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Impact of Variability in Mechanical Properties of Local Aggregates on Concrete Strength

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Abstract

Sedimentary rock is one of the commonest rock aggregates used in Nigeria for concrete production. Its properties vary significantly from one quarry site to the other due to differences in production technique and variability in physical properties of sedimentary rocks in general. The Acquisition of the skill of knowing a good aggregate by visual inspection becomes necessary for users of these aggregates. This report, therefore, demonstrated the relative influences of aggregate strength, porosity, grading and clay/silt contamination on the strength of concrete based on the experimental results from three aggregate samples obtained from three different quarry sites, namely Umunya, Umuaga and Nkwere-Ezunaka quarries. The samples from Umunya quarry had a very high percentage of clay/silt contamination of 37.5% and very poor grading and therefore produced concrete of lowest strengths. The samples from Nkwere-Ezunaka and Umuaga had very good grading, much lower silt/clay contaminations, lower porosity and good aggregate strength and therefore produced concrete of strengths much higher than that of Umunya sample. The presence of clay in all the samples affected the strengths of the concrete generally as a result of the fact that stress must be transferred from the mortar phase to the aggregate phase, it is only when the mortar phase is strong enough that the effects of the aggregate phase become apparent. For this reason, the strengths of concretes from the three samples were generally lower than expected. Stake holders were, therefore, advised to avoid aggregates with contaminations above 5 percent. Very strong aggregates with crystalline texture were also recommended. For all− in aggregates, good grading was also recommended.

Keywords: Aggregate, Mechanical property, concrete strength

1.1 Introduction

Concrete is a commonly used construction material which is artificially produced by mixing cement, sand, gravels, water and (sometimes) admixtures together in a prescribed proportion. In the presence of water, cement undergoes a hydration reaction and turns into a rock like substance that binds the aggregates together.

In the hardened concrete, the sand and cement form the mortar phase, while the gravels form the aggregate phase. The strength and quality of the concrete depends on the strength of these two phases. The presence of impurities such as clay and silt in the aggregate can adversely affect the strength of the mortar phase (Aginam et al, 2013;Ephraim and Rowland,2015) addition of admixture and change in water/cement ratio also alter the strength properties of the mortar phase. For the aggregate phase, the graduation, crushing value, abrasion value etc, affect the strength of the aggregate phase (Glavind et al,1993;Johansan Anderson,1989). In this way, the strength of the mortar and the strength of the aggregate together form the total strength of a concrete. Since many of these factors that determine the strength of concrete are inherent in the aggregates, it is important for the engineer to understand the relative impacts of these factors on the quality of a structural concrete.

Most concrete aggregate are obtained from rocks. The commonest rock aggregate used in Nigeria are sedimentary rock and granite rock aggregates. Granite rock aggregate are very scarce and costly except in very few state where it outcrops. Sedimentary rock aggregate, on the other hand, are abundant and relatively cheap, and engineers often resort to the use of sedimentary rock aggregates to reduce cost of construction, in spite of the fact that granite aggregates are of better quality (Kogbe, 1989). In addition, sedimentary rock aggregates vary in property and quality from one quarry site to the other (Shetty , 2005). It is therefore important for the engineer to develop the skill of selecting a good aggregate from available types based on his wealth of knowledge of the relative qualities of aggregate's property in relation to concrete strength.

This study, therefore, seeks to demonstrate through laboratory test, the relative effect (or impacts) on concrete strength of the aggregate crushing value, water absorption, clay/silt content and graduation of the aggregate, based on test results from three sedimentary rock quarry sites used in Anambra State of Nigeria. The quarry sites are located at Nkwere-Ezunaka, Umuaga and Umunya , respectively.

