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Influence of Aggregate Texture on the Strength of Concrete for Rural School Buildings in Benue State, Nigeria

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Abstract:
The primary objective of study was to determine the mean influence of aggregate texture on the strength of concrete for use in rural schools in Benue State, Nigeria. These aggregates which are common known as inert fillers within the construction industry account for 60 to 80 percent by volume and 70 to 85 percent of the weight of building concrete. The study was purely an experimental research design. Material collation and the experiment were carried out in Benue State, Nigeria. Different aggregate textures and sizes at different mix combinations were involved in the experiments. Cement-water ratio was held constant in the experiment. From the analysis of the data from experiments, this study has discovered that: i) a good quality concrete strength is possible from locally available aggregates with different textures and sizes for rural school buildings in Benue sate; ii) a mix combination of dulled quarry dust and granite of 20mm texture gives the highest compressive strength of 26.52 N/mm² is highly recommended; iii) the use of quarry dust and granite of 20mm with rough surface texture improves the concrete strength by 34 % over that from sand and gravel of polished surface with maximum size of 28mm; iv) as the polished texture of coarse aggregates increases, the more the concrete strength decreases and iv) owning to the weak nature of the soil in Benue state, a mixture of quarry dust and granite aggregates of rough surface can produce concrete with expected strength for use in rural school buildings. The study therefore recommends that for the attainment of higher concrete strength, dulled or rough surface textured aggregates should be used. The construction of rural school buildings in Benue state should be based on adherence to stringent engineering test of materials.

Keywords: *Particle orientation, coarse aggregate, aggregate shape, texture, polished, dulled*

1. Introduction

Concrete is a composite material produced from a homogenous mix proportions of water, cement and aggregates (fine and coarse). Aggregates are commonly considered as inert filler, which accounts for 60 to 80 percent by volume and 70 to 85 percent by weight of concrete (Neville, 2003) and strength is the most desired quality of a good concrete. Construction concrete should be strong enough, at hardened state, to resist the various stresses to which it would be subjected to. Strength of concrete, therefore, is the value of test strength below which not more than a prescribed percentage of the test results should fall (Aginam, et al, 2013).

According to Shetty, (2005) although aggregate is considered inert filler, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability. Aggregate is classified into two different types, coarse and fine. Coarse aggregate is usually greater than 4.75 mm (retained on a No. 4 sieve), while fine aggregate is less than 4.75 mm (passing the No. 4 sieve). Compressive aggregate strength is an important factor in the selection of aggregate. When determining the strength of normal concrete, most concrete aggregates are several times stronger than the other components in concrete and therefore not a factor in the strength of normal strength concrete (Meininger, 2009). Lightweight aggregate concrete may be more influenced by the compressive strength of the aggregates. It is to this extent that, the quality of the coarse aggregates is essential when considering the quality of the concrete itself. The properties of coarse aggregates do grossly affect the durability and structural performance of concrete. Such properties as texture conditions and size of aggregates are considered alongside the mineral composition of the rock material from which the aggregate formed a part (ASTM, 2009).

In Benue state, locally found aggregates (washed and unwashed gravels) are mostly used for construction purposes especially in rural schools. The integrity of these aggregates affects the performance the structural members there from and should therefore be investigated to ascertain quality. Regrettably, many constructions programmes in Nigeria, Benue state and its environs in particular, make indiscriminate use of aggregates without considering their textures and not minding their physical condition at the time of use. For instance, gravels may be obtained from the same source but varies in the texture and hence, level of strength performance especially when some are used without washing and others are washed before usage.

These coarse aggregates are obtained naturally or synthetically and occupy approximately up to 60% by weight or volume of the concrete, depending on the mix proportion adopted which, in turn, depends on the expected strength (Abdullahi, 2012). The high variation in strength between concrete and mortar of the same cement/aggregate proportion, suggests the embodiment of coarse aggregates in the development of strength in concretes. The relative effect of these variations in texture of aggregates (coarse) on the strength achievable in concretes formed the major thrust of investigation and presentation in this study.

