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Locally Sourced Coarse Aggregate Effect on the Compressive Strength of Concrete: Case Study of Anambra State Sandstone

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ABSTRACT

This paper examines the coarse aggregate effect of Anambra State sandstone on the compressive strength of concrete using response surface methodology. This has become imperative due to its abundant availability in the south east region of Nigeria. Regression equations relating the compressive strength of the sandstone and granite concrete with both the curing duration, fine aggregate, cement and water/cement ratios were developed. The suitability of these equations was tested using the analysis of variance (ANOVA).The results show that the maximum compressive strength of the granite and sandstone concrete were 36.25 N/mm^2 and 35.0 N/mm^2 at 28 days of curing using 0.48 w/c ratio, This was only a 1.04% increase of compressive strength of the granite concrete over the sandstone concrete. The ANOVA for the quadratic model shows the adjusted R^2 of 0.9860 and a linear model for the sandstone shows the adjusted R^2 of 0.9084. This shows that quadratic model for the granite concrete and linear model for the sandstone can predict the compressive strength of the respective concrete. Therefore, Anambra State sandstone can be used for heavy structural works.

1. Introduction

Concrete is an artificial engineering material made from a mixture of Portland cement, water, fine and coarse aggregates, and small amount of air. It is the most widely used construction material in the world [1]. It is well recognized that coarse aggregate plays an important role in concrete. Coarse aggregate significantly occupies over one-third of the volume of concrete which account for about 60-75% of the total volume of concrete [2, 3] and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and the economy [4]. Research has shown that changes in the coarse aggregate can lead to a change in the compressive strength and fracture properties of the concrete. To predict the behavior of concrete under general loading requires an understanding of the effects of aggregate type and aggregate size. This understanding can only be gained through extensive testing and observation. It was reported in [5] that sandstone is increasingly being used in concrete construction around the world as a widespread aggregate resource and can compete favourably with granite chipping in term of strength and other properties such as workability if properly graded [6]. Studies have shown that the basic reason for coarse aggregates is to provide bulk to the concrete, as economic filler which is much cheaper than cement. Other studies have shown that aggregates provide volume stability and durability of the resulting concrete [7].

Research carried out by [8] on an investigation to compare the effect of various types of coarse aggregates on the compressive strength of concrete. In its study, [8] took into consideration five different types of coarse aggregates: granite, gravel, waste marble, limestone, and sand stone. Among the test carried were specific gravity test, sieve analysis, aggregate impact value test, fineness test and compressive strength test.

The fine aggregate (River Ekwaen sand) gave a specific gravity of 2.75 and sieve analysis showed that it was well graded. For the different coarse aggregate considered, sieve analysis, aggregate impact test and compressive test of 28 days revealed that granite which was well graded, had the lowest impact value of 32.50% (low impact value, more strength for aggregate) and compressive strength of 21.79 N/mm^2, sand stone was a gap graded with impact value of 69.55% and a compressive strength of 12.39 N/mm^2, gravel was poorly graded with impact value of 44.24% and compressive strength of 16.12 N/mm^2, waste marble was poorly graded with impact value of 39.71% and a compressive strength of 19.89 N/mm^2, and limestone was poorly graded with impact value of 59.55% and a compressive strength of 14.73 N/mm^2. On the basis of their study of compressive strength of the five different coarse aggregates, it was concluded that granite is the most preferred coarse aggregate material [8]. Research carried by [9] studied the effect of coarse aggregate type (basalt, granite and limestone) on the mechanical properties of high strength concrete. Compressive and flexural strength, modulus of elasticity, and stress-strain behavior were analyzed for concrete, mortar, and rock. They found that weaker aggregates, such as limestone, reduce compressive strengths significantly, since the concrete strength is limited by the aggregate strength. However, aggregate type did not affect flexural strength. The work reported by [10] concluded that normal-strength concretes are not greatly affected by the type or size of coarse aggregates However, for high strength concretes, coarse aggregate type and size affect the strength and failure mode of concrete in compression. The effect of using crushed quartzite, crushed granite, limestone, and marble as coarse aggregate on the mechanical properties of high-performance concrete was investigated [11]. The outcome of the study revealed that the strength, stiffness, and fracture energy of concrete for a given water/cement ratio depend on the type of aggregate. Basalt, limestone and gravel have been used as coarse aggregate to produce normal and high performance concrete [12].The research work revealed that for high performance concrete at 28 days, basalt produced the highest strength, whereas gravel gave the lowest compressive strength. Normal strength concrete made with basalt and gravel gave similar compressive strength while the concrete containing limestone attained higher strength.

