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Comparative Assessment of Effects of Types of Coarse Aggregate on Strength of Different Grades of Concrete in Imo State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author UFI designed the study, prepared the field work, wrote the protocol, did the first draft of the manuscript and analyzed the data. Author FCK managed the literature searches, managed the field survey and processed the data. Both authors read and approved the final manuscript.

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ABSTRACT

Production characteristics and compositions of constituent ingredients of concrete influence to a large extent the quality of concrete works in general. The levels of implication of these factors on performance of concrete are therefore appraised for improved production of concrete work in the study area. Experimental research method was adopted to obtain data on the compressive strength of concrete produced at some construction sites in the study area. A preliminary survey conducted confirmed that 1:2:4 and 1:3:6 mix ratios are commonly used as their mix designs. Forty eight concrete cubes of 150mm x 150mm x 150mm were used to collect sample at the selected sites for the laboratory tests. Product moment correlation coefficient was used to determine the strength of relationship for changes in the increasing strength of concrete with increase in curing ages between concrete produced with sedimentary and granite aggregates. On the other hand, differences in proportion of variation on strength of 1:2:4 and 1:3:6 concrete mix ratios between concrete produced with the various types of aggregates at 7-day and 28-day curing ages respectively were analyzed using Z–test statistics. Findings reveal that it is only concrete produced with granite material aggregate at the 28-day curing age reached the minimum stipulated standard

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strength values of 21N/mm^2 and 18N/mm^2 for 1:2:4 and 1:3:6 concrete mix ratios respectively. The correlation coefficient (r) of 0.999 and 0.993 for 1:2:4 and 1:3:6 concrete mix ratios respectively were calculated to confirm very strong association in changes in strength as the curing age increases between concrete produced with the two different aggregates. The difference in proportion of the variations in the two different mix ratios between the two different aggregates at the curing ages however are not significant in the study. Thus, the study concludes that mix ratio and curing age which remain positively strong on their effects on quality of concrete are as well significant as aggregate type in the overall performance of concrete. Granite material aggregate therefore was recommended to be used for concrete production of higher quality; and as well be always cured till the 28th day of production for desired strength of the concrete.

Keywords: Concrete; production characteristics; aggregate types; compressive strength; desired quality.

1. INTRODUCTION

Quality of concrete in general is dependent on some major factors ranging from forms and natures of the constituent composition to its production characteristics. According to [1], concrete products in the tropical region of Nigeria are susceptible and every effort made through public enlightenment, symposia, media and inaugural lectures to improve quality of delivery yielded just little result. [2] considered that concrete will only become a quality material for durable construction when the ingredients are properly sourced and selected, as long as it is being manufactured under a controlled standard and practical procedure. The issue of materials soundness is very important during selection; otherwise the concrete may eventually fail when it cannot provide the required function ability.

General survey showed that most modern buildings in the south-east Nigeria have concrete as their major components; hence quality of the constituent materials remains of paramount importance [3]. Coarse aggregate as one of the constituent ingredients of concrete contributes to more than two-third of the bulk volume of concrete in the construction industry [4]. The aggregate is usually of different composition, structure, density and texture; hence of varying effects on properties of concrete produced in construction industry. [5] emphasized therefore the need for accurate assessment of quality, strength and variability of the constituent materials used in forming the structural components. Quality of any aggregate according to [6] depends to a large extent on quality, size, shape, texture, strength, grading and source of the aggregate. Besides, the overall mechanical property of concrete depends on certain properties of the constituent aggregate in the mix.

There are various types of coarse aggregate used in the study area. They range from factory crushed, naturally occurring or quarried sedimentary aggregates, unwashed local and river pebbles, and igneous quarried chippings. Majority of the small and medium sized firms make use of factory crushed and naturally occurring sedimentary aggregates, and quarried igneous chippings for making concretes. Most stakeholders in the industry use aggregates of all kinds for different types of works without guide. Whereas aggregates are by standard usually tested to ascertain its suitability for a certain work, experience has shown however that the choice of aggregate type in practice is usually based on mere assumption rather than empirical data [7]. As a result, most concrete works produced are suspects, with greater probability of being prone to failures.