2.0 Material and methods

2.1 **Materials**

The materials used for the experiments were coarse aggregates of 12-mm maximum size, fine aggregate, Portland cement and water. Three samples of coarse aggregates were collected from three different sedimentary rock aggregate quarries located at Nkwere-Ezunaka, Umuaga and Umunya, respectively. The fine aggregate was collected from the bed

of the Niger River at Onitsha, Anambra State of Nigeria. It was a clean river sand and free from impurities.
The Portland cement was obtained from cement dealers in the open market; brand name, Dangote Cement.

The equipment used include universal cube crushing machine, concrete moulds, B. S sieves, sieve shaker and weighing balance.

2.2 Experiments

The experiments conducted include sieve analysis, concrete cube crushing text, aggregate crushing value and aggregate water absorption test. Each of these tests were carried out independently on the respective aggregate samples.

Procedures for the tests

i. Sieve Analysis

In accordance with B.S 812 Part I, standard sieves were selected and arranged in descending order of size, with the tray at the bottom. 1000 grams of air-dried aggregate sample was measured with a balance and introduced at the top of the stack of sieves. The sieves were vibrated with a sieve shaker until passage of aggregates stopped. Aggregates retained in each sieve were weighed and recorded. From the tabulation, percentage of aggregates retained on each sieve, and cumulative percentage passing were calculated and recorded in the usual manner. Grading curves of the aggregate were plotted on semi-log graphs.

ii. Crushing value text

A 3-kilogram weight of aggregate consisting of aggregates passing B.S sieve size 12.5mm and retained on BS-sieve size 10mm was filled into a standard cylindrical mould in three layers, each layer tamped 25 times with a tamping rod and finally leveled off by using the same tamping rod as a straight edge. The cylinder and aggregate was placed on the base plate of a concrete crushing machine with the plunger inserted over the aggregate. The plunger was loaded uniformly up to 40 tons, using the compression machine, in 10 minutes and stopped. The aggregate was removed from the cylinder and sieved through B.S sieve size 2.36mm. The fraction passing through the sieve was weighed. The crushing value was obtained by expressing this weight as a percentage of the total weight taken in the standard cylinder.

i. Water Absorption

About 1000 grams of air-dried aggregate sample was taken in a container and weighed. It was then immersed in water for 24 hours. The increase in weight was obtained. The water absorption of the aggregate was calculated as the ratio of increase in weight to the weight of the original air-dried aggregate samples expressed in percentage.

ii. Concrete Strength Test

For ten pre-selected mix proportion, two concrete cubes were prepared for each mix proportion using one of the aggregate samples at a time. The cubes were cured in water for 28 days and crushed at the end of 28-days curing. The average crushing strength was calculated and the average was recorded against each mix proportion. The same process was repeated for the remaining two samples.

The preparation of the cubes was as follows: for each mix proportion and for each sample, water, cement, fine aggregate and coarse aggregate were weighed out in such a quantity as to fill two concrete moulds of 150 x 150 x 150- mm size. They were thoroughly mixed together in a non-absorbent container and the paste was filled into the moulds in three layers, each layer tamped 25 times to remove air space. The top was then scraped level and concrete allowed to set for 24 hours. After 24 hours, the concrete cubes were demoulded and cured in a water tank for 28 days, after which the cubes were crushed and the crushing strengths calculated and recorded.

3. Results and Discussion

(i) Results

The results of the sieve analysis tests are given in Figs(1.0), (2.0) and (3.0) which gives information on the gradation of the aggregate samples.