In most part of the eastern country in Nigeria, red sandstones are mostly used for coarse aggregate in place of granite due to its availability in the region. The certainty of the compressive strength of the concrete may not be guaranteed due to the lack of standard code for the use of sandstones in concrete. This study tends to unravel its effect in concrete.

2. Materials and Method

2.1. Material Collection and Preparation of Samples

The materials used includes Portland cement, fine aggregate, coarse aggregate (sandstone and granite) and water. The tools include steel moulds (100mmx100mmx100mm size), shovel and head pans. Eighty two (82) cubes of 100 mm x 100 mm x 100 mm with two cubes were made for each mix. However, the concrete were cast and cured between 7 days and 28 days respectively according to [13]. Data were sourced from the compressive strength test carried out in the laboratory.

The regression equations relating the compressive strength of the sandstones and the granite 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 (compressive strength of the sandstone and granite concrete) 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)

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

where;

$\mathrm{y_i} =$ predicted response (compressive strength of sandstone and granite concrete)

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

$\mathrm{n} =$ number of independent variables

$\mathrm{x_i, x_j} =$ actual factors

$\mathrm{e} =$ error term

F-test was used to evaluate the significant of the model while the adequacy of the model was checked using the coefficient of determination R^2 and adjusted R^2

3. Results and Discussion

Regression equations relating the compressive strength of the sandstone and granite concrete with both the curing duration, fine aggregate, cement and water/cement ratios were developed. The suitability of these equations was tested using the analysis of variance (ANOVA). Table 1 shows the design matrix of the granite and sandstone concrete. The maximum compressive strength of the granite and sandstone concrete were 36.25 N/mm^2 and 35.0 N/mm^2, obtained at 28 days of curing using 0.48 w/c ratio. According to Table 2, the ANOVA for the quadratic model shows the adjusted R^2 of 0.9860, which indicates that 98.60% 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). The F-value of 142.27 and the p-value of 0.0001 which is less than 0.05 is statistically significant which indicates that the quadratic model can help us to predict the compressive strength of the granite concrete.

Furthermore, Table 3 shows ANOVA for the linear model of the sandstone concrete. The adjusted R^2 of 0.9084 reveals that 90.84% of the systematic variations in the compressive strength of the sandstone concrete are accounted for by the independent variables (cement, fine aggregate, coarse aggregate, w/c ratios and curing duration). The p- value of 0.001 which is less than 0.05 is statistically significant which indicates that the linear model can help us to predict the compressive strength of the sandstone concrete.

Table 1: Experimental design matrix for the factorial design and response value for the granite and sandstone concrete