Since weather condition plays a vital role in the curing of masonry materials, climatic situation of the study area is critical. Imo state therefore is located in the Warm Humid Climatic (WHC) Zone of Nigeria - the fourth category of the climatic division for construction purposes [1]. It is characterized with long torrential rainfall, high humidity and average maximum steady temperature and wind pressure [1].

In view of the uncertainty in the quality assurance of concrete arising from indiscriminate choice of coarse aggregates among others in the industry, studies are required to ascertain the average performance influences of the various types of aggregates on concrete; as well as their relationships with some production characteristics in the industry. For the purpose of the study, compositions of the various aggregates were examined and compressive strengths of concrete they were used to produce measured.

2. RESEARCH METHODOLOGY

The study adopted an experimental design method of scientific investigation where a standard procedure (ASTM – Section C) in concrete work production was applied for the test of compressive strength in the laboratory. Although data was collected through experimental design methods, method study on mode concrete production in selected settings within the study area was conducted using survey method, with a view to forming basis for experiments. The data collected are quantitative in nature for objective and deduction reasoning.

The procedure applied involves collection of in-situ concrete mix samples of known aggregates and production characteristics from the selected on-going construction sites. Different concrete mix samples constituted of sedimentary and granite aggregates respectively with corresponding mix ratios of 1:2:4 and 1:3:6 were respectively collected for the strength tests respectively. A total of forty eight cubes of 150 mm x 150 mm x 150 mm were casted, cured and tested of their compressive strengths. The cubes are of two main categories (factory crushed sedimentary and granites aggregates respectively). Each of these categories is further grouped into two nominal mix ratios of 1:2:4, and 1:3:6. The grades of in-situ concrete sampled at the ongoing project sites were confirmed as 1:3:6 of 19 mm aggregates, and 1:2:4 of 19mm aggregates mix ratios for plain concrete and structural works respectively. The mix ratios were respectively tested for four different curing ages (3-day, 7-day, 21-day, and 28-day ages). Average result of three cubes tested for each of the respective conditions of the experiments is taken to represent that condition in the study.

The test for compressive strength of each sample was in accordance with [1]. At the end of each of the respective period of curing, specimen of the concrete cubes were removed and dried for 24 hours before they are weighed, and crushed to point of failure through the shear failure plane using compressive strength testing machine in the laboratory. Value of the applied force at which the specimen failed was recorded, with which the compressive strength was calculated in each case.

In general, data were analyzed using Karl Pearson Product Moment Correlation Coefficient to measure the degree of association between changes in compressive strength of concrete mix with sedimentary coarse aggregate and changes in the strength of concrete mix with igneous coarse aggregate as the curing age varies respectively. The Z- test statistical tool was applied to measure the difference in the proportional changes in compressive strengths of the respective nominal mix ratio from one category of aggregate concrete mix to the other at 7-day and 28-day curing ages respectively. The statistical tools used in the study are therefore respectively expressed as follows:

The Product Moment Correlation;

$$r = \frac{\{n\Sigma xy^2 - \Sigma x \Sigma y}{\sqrt{\{n\Sigma x^2 - (\Sigma x)^2\}\{n\Sigma y^2 - (\Sigma y)^2\}}} \qquad \text{(Equ. 1)}$$

Where; x is sample 1, y = sample 2, and n = number of sample.

The Z test; $$z = \frac{(P_1 - P_2) - (\cap_1 - \cap_2)}{\sqrt{P_1(1-P_1)/n_1 + (P_2(1-P_2)/P_2}} \qquad \text{(Equ. 2)}$$

n_1 is base number for population x_1,

n_2 = base number for population $x_{2,}$

p_2 = ratio of difference in x_1 to the base number $n_{1,}$

p_2 = ratio of difference in x_2 to the base number $n_{2.}$

3. PRESENTATION OF DATA, ANALYSES AND DISCUSSION

Data from experiments in the study are presented in tabular and graphical forms. They are as shown in Table 1; and are represented in chart form in Fig. 1 for clarity.