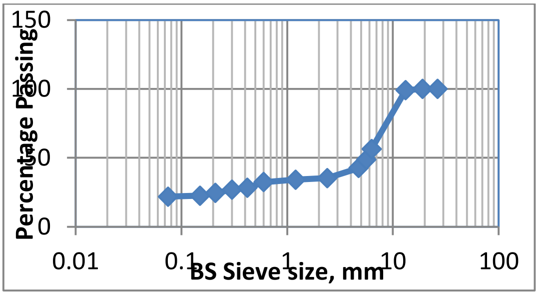

Fig.1.0 Grading curve for Nkwere-Ezunaka sample

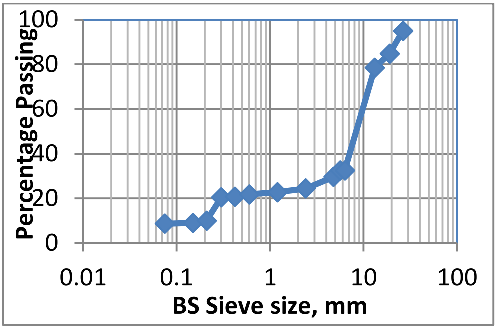

Fig.2.0 Grading curve for Umuaga sample

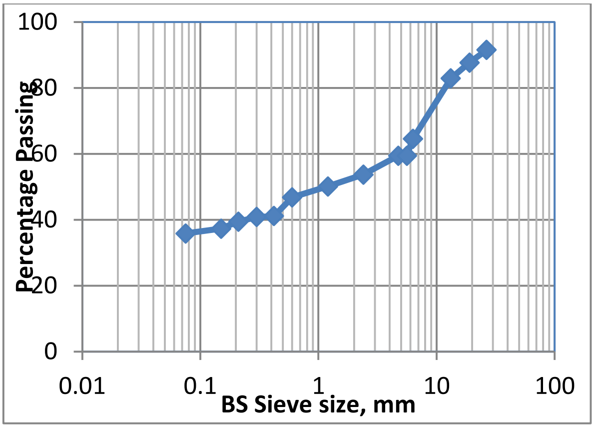

Fig.3 Grading curve for Umunya sample

The results of rest of other mechanical properties tests are given in Tables (1.0) and (2.0) which, respectively, shows crushing value, water absorption, fineness modulus, clay/silt contaminations of the aggregates; and crushing strength of the concretes from the respective aggregate samples for each of the prescribed mix proportions.

Table 1.0: Aggregate crushing value, Fineness modulus, Clay/Silt content and water absorption values for the various samples

Samples	Aggregate crushing value %	Water absorption value %	Fineness Modulus	Clay/Silt content %
Nkwere-Ezunaka	44	8.4	7.3	21.9
Umuaga	35	9.35	7.4	8.7
Umunya	42.66	13.6	5.4	37.3

Table 2 Concrete strength for various samples

S/N	Mix proportion	Concrete Strength for each sample		
		Nkwere-Ezunaka	Umuaga	Umunya
1	1:1½:4, w/c=0.6	4.58	4.15	2.59
2	1:1:1½ , w/c=0.5	8.7	8.59	6.96
3	1:1½:3, w/c=0.55	6.2	5.41	5.41
4	1:2½:3, w/c=0.555	4.87	4.59	3.85
5	1:1¼:2¾, w/c=0.55	10.77	7.48	4.47
6	1:1½:3½, w/c=0.575	8.96	9.41	4.07
7	1:2:4, w/c=0.578	8.12	9.85	3.26
8	1:1¼:2¼, w/c=0.525	10.18	10	4.74
9	1:1¾:2¾, w/c=0.528	9.89	11.41	4.37
10	1:2:3½, w/c=0.553	7.82	10.67	3.85

Fig(4.0) shows the variation of the concrete strengths with the prescribed mix proportions for the various samples, while Table(3.0) is ANOVA test to show how significant these variations are

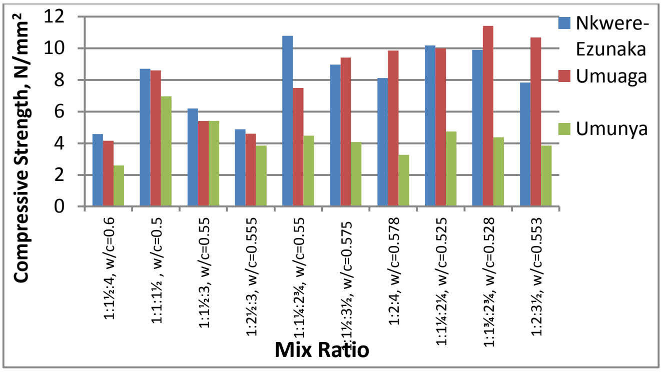

Fig 4.0 Bar Chart of variation of Strength of concrete with respect to samples and mix proportions