Experiment	Independent Variable					Compressive strength of granite Concrete (N/mm²)	Compressive strength of sandstone Concrete (N/mm²)
	Cement (kg)	w/c ratios	Fine aggregate (kg)	Coarse aggregate (kg)	Curing duration (days)		
1	0.9925	0.48	1.1725	3.408	7	23.00	20.00
2	0.9925	0.43	1.1725	3.448	17.5	30.00	23.75
3	0.88	0.43	1.1725	3.428	17.5	20.00	17.75
4	0.9925	0.48	1.1725	3.448	28	31.00	24.75
5	0.9925	0.48	1.27	3.408	17.5	30.85	23.60
6	0.88	0.48	1.1725	3.448	17.5	20.00	17.75
7	1.105	0.48	1.1725	3.428	7	24.00	24.25
8	0.9925	0.43	1.1725	3.428	28	31.00	24.75
9	0.88	0.48	1.1725	3.428	28	21.25	19.25
10	0.88	0.48	1.1725	3.428	7	17.00	13.25
11	0.9925	0.43	1.27	3.428	17.5	30.00	23.55
12	0.88	0.48	1.075	3.428	17.5	19.95	17.60
13	0.9925	0.48	1.1725	3.428	17.5	30.00	23.75
14	1.105	0.48	1.27	3.428	17.5	32.25	26.75
15	0.9925	0.48	1.27	3.428	7	23.00	20.00
16	0.9925	0.53	1.075	3.428	17.5	30.05	23.60
17	0.9925	0.43	1.1725	3.408	17.5	30.00	23.75
18	0.9925	0.48	1.075	3.408	17.5	30.05	23.70
19	1.105	0.48	1.1725	3.428	28	36.25	35.00
20	0.9925	0.53	1.27	3.428	17.5	30.05	23.60
21	1.105	0.48	1.1725	3.408	17.5	32.25	26.75
22	0.88	0.48	1.1725	3.408	17.5	20.00	17.75
23	0.9925	0.43	1.075	3.428	17.5	30.05	23.60
24	0.9925	0.48	1.1725	3.408	28	31.00	24.75
25	0.9925	0.48	1.075	3.428	28	30.85	24.50
26	1.105	0.43	1.1725	3.428	17.5	32.25	26.75
27	0.9925	0.43	1.1725	3.428	7	23.00	20.00
28	0.9925	0.48	1.27	3.428	28	30.90	24.60
29	1.105	0.48	1.1725	3.448	17.5	32.25	26.75
30	0.9925	0.48	1.1725	3.448	7	23.00	20.00
31	0.88	0.48	1.27	3.428	17.5	20.05	17.60
32	0.9925	0.53	1.1725	3.408	17.5	30.00	23.75
33	0.9925	0.48	1.27	3.448	17.5	30.05	23.70
34	0.88	0.53	1.1725	3.428	17.5	20.00	17.75
35	0.9925	0.53	1.1725	3.428	28	31.00	24.75
36	0.9925	0.53	1.1725	3.448	17.5	30.00	23.75
37	0.9925	0.48	1.075	3.448	17.5	30.05	23.60
38	0.9925	0.48	1.075	3.428	7	23.00	20.00
39	1.105	0.53	1.1725	3.428	17.5	32.25	26.75
40	1.105	0.48	1.075	3.428	17.5	32.00	26.65
41	0.9925	0.53	1.1725	3.428	7	23.00	20.00

Table 2: Analysis of Variance for Quadratic Model Values of the Granite Concrete

Source	Sum of Squares	Degree of Freedom	Mean Squares	F value	p-value Prob >F	
Model	982.79	20	49.14	142.27	< 0.0001	Significant
A-Cementl	567.04	1	567.04	1641.67	< 0.0001	
B- curing duration	74.88	1	74.88	94.53	< 0.0001	
B-W/C RATIO	0.0002	1	0.0002	0.0005	0.9832	
C-FINE AGGREGATE	0.0827	1	0.0827	0.2393	0.6300	
D-COARSE AGGREGATE	0.0400	1	0.0400	0.1158	0.7372	
E-CURING	258.00	1	258.00	746.97	< 0.0001	
Cor Total	989.69	40				
		Adj R^2=0.9860				

Table 3: Analysis of Variance for Linear Model Values of the Sandstone Concrete

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	535.28	5	107.06	80.30	< 0.0001	significant
A-CEMENT	409.56	1	409.56	307.22	< 0.0001	
B-W/C RATIO	0.0002	1	0.0002	0.0001	0.9914	
C-FINE AGGREGATE	0.0014	1	0.0014	0.0011	0.9743	
D-COARSE AGGREGATE	0.0000	1	0.0000	0.0000	1.0000	
E-CURING	125.72	1	125.72	94.31	< 0.0001	
Residual	46.66	35	1.33			
Cor Total	581.94	40				
	Adj R^2=0.9084	Pred R^2=0.8897				

3.1. The Effect of Granite on the Compressive Strength of Concrete

The three-dimensional plots of the combined effect of both the weight of the coarse aggregate (granite) and cement on the compressive strength of concrete are shown in Figure 1. Increasing the granite weight in the concrete increases the compressive strength. While increasing also the cement weight in the concrete, increases the compressive strength. Maximising the compressive strength of the granite concrete at 28 days of curing using 0.48 w/c ratio gave a compressive strength of 36.25 N/mm^2. This was 1.04% increase over the compressive strength of sandstone concrete. These results were collaborated by [3].