Table 1 shows that the closer the proportion of other constituent ingredients to cement the higher the strength. It also reveals that compressive strength of concrete mix with granite is significantly higher than concrete of the same mix ratio with sedimentary aggregate. This condition is confirmed in the study conducted by [8], where he concluded that the locally sourced (sedimentary) coarse aggregates contain impurities that lower the strength of concrete. In all conditions, the higher the curing age of the concrete the higher the strength, as shown in Fig. 1 [9]. In the National Building Code, (NBC) however set a minimum standard value of 21.0 N/mm^2 for compressive strength of concrete in

Nigeria. According to the experiments, this value is only reached at 28-day curing age with the concrete mix of granite coarse aggregate at the value of 23.30 N/mm^2.

In the experiment, it is seen in Fig. 1 that there is linear and positive relationships between the curing ages and the strength values of the various categories of concrete in the study. Average strength values for 1:2:4 concrete mixes with the sedimentary aggregate measures approximately the same with the average strength value for 1:3:6 concrete mix with granite. This emphasizes the strong effects of both mix ratio and aggregate type in quality control of concrete works. Thus, the positive effect of granite as an aggregate over the sedimentary aggregate therefore made up the shortcoming that characterizes the lower mix proportion of 1:3:6; while on the other hand the benefit in the higher mix proportion of 1:2:4 compensated for the shortcoming that characterizes the sedimentary aggregate in the study. Although nominal mixes of fixed cement-aggregate ratio vary widely in strength, it can be used to influence quality of concrete [10]. Evidently, concrete mix ratio as contained in both Table 1 and Fig. 1 therefore is seen to be stronger in its effect on the strength of concrete than aggregate type in the experiments.

Note that all the values in 'Y' axis of Fig. 1 represent the Compressive Strength of the concrete. They are measured in N/mm^2.

Using Equation1.0; the product moment correlation coefficient on compressive strength values of 1:2:4 concrete mixes produced with sedimentary, and granite coarse aggregate respectively was calculated in the study. From the data set contained in Table 2, the correlation (r) is 0.999. Since the value of correlation is approximately one unit therefore, it is concluded that there is near perfect relationship between compressive strength values of 1:2:4 concrete mixes produced with sedimentary and granite coarse aggregates at the various curing ages; as shown in Fig. 1.

Table 1. Results of experiments on the various properties of concrete with the various types of coarse aggregates at different curing ages

Concrete production with sedimentary aggregates			Concrete production with quarried igneous aggregates		
Curing age	1:2:4 Mix Ratio N/mm^2	1:3:6 Mix Ratio N/mm^2	Curing age	1:2:4 Mix Ratio N/mm^2	1:3:6 Mix Ratio N/mm^2
3-day	8.3	6.5	3-day	10.5	8.1
7-day	11.7	9.0	7-day	13.9	11.2
21-day	16.9	13.3	21-day	20.6	16.8
28-day	19.6	16.7	28-day	23.3	19.2

