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Investigating the Effects of Coarse Aggregate Types on The Compressive Strength Of Concrete

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ABSTRACT

Concrete has a far greater strength than mortar and sandcrete of the same cement: aggregate ratio. This exceeding strength is, most times, found to be triple (or more) that of mortar. Coarse aggregates, which are the interest of this study, make the difference. Three different types of coarse aggregates, with 20mm maximum size, were employed in the investigation, namely; crushed granite, washed gravel, and unwashed gravel. The grading and relative densities of the aggregates were studied. The mix ratio and water/cement ratio adopted for the study was 1:3:6 and 0.6 respectively. The target mean strength at 28 days was 15N/mm^2. Twelve concrete cubes (150mm x 150mm x 150mm) were cast for each coarse aggregate type of which four were crushed at each maturity age namely; 7, 14, 21, and 28 days. All cubes reached the target mean strength after 7 days of curing. The 28 day strengths of the concretes made with crushed granite, washed gravel, and unwashed gravel were 25.1 N/mm^2, 20.0 N/mm^2, and 16.9 N/mm^2 respectively. Consequently, it was concluded that the strength of concrete depends greatly on the internal structure, surface nature and shape of aggregates.

Keywords: aggregates, concrete, compressive strength, granite, gravel, curing.

I. INTRODUCTION

Concrete is a composite material produced by the homogenous mixing of selected proportions of water, cement, and aggregates (fine and coarse). Strength is the most desired quality of a good concrete. It should be strong enough, at hardened state, to resist the various stresses to which it would be subjected. Compressive strength of concrete, therefore, is the value of test strength below which not more than a prescribed percentage of the test results should fall (Kong and Evans, 1987) [7].

The high variation in strength between concrete and mortar of the same cement/aggregate proportion, suggests the quintessence of coarse aggregates in the development of strength in concretes. The coarse aggregates are obtained naturally or artificially and occupies up to 60% by weight or volume of the concrete, depending on the mix proportion adopted which, in turn, depends on the expected compressive strength. Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. 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). The 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. Lightweight aggregate concrete may be more influenced by the compressive strength of the aggregates [18].

For this reason, 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 size, shape, and surface conditions of aggregates are considered alongside the mineral composition of the rock material from which the aggregate formed a part.

It is a common practice in Nigeria to use locally found aggregates (washed and unwashed gravels) for construction purposes. The integrity of these aggregates should be investigated to ascertain their performance in structural members. Recent constructions in Nigeria, especially in Awka and its environs make indiscriminate use of aggregates notwithstanding their sources and not considering their physical condition at the time of use. For instance, gravels may be obtained from the same source but one should not expect the same strength performance from them if some were used without washing and others used after washing. The relative effect of these variations in the nature of coarse aggregates on the compressive strength achieved by the concretes has been investigated and presented in this study.

II. REVIEW OF PAST WORKS

The strength of concrete is its major characteristic. Neville, 1981 [8] stated that aggregates are inert materials that are dispersed through-out the cement paste whose strength depends majorly on its shape, surface texture, and cleanliness. In his research findings, he published that entirely smooth coarse aggregates lowered the strength of concrete by 10% than when the aggregates were roughened. Young and Sam, 2008 [14] also stated that smooth rounded aggregates was more workable but yielded a lesser compressive strength in the matrix than irregular aggregates with rough surface texture. They were also of the opinion that a fine coating of impurities such as silt on the aggregate surface could hinder the development of a good bond and thus affects the strength of concrete produced with the aggregates.

The test carried out by Soroka, 1993 [12] revealed the variations between the compressive strengths of concrete made with crushed stone and uncrushed stone. He achieved a better compressive strength with the crushed stone than the uncrushed stone. This strength performance was as a result several factors like water/cement ratio, grading, surface texture, shape, strength, and stiffness of aggregates used. Bloem and Gaynor, 1963 [1], also studied the effect of shape, surface texture, fine coatings, and maximum size of aggregates on the water requirement and strength of concrete. The study reported that at equal water/cement ratio, irregular shaped smaller sized aggregates without coatings achieved a better strength than smooth rounded large sized aggregates. They also opined that individual properties of aggregates and the magnitude of the size difference may lead to increase or decrease in concrete strength at a fixed cement content.

Stanon and Bloem, 1960 [13] reported that at different water/cement ratios, strength levels exist for different maximum sizes of aggregates. Without exception, they discovered that there is always a reduction of concrete strength as the maximum size of aggregate increased at the same water/cement ratio. The presence of clay, silt, crush dust and all forms of over coating was also judged as deterrent to the development of aggregate-cement bonds and this brings about reduction in the strength of concrete.

Chen and Liu, 2004 [2] as well as Rao and Prasad, 2002 [10] viewed aggregates as the skeleton of concrete and consequently persuaded that all forms of coatings should be avoided in order to achieve a good concrete. When a concrete mass is stressed, failure may originate within the aggregates, the matrix, or at the aggregate-matrix interface. The aggregate-matrix interface is an important factor determining the strength of concrete. The surface texture of concrete is generally considered in relation to concrete flexural strengths (Kaplan, 1959) [6]. Raju,1988 [9], also stressed that good concrete can be made by using different types of aggregates(considering shapes