Table 3.0. Result of two-way ANOVA test conducted on the data in table 2 at α = 0.05

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	73.67079	9	8.185643	3.411857	0.012798	2.456281
Columns	92.63705	2	46.31852	19.30602	3.32E-05	3.554557
Error	43.18515	18	2.399175			
Total	209.493	29				

(ii) Discussion

The clay and silt content is determined by the percentage of aggregate passing B.S sieve size of 0.75μ - 0.075 mm. For Nkwere-Ezunaka, Umuaga and Umunya, it is 21.9, 8.7 37.3 percent respectively. The clay and silt content of the aggregate makes the mortar phase of the concrete weak. For this reason Umunya samples gave the weakest concrete of the three, having a clay and silt content of 37.3 percent greater than 8.7 and 21.9 percepts for Umuaga and Nkwere-Ezunaka respectively. When this contamination is mainly silt, the detrimental effect on concrete is relatively lower as some of the silt can play the role of fine aggregates. This is the case with Nkwere-Ezunaka and Umuaga samples whereby the relatively high value of 21.9% of silt/clay in Nkwere-Ezunaka sample did not produce the expected, comparatively, lower strength of concrete than Umuaga sample. See Table (1.0).

The crushing value, curvature and spread of the grading curve, and also water absorption, are indictors of strength of the aggregate phase. The crushing value characterizes the aggregates in terms of physical strength of each individual aggregate particle, and a good grading curve describes the aggregate particles as being able to park closely together and form a strong compact mass. Fineness modulus indicates the proportion of coarse particles in the aggregate, see Table(1.0) Nkwere-Ezunaka and umuaga have almost the same fineness modulus and grading curve property and therefore have similar strength.

Table (3.0) is a two-way ANOVA conducted on the samples -from Table (2.0)- using computer software. Table (3.0) confirms the variations in the strength of concretes from the various samples as significant; and an issue of serious concerned as all these are assumed equal in practice. Fig (4.0) shows these variations pictorially showing the significant variation in concrete strength caused mainly by clay and silt contamination. This is in line with the conclusions of (Aginam et al, 2013) which opined that only a maximum of 5% clay contaminations can be allowed in concrete aggregates. It is therefore possible to bring uniformity in strength of concrete made from local gravel aggregates by regulating the silt and clay contaminations. This will enable approximately equal strengths for all of the samples for any mix proportion to be obtained, and this will improve the usefulness of local aggregates greatly

The water absorption measures the porosity of the individual aggregate. High water absorption of aggregate means high porosity and therefore less strength. High water absorption of aggregate also suggest larger quantity of water for making a given concrete, which increase the water/cement ratio and reduces the strength of the concrete.

In the result of Table (1.0), Umuaga has a higher water absorption value than Nkwere-Ezunaka but has a lower crushing value and silt/clay content. These combine together to make the strength of concrete from the respective aggregate samples to be similar.

Finally the two samples, Umuaga and Nkwere-Ezunaka, have both better grading, lower water absorption, higher grading modules and lower silt and clay contaminations than Umunya sample, and so have better concrete quality than Umunya sample.

4. Conclusion

From the discussion, contaminations in the aggregate in the form of silt and clay has a very strong adverse effect on the strength of concrete, since it affects the strength of the mortar through which stresses are transferred to the aggregate. Where aggregates have the same level of contamination, the one that has lowest crushing value, lowest water absorption and better grading will have the highest strength

5.Recommendations

It is therefore recommended that aggregate with very low contamination (at least below 5%) with hard and crystalline texture be preferred. For all-in aggregate, the aggregate, in addition to low contamination, should be well graded.

The local authorities should register local aggregate quarries and monitor quality of aggregates produced by ensuring low silt content.

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