It has already been established, within the construction industry, that concrete is among the most commonly used structural materials alongside steel, as such a good knowledge of the properties of concrete makes possible the selection of a more suitable economic mix. Benue state as one of the Nigerian states along the Benue valley has several rivers/streams surrounding the environs. It has a poorly drained land area with alternating wet and dry season accompanied by uncontrolled dump of agricultural residue. Most of these residues are fibre-related and have made the condition of the soil relatively weak for building construction purposes. (It was observed by the researchers, during preliminary investigation, that rural school buildings are commonly erected without standard engineering test analysis of the materials such as the texture of aggregate. Most of the rural school buildings are in frightening shape of cracks and deflections and some already collapsed). The assumption therefore is that the poor condition of rural school buildings in Benue state can be attributed to poor aggregate texture as one of the factors.

It is also common knowledge within the construction industry that the strength of the concrete is very significant as it determines the maximum stress that the concrete can carry (Joel, 2010). As the strength of concrete increases, its other properties usually improve. It is this knowledge of the relationship between concrete strength and the maximum stress that the structure can carry that further propelled these researchers to become interested in determining the influence of aggregate texture on the strength of concrete.

2. Background Literature on Aggregates Particles Texture and the Strength of Concrete

2.1. Aggregates Particles Texture

Aggregates' shape and surface texture can affect the properties of concrete in both its plastic and hardened states (Arum, & Alhassan, 2005). The roundness of shape measures the relative sharpness or angularity of the edges and corners of a particle and is controlled largely by the strength and abrasion resistance of the parent rock and by the amount of wear to which the particles have been subjected to. In addition to the petrologic character of aggregate, its external characteristics are of importance, namely, the particles shape and surface texture (Neville, 1996).

In the case of crushed aggregate, the particle shape depends on the nature of the parent material and on the type of crusher and its reduction ratio (Neville, 1996). This is the difference between the solid volume of rounded aggregate particles after compaction in a standard cylinder, expressed as a percentage of the volume of the cylinder, and the solid volume of the particular aggregate being investigated when compacted in a similar manner (Arum, & Alhassan, 2005). The angularity number ranges from zero for a perfectly rounded aggregate to about 12. A development in the measurement of angularity is the angularity factor defined as the ratio of the solid volume of loose aggregate to the solid volume of glass spheres of specified grading (Bhikshma & Florence, 2013). This method has been shown to be suitable for both fine and coarse aggregates (Arum, & Alhassan, 2005). The void content of aggregate can be calculated from the change in the volume of air when a known degree of pressure is applied; hence the volume of air can be calculated (Gupta and Cupta, 2004). It has also been found that aggregate particles with a high ratio of surface area to volume lower the workability of the mix (Neville, 1996).

The surface texture of aggregates is based on the degree to which the particles surfaces are polished or dulled, smooth or rough. It also depends on the hardness, grain size and pore characteristics of the parent material as well as on the degree to which forces acting on the particle surface have smoothed or roughened it (Neville, 1996). There is no recognized method of measuring the surface roughness but Wright's approach (Wright, 1955) is of interest in this research. According to Neville (1996), it appears that the shape and surface texture of aggregates influence considerably the strength of concrete, especially the flexural strength which is more affected than the compressive strength. These effects are particularly significant in the case of high strength concrete.

According to (Neville, 1996), although the full role of shape and surface texture of aggregates in the development of concrete strength is not known, but possibly a rougher texture results in a greater adhesive force between the particles and the cement matrix. Furthermore, Neville (1996), clearly stated that the shape and surface texture of fine aggregates have significant effect on the water requirement of the mix made with the given aggregates, whereas the influence of coarse aggregate is less definite and that the shape of coarse aggregates in general has an appreciable effect on the workability of the concrete. On the other hand, experiments have shown a pattern of the relationship between angularity of coarse aggregate and the compacting factor of concrete made with it (Adom-Asamoah, et al, 2014). According to Adom-Asamoah, et al, (2014), an increase in angularity from minimum to maximum would reduce the compacting factor by about 0.09. However, there is no confirmation that the surface texture is a factor (Ahmed, 1989). Aggregates should preferably be spherical or cubical in shape and excessively elongated or flat particles should be avoided (Mohammed, Salim & Said, (2010).

