	0.475	0.925	3.3	28	18	20	20
20	0.8	0.475	0.925	3.3	18	20	14	25
21	0.8	0.45	0.925	3.3	7	18	24	21
22	0.7	0.475	0.925	3.2	18	27	17	24
23	0.8	0.45	0.925	3.4	18	23	15	22
24	0.8	0.475	0.925	3.3	18	22	18	25
25	0.8	0.475	0.95	3.2	18	23	20	23
26	0.8	0.475	0.925	3.3	18	30	25	23
27	0.7	0.475	0.95	3.3	18	22	18	22
28	0.9	0.5	0.925	3.3	18	23	16	25
29	0.8	0.475	0.95	3.4	18	17	18	24
30	0.8	0.5	0.9	3.3	18	22	20	22
31	0.8	0.475	0.9	3.3	28	35	24	23
32	0.8	0.475	0.925	3.3	18	16	18	25
33	0.8	0.475	0.925	3.4	28	21	17	15

34	0.9	0.475	0.95	3.3	18	34	23	23
35	0.8	0.45	0.95	3.3	18	23	18	23
36	0.9	0.475	0.925	3.2	18	25	22	22
37	0.8	0.5	0.95	3.3	18	26	22	20
38	0.8	0.5	0.925	3.4	18	14	25	23
39	0.7	0.475	0.9	3.3	18	23	21	23
40	0.7	0.475	0.925	3.4	18	25	21	24
41	0.8	0.475	0.925	3.3	18	23	20	25
42	0.8	0.5	0.925	3.3	28	21	25	22
43	0.7	0.45	0.925	3.3	18	18	23	21
44	0.8	0.475	0.9	3.2	18	22	21	22
45	0.8	0.475	0.95	3.3	28	22	22	23
46	0.8	0.475	0.925	3.3	18	24	20	21

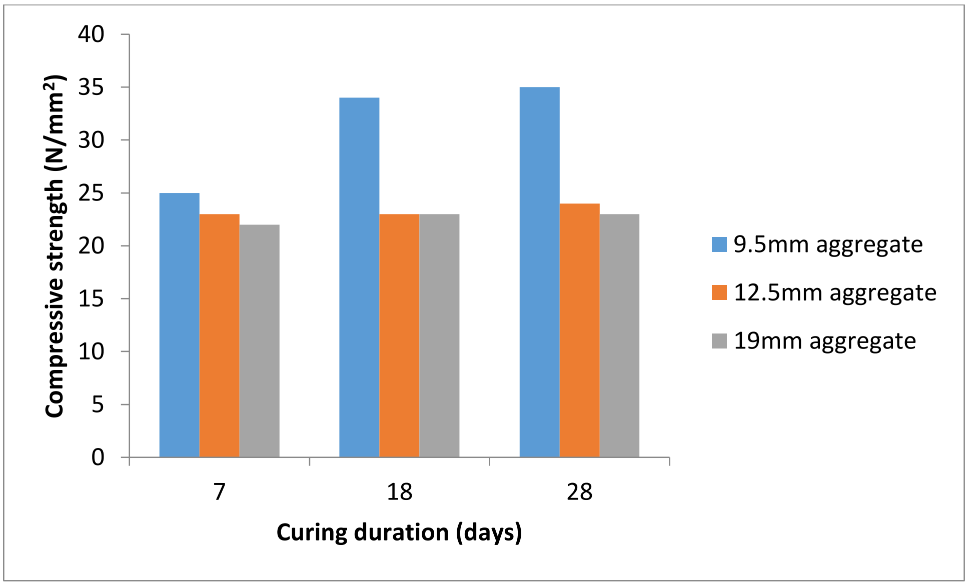

Figure 1: compressive strength and curing duration for different aggregate sizes

Table 2: Fit statistics for different aggregate sized concrete

Statistics	9.5mm aggregate size concrete	12.5mm aggregate size concrete	19mm aggregate size concrete
Std Dev.	6.35	5.54	4.15
Mean	21.57	18.87	21.80
C.V.%	29.44	29.34	19.02
R^2	0.1270	0.1322	0.1243

4. Conclusion

It can be concluded from this study that the optimum compressive strength obtained at 28 days of curing for 9.5 mm, 12.5 mm and 19 mm aggregate sized concrete were 35 N/mm^2, 24 N/mm^2 and 23 N/mm^2 respectively. These translate to an increase of 1.46% and 1.52% of compressive strength for 9.5 mm aggregate sized concrete over the 12.5 mm and 19 mm aggregate sized concrete. The low coefficient of determination (R^2) of 0.1270 for 9.5 mm aggregate sized concrete, R^2 of 0.1322 for 12.5 mm aggregate sized concrete and R^2 of 0.1243 for 19 mm aggregate sized concrete shows that the linear model could not predict the compressive strengths of the different aggregate sized concrete efficiently.

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