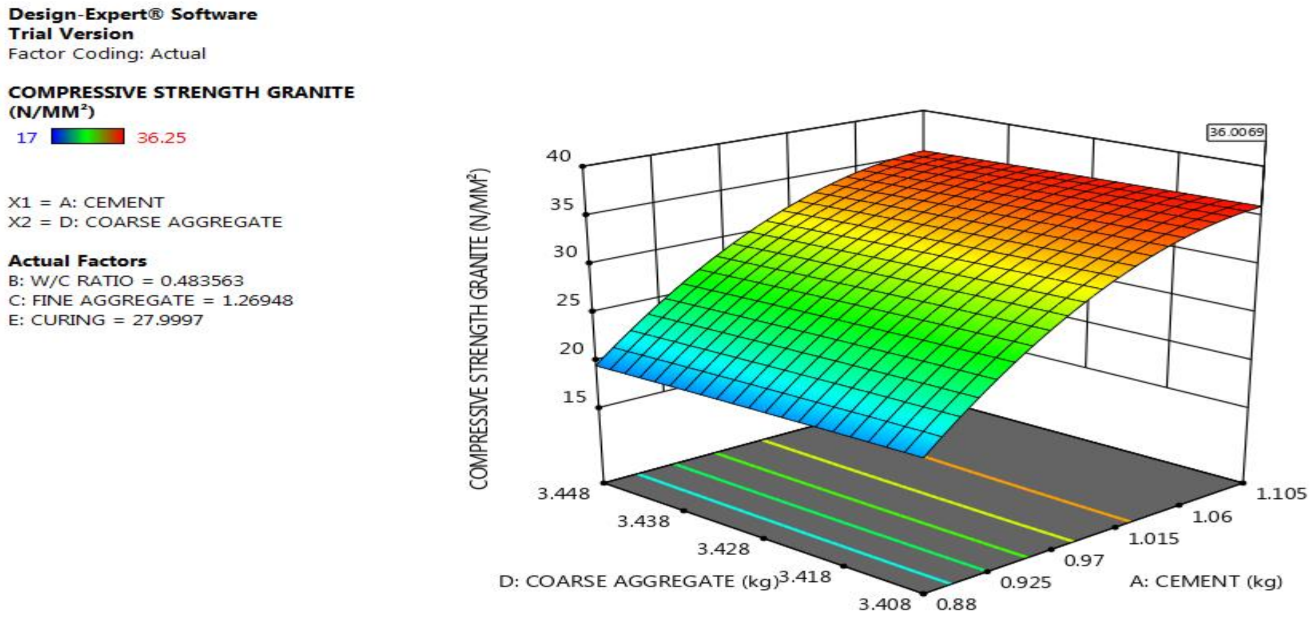

Figure 1: The effect of granite on the compressive strength of concrete

3.2. The Effect of Sandstone on the Compressive Strength of Concrete

The three-dimensional plots of the combined effect of both the weight of the coarse aggregate (sandstone) and cement on the compressive strength of concrete are shown in Figure 2. Increasing the sandstone weight in the concrete increases the compressive strength. While increasing also the cement weight in the concrete, increases the compressive strength. However, at 7 days curing duration and 0.48 w/c ratio, the compressive strength of the sandstone concrete was higher than the compressive strength of granite concrete by 1.01%. The optimum compressive strength of the sandstone concrete at 28 days of curing using 0.48 w/c ratio was 35.0 N/mm^2. This was 3.4% decrease of compressive strength when compared to granite concrete. This decrease in compressive strength at 28 days was collaborated by [14] in their studies which may be due to some impurities in the sandstone aggregate. This implies that there is a negligible decrease in compressive strength of concrete when sandstone is used as coarse aggregate in concrete at 0.48 w/c ratio for concrete grade 20 N/mm^2.