2.2. The Strength of Concrete

The quality of concrete is often judged by its compressive strength, as indicated by a cube crushing test (Azevedo & Lemon, 2006). The strength of concrete is the maximum load (stress) it can carry. The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strengths of up to 80N/mm^2 can be achieved by selective use of the type of cement, mix proportions, method of compaction and curing conditions. Concrete structures, except road pavements, are normally designed on the basis that concrete is capable of mainly resisting only compression, the tension being carried by steel reinforcement (Abdullahi, 2012).

From literature, rough and highly angular aggregate particles increase internal friction in concrete, but lead to higher percentage of voids (Gupta & Gupta, 2004). The internal friction increases concrete strength while, the void leads to decrease in strength (Shetty, 2005). In contrast however, from Neville (2003), smooth gravel, which produces low voids confer lower stresses than the rough and angular crushed rock. This indicates that aggregate types and sizes influence the concrete strength. In this research the effects of these aggregate properties on strength of concrete based on commonly used mix ratio I: 2:4 was studied.

3. Purpose of the Study

The main purpose of this study was to investigate the influence of aggregate texture on the strength of concretes for possible use in rural schools in Benue State, Nigeria. The specific objectives of this study were;

- to identify the different texture of aggregate used in the study area;
- to evaluate the engineering properties of the aggregate textures and
- 3 to find out the influence of the texture orientation on concrete strength.

4. Materials and Method

The study employed a true experimental research design in which both the materials and the experiment were carried out within Benue State, Nigeria. The Ordinary Portland Cement (OPC) cement (Dangote Brand) and drinkable pipe-bone water were used. The fine aggregates and quarry dust were surface dried before use. The granite stones were of the dulled, crushed natural rock of sizes between 20mm and 28mm. The gravel sample was washed to remove any clay, dust and deleterious substances on the surface. The gravel sample sizes were prepared with sieves 28 and 20mm orifice respectively and the quantity passing each of them (the sieves) was used for the study.

4.1. Properties of the Materials

Two major properties of the aggregates were ascertained before the main experiment took off as reported here. These include the Specific Gravity and Sieve analysis of the aggregates.

4.1.1. Specific Gravity (SG) of the Aggregates

The specific gravity of the aggregates used in the experiment (concrete production) was based on the saturated surface dry condition of the aggregate (Neville, 2003). A metallic container used as the main apparatus, a measuring cylinder, balance, glass rod and drying duster were used to determine this aggregate property as follows:

- The cylinder was weighed and recorded as A.
- The cylinder was filled to 110cm of its capacity with the sample aggregate, weighed and recorded as B.
- The content of the cylinder was then filled half-way with water, stirred thoroughly with a rod and then filled to top, and weighed as C.
- The content was poured away and the cylinder properly cleaned, and filled with water to the top and weighed as D.
- The whole process is repeated 10 times for each aggregate sample.

VI. The specific gravity (SG) was computed for each sample applying the standard formula as follows:

$SG = \frac{B-A}{(D-A)-(C-B)}$ while $Density = \frac{B-A}{(D-A)-(C-B)} x\ 1000$

In the computation the masses (A, B, C and D) were substituted in equation after each set of specimens to obtain the result for each sample group. From here the density of the products were computed accordingly. The mean densities obtained from each material sample group were as follow: i. s and = 2400kg/m^3

ii. gravel = 25000kg/m^3
iii. quarry dust = 25000kg/m^3 and
iv. granite = 2650 kg/m3 respectively.