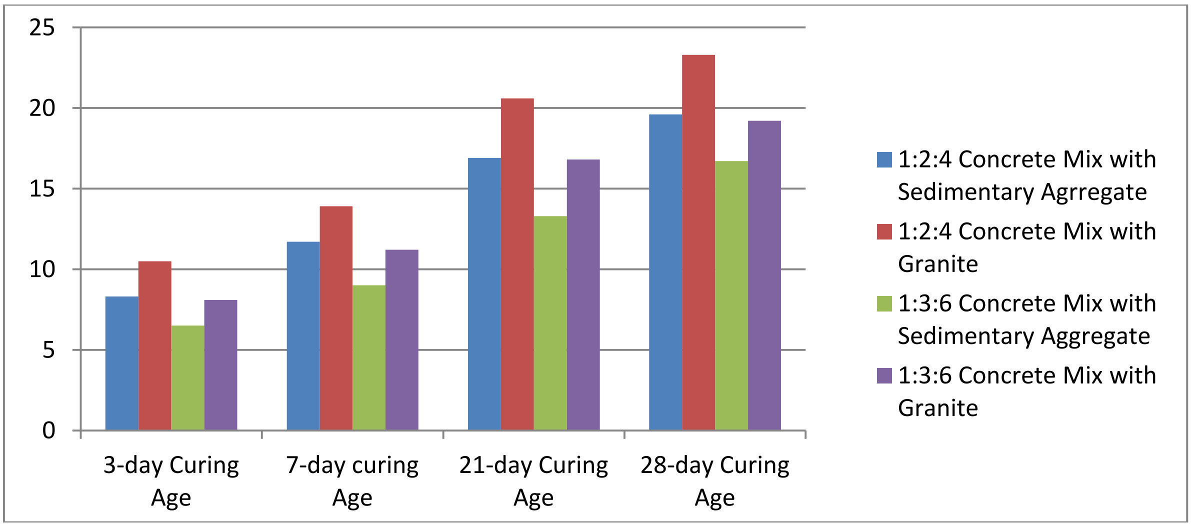

Fig. 1. Compressive Strength (N/mm^2) Values of the Respective Categories of Concrete of 1:2:4 and 1:3:6 Mix Ratios at the Various Ages of Curing

Table 2. Calculated Values of Parameters for Product Moment Correlation on 1:2:4 Concrete Mixes

Curing Age	Sample 1 X_1 (1:3:6)	X_1^3	Sample 2 X_2 (1:2:4)	X_2^2	X_1X_2
3-day	8.30	68.89	10.50	110.25	87.15
7-day	11.70	136.89	13.90	193.21	162.63
21day	16.90	285.61	20.60	424.36	348.14
28day	19.60	384.16	23.30	542.89	456.68
Total	56.5	875.55	68.30	1270.71	1054.60

Table 3. Calculated Values of Parameters for Product Moment Correlation between 1:3:6 and 1:2:4 Concrete Mixes

Curing Age	Sample 1 X_1 (1:3:6)	Sample 2 X_2 (1:2:4)	X_1^2	X_2^2	XY
3-day	6.50	8.10	42.25	65.61	52.65
7-day	9.00	11.20	81.00	125.44	100.80
21day	13.30	16.80	176.89	282.24	223.44
28day	16.70	19.20	278.89	368.64	320.64
Total	45.50	55.30	579.03	841.93	697.53

This development reveals that changes in the compressive strength of concrete of the same mix ratios but with different types of coarse aggregates at the various curing ages are very much alike. Hence, type of aggregate is less significant than the curing age in the study, since change in aggregate type does not affect noticeably the trend of changes in the strength from one curing age to the other.

In Table 3 are contained the information for correlation coefficient (r) of the two categories of concrete work on 1:3:6 mix ratio. Using Equation 1.0 also, the product moment correlation on compressive strength values of 1:3:6 concrete mixes produced with sedimentary and igneous coarse aggregates was calculated as 0.993. Fig. 1 shows a strong linear and positive relationship in the experiment; and the same correlation scenario that abounds in 1:2:4 concrete mix experiments also abound in this experiment.

Nevertheless, Z - Tests for significant difference in change proportion of compressive strength on concrete with the two nominal mix ratios between the productions with sedimentary and igneous coarse aggregates respectively, at 7-day and 28-day curing ages only were carried out using Equ. 2.0.

Recall that Z test $(z) = \frac{(P_1 - P_2) - (\cap_1 - \cap_2)}{\sqrt{P_1(1-P_1)/\mathrm{n}_1 + (P_2(1-P_2)/P_2}}$

(Equ. 2.0)

According to Equ. 2.0.

Where for;

7-day Curing Age:

n_1 for x_1 is 11.70, and n_2 for x_2 becomes 13.90, variation in x_1 (d_1) is 11.70 – 9.00 = 2.70, and variation in x_2 (d_2) becomes 13.90 – 11.20 = 2.70.