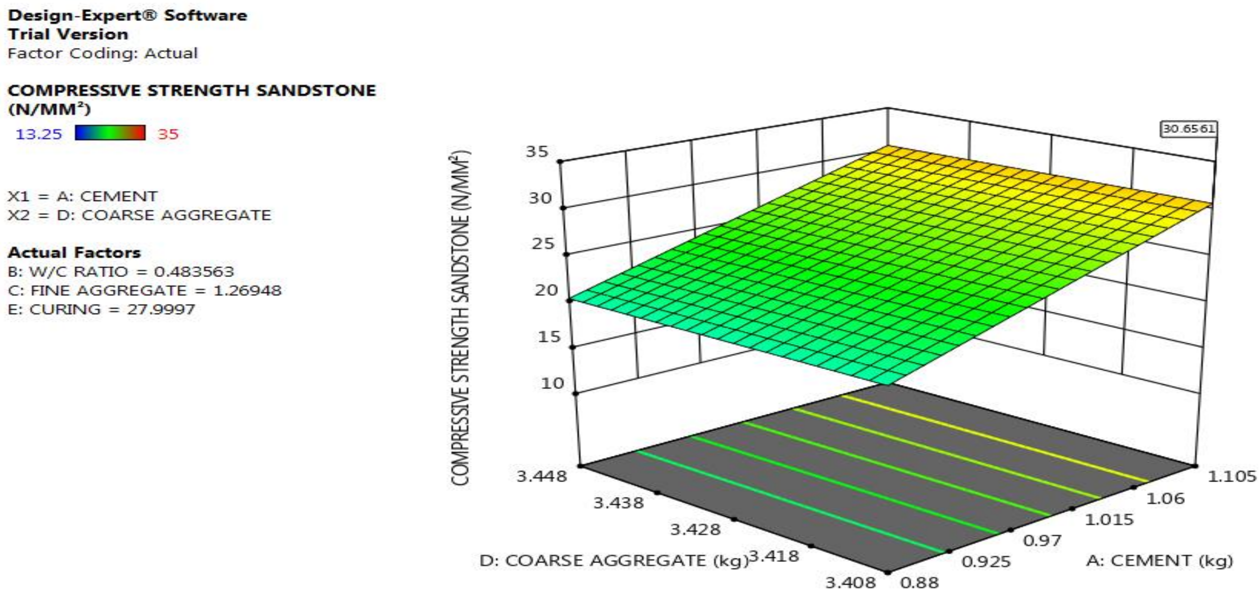

Figure 2: The effect of sandstone on the compressive strength of concrete

4. Conclusion

It can be concluded from the study that the optimum compressive strength of concrete when granite was used as coarse aggregate was 36.25 N/mm^2. This was obtainable at 0.48 w/c ratio, when cured at 28 days. The maximum compressive strength of concrete when Anambra sandstone was used as coarse aggregate in concrete was 35.0 N/mm^2. This was obtainable at 0.48 w/c ratio, when cured at 28 days. The compressive strength percentage increase of granite concrete over sandstone concrete was 1.04% which was negligible. There was an appreciable early compressive strength increase of sandstone concrete by 1.04% over granite concrete at 7 days of curing using 0.48 w/c ratio. The quadratic model was able to predict the compressive strength of the granite concrete with a coefficient of determination (R^2) of 0.9860. The linear model was able to predict the compressive strength of the sandstone concrete with a coefficient of determination (R^2) of 0.9084. Anambra State sandstone can be used for heavy structural concrete works due to its high compressive strength of 35.0 N/mm^2 value obtained at 0.48 w/c ratio.

5. Conflict of Interest

There are no conflicts of interest associated with this work.

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