4.1.2. The Sieve Analysis

The sieve analyses of both the fine and coarse aggregates were done in accordance with BS 812: Part 103 (1983) and the test sieves selected according to BS 410 (1986). The analysis was carried out to obtain the fineness modulus that gave the average size of the sand. This was in line with the procedure recommended by Neville (2003) as follow:

- A set of sieves are weighed and arranged in descending order of aperture.
- The air-dried sample aggregate of 800g was obtained and poured into the uppermost sieve and the whole set were shaken manually, until no particle passes from one sieve to another.
- The samples retained on each sieve was weighed and recorded, from where the percentage retained and cumulative percentage weight passing and retained on each sieve were calculated.
- The cumulative percentage weight retained were summed up and divided by 100 to obtain the fineness modulus.

- This test returned a value is 6.56, showing that the average size of sand in the experiment was retained between the 6th and the 7th sieve and the corresponding sieve sizes were 0.4mm and 0.3mm, respectively.

4.2. The Experimental Procedure

The main experiment of this research was carried out under four major steps form the batching and mixing of the materials to the testing of the specimen samples, recording of measurements and computation of the data as follows:

4.2.1. Preparation and Testing of Concrete

- Batches and Mixing: The component ingredients for each mix were batched by weight as already determined for each mix and poured on a flat, non-absorbent smooth surface. All the component ingredients were mixed thoroughly and water added carefully until uniform reliability was achieved. The methods of curing concrete specimen as specified in the code (BS 1881, 1970) were applied. From each mix, ten cubes were cast for the test.
- The Slump Test: This test was to determine the degree of consistency in the wet concrete. The procedure as found in Neville (2003) with Gupta and Cuputa (2004) was adopted in this experiment. The slump test was carried out using a cylindrical cone with a bottom diameter of 200mm, top diameter of 100mm and height of 300mm. The inside surface of the cone was moistened and placed on a smooth, flat, non-absorbent surface and held firmly in place while it was filled with the fresh concrete in three layers. Each layer was tamped 25 times with a 16 mm diameter and 520 mm long tamping rod. The excess concrete, above the top of the cone was then struck off and immediately after filling. The mould was raised vertically, slowly and carefully to empty the concrete content. The empty mould was placed beside the concrete mass. The vertical difference between the top of the mould and the highest point of the wet concrete mass was measured to obtain the degree/level of slump. The result of the data is presented in Table 1 indicating that the slump values varied between 49 and 82mm. The lowest value coming from the concrete produced from sand and polished gravel of maximum size 20mm, while the highest slump value is for quarry dust and dulled granite of 20mm.
- Compression Test: Following the slump test, the concrete cubes were cast with the inner surface of the concrete cube moulds oiled and before pouring in the wet concrete. The concrete was placed in three layers with each layer compacted using steel rods of 25 mm square size, with 35 blows per layer and the surface was leveled using a hand trowel. Each concrete cube was marked with a number and the production date for easy identification. After 24 hours, the concrete cubes were removed from their respective moulds and cured in a water tank after which they were tested after 28 days.

On the testing day (28th day) the cubes were further air-dried then weighed and tested. The test was performed using a standard hydraulic compressive strength testing machine. The load was applied until the specimen failed and the failure load recorded accordingly.

The compression strengths were computed and analyzed accordingly. The specimen block compressive strength was computed from the following formula:

$$\text{Compressive Strength}(\alpha) = \frac{\text{Crushing Load (N)}}{\text{Effective Surface Area (mm)}} \quad \text{Mpa}$$

[where: a Crushing Load(N) = load at which the block crumbles/crushes. b. Effective Surface Area (mm = the surface area of the block in direct contact with the hardwood surfaces on the crushing machine].

5. Results and Analysis

The mean values of the compressive strengths and densities respectively are presented in Table 1. The results are plotted on a bar chart with concrete strength on Y axis and corresponding aggregate combination on X axis in Fig 1. The information presented in this Table 1 show that concrete produced from polished surface and 28mm gravel size and sand, gave a mean compressive strength of 19.78N/mm^2 while, complete replacement of sand with crushed stone produced a strength of 20.69N/mm^2, an increase of 0.91N/mm^2 (4.6% improvement).