Therefore; in the same experiment, p_1 is d_1/n_1 = 2.70/11.70 = 0.231, and p_2 becomes d_2/n_2 = 2.70/13.90 = 0.194.

Thus, by substituting in Equation 2.0, Z is calculated as 0.23.

Critical value at α level of 0.10 significance, $Z_{\alpha/2} = Z_{0.05} = 1.64$.

Since Z_{cal} (0.23) < Z_{tab} (1.64), the null hypothesis that there is no significant difference in the proportion of compressive strength variation from 1:2:4 to 1:3:6 mix ratios between the sedimentary and igneous aggregates concrete mixes at 7-day curing age is therefore accepted.

28-day Curing Age:

n_1 for x_1 is 19.60, and n_2 for x_2 becomes 23.30, variation in x_1 (d_1) is 19.60 – 16.70 = 2.90, and variation in x_2 (d_2) becomes 23.30 – 19.20 = 4.10.

Therefore; in the same experiment, p_1 is d_1/n_1 = 2.90/19.60 = 0.148, and p_2 becomes d_2/n_2 = 4.10/23.30 = 0.176.

Thus, by substituting in Equation 2.0, Z is calculated as 0.25.

Critical value at α level of 0.10 significance $Z_{\alpha/2}$ = $Z_{0.05}$ = 1.64.

Since Z_{cal} (0.25) < Z_{tab} (1.64), it is therefore concluded according to the null hypothesis (H_{o1}), that there is no significant difference in the proportion of the compressive strength variation from 1:2:4 to 1:3:6 mix ratios between the sedimentary and the igneous aggregates concrete mixes at 28-day curing age. Hence, the null hypothesis is accepted in the study.

Although there are significant changes between the compressive strengths of concrete with the various mix ratios, proportions in changes from 1:2:4 to 1:3:6 mix ratios do not vary noticeably when concrete of different aggregates are compared to one another. Consequently, the mix ratio has more significant influence on the concrete than the coarse aggregate type in both the 7-day and the 28-day curing ages; although according to [11] aggregate becomes increasingly significant as the distribution proportion of the size improves.

4. CONCLUSION AND RECOMMENDATIONS

In the study, it is recommended that a standard production procedure that is enforceable by local authority be instituted in the area for improved concrete work production and uniformity. The factors to be considered should be in sympathy with the local environment and conditions to ensure appropriateness in its regulation. While effort should be made to educate the practitioner on the importance of quality assurance and control in the industry, government should not hesitate to establish centrally a standard construction material laboratory in every zone in the state for quality control of construction and related materials.

In line with the findings, use of igneous coarse aggregates is recommended rather than the sedimentary aggregates for improved quality of concrete. Practitioners in the study area are advised however to adopt higher mix ratios of concrete especially, when the available or affordable coarse aggregate to be used is sedimentary. Besides, finished and hardening concrete works should as a matter of procedure be subjected always to longer days of curing; possibly till 28-day age in the study area.

Conclusively, the igneous material's aggregate in concrete mixes enhances quality of concrete works. Although it is confirmed that high concrete mix ratio improves the quality of concrete in the study, the use of granite aggregate in concrete production overrides the weakening effects of lower mix ratio for desired quality of concrete in the study area. The current economic situation in general affects adversely the cost of construction materials especially, the constituent ingredients of concrete. Cement as one of the main ingredients is a constant variable in any mix ratio. It is among the worst hit economically, making most stake holders in the industry to be compromising the mix ratio by reducing the cement content in every concrete mix.

On the other hand, it is observed that the adoption of longer days of curing enhances the strength of the various categories of concrete. This is more significant in a Warm Humid Climate (WHC) zone where the study area belongs. Since the area is characterized with warm and high humidity, it is obvious that any masonry material seeking hydration to gain more strength will leverage on the condensing and moist environment of the WHC to hydrate very well, in order to attain maximum strength after a long time.

Finally, the strong effects of aggregate type, mix ratio, and curing age on the strength of concrete works in the study therefore are emphasized in the overall performance of concrete works, toward making better decision in choice of material's aggregate and the production characteristics for effective concrete work production in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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