Sample	Aggregate Texture	Slump	Sand	Quarry Dust	Granite	Gravel	Concrete Strength N/mm²	Concrete unit Weight Kg/m³
A	28 polished gravel size and sand	51	2.4	-	-	2.5	19.78	2393
B	20 dulled gravel size and sand	49	2.4	-	-	2.5	20.00	2355
C	28 polished granite size and quarry dust	82	-	2.5	2.65	-	23.78	2409
D	20 dulled granite size and quarry dust	79	-	2.5	2.65	-	26.52	2311
E	28 polished gravel size and quarry dust	52	-	2.5	-	2.5	20.69	2272
F	20 dulled gravel size and quarry dust	50	-	2.5	-	2.5	21.19	2365
G	28 granite size and sand	81	2.4	-	2.65	-	21.70	2346
H	20 granite size and sand	77	2.4	-	2.65	-	23.11	2434

Table 1: Results on the Mean Values from the Different Aggregate Specimen Concrete Products

Correspondingly, the concrete with 20mm dulled-gravel size and sand gave a strength of 20.00N/mm² whilst, complete replacement with crushed stone yielded strength of 21.19N/mm² an increase of 1.19N/mm² (5.95% an even higher improvement). Experiment D with 20mm dulled granite size and quarry dust at 79mm slump produced the highest compressive strength 26.52N/mm².

In summary, the result of these different aggregate combinations shows that concrete strength and aggregate surface texture at different sizes indicate that the more surface texture become polished (smooth) with increase in size, the less the concrete strength. This data also illustrates that as aggregate sizes increase, the amount of fine aggregate are reduced in the concrete thus reducing the surface area to absorb water thereby increasing the free water content in the concrete. The results of this experiment are further demonstrated in bar chart as shown in Fig 1 showing the concrete strength versus aggregate type in the concrete. From this figure, the highest strength of 26N/mm² is obtained for concrete containing quarry dust and granite with 20mm maximum size while the lowest strength is obtained from concrete made of sand and polished gravel of 28mm maximum size.

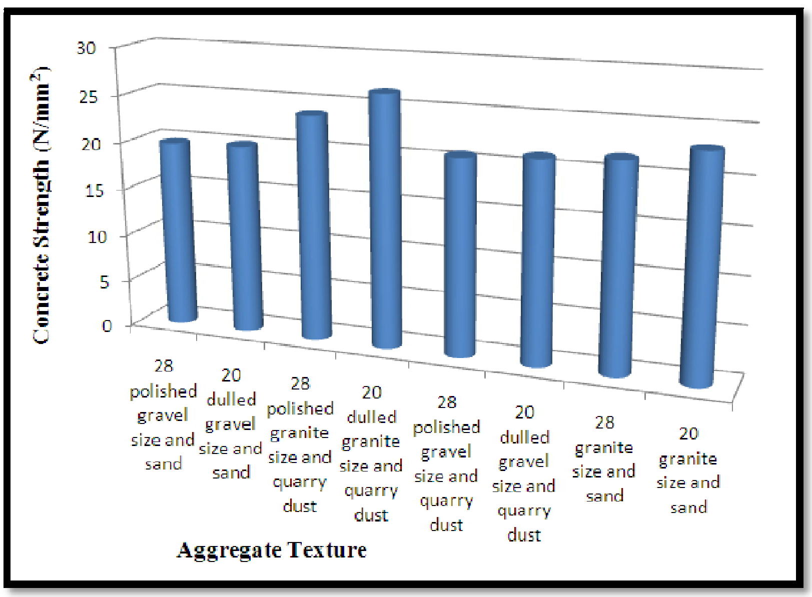

Figure 1

6. Discussion of Findings

The data and the subsequent analysis resulting from this experiment as presented in Table 1 and demonstrated in Fig 1 clearly show that the highest concrete strength of 26N/mm² is possible from concrete made from quarry dust and of 28mm maximum size. The intermediate strengths are associated with concrete with the combination of man-made and natural aggregates. This result also affirms a common knowledge within the construction industry that, normally concrete produced from man-made aggregates produce higher strength than the natural aggregate. But this study has further demonstrated that the concrete with sand and granite is stronger than the corresponding one with quarry dust and gravel. This agrees with Joel's (2010) finding that crushed stones can be used effectively in the replacement of natural sand in concrete and that concrete made with this replacement can attain the same strength.

The finding from this study has also shown that a replacement of natural sand with crushed dust was not only effective, it also caused marginal increase in strength. For example, concrete with polished surface and 28mm gravel size and sand produced a mean strength of 19.78N/mm^2 while, complete replacement of sand with crushed stone produce a mean strength of 20.69N/mm^2 giving an increase of 0.91N/mm^2 (4.6%). Correspondingly, the concrete with 20mm polished gravel size and sand showed a mean strength of 20.00N/mm^2 whilst, a complete replacement with crushed stone yielded a mean strength of 21.19N/mm^2 an increase of 1.19N/mm^2 (5.95%).

From the findings of this study, a comparison of the concrete strength and aggregate surface texture with sizes reveal that the more surface texture becomes polished (smooth) with increase in size, the less the concrete strength. This indicate that as aggregate size increases, the amount of fine aggregates are reduced in the concrete thus reducing the surface area to absorb water thereby increasing the free water content in the concrete. This finding is also in line with Neville (2003) who stated that the increase in free water content is the cause of decrease in concrete strength. From the slopes in the charts of Fig. 1, for each of the aggregate combinations, one can easily deduce that the rate of strength of concrete produced from the different combinations decrease as the roughness of aggregate texture and size increases. The result from the data also shows that the rate of decrease in strength is higher in the man-made aggregates than in the natural aggregates. In the natural aggregates the rate of change in strength with change in size, is very low (0.02), and therefore, change in texture of natural aggregate (gravel) from 20 to 28mm does not change the concrete strength significantly.

The data in Table 1, show that the slump values for the mixes vary between 49 and 82. The lowest value is for wet concrete with sand and polished gravel of maximum size 20mm and the highest slump is for quarry dust and dulled granite of 20mm. Similar result was obtained by Ahmed (1989) who discovered that with a constant water-cement ratio, as was the case in this study, the incorporation of fine sand to replace quarry dust, resulted in significant reduction in slump. This shows that combination of gravel and sand requires more water than the combination of granite and quarry dust in concrete work of similar slump. The reason could be that the polished gravel and sand have lower size aggregates and therefore higher gross surface area that will absorb more water than in the combination of granite and quarry dust.

7. Conclusion and Recommendations

The findings of the research have clearly demonstrated that in Benue state, Nigeria, the use of a combination of quarry dust and granite aggregates of rough surface produce concrete of higher strength than concrete containing sand and gravel polished smooth surface. In the case of a combination of man-made and natural aggregates, the concrete having sand and granite is stronger than the corresponding one with quarry dust and gravel. In addition, as sizes of course aggregate increases, concrete strength decreases whether the aggregate is man-made or natural. The rate of decrease in strength with change in aggregate texture is highest in concrete with quarry dust and granite and lowest in concrete having combination of sand and gravel. This indicates that the strength of concrete is more sensitive to differences in aggregate texture, especially when the aggregates are granite and quarry dust as against a similar one with gravel and sand.

In the final analysis this study has also discovered that in Benue state, Nigeria, with concrete made from gravel and sand, the rate of change in strength with change in aggregate texture is not significant. It is therefore recommended that a combination of quarry dust and granite aggregates of rough surface should be employed in the concrete components of rural school buildings in Benue State. The construction of rural school buildings in Benue should be based on adherence to stringent engineering test of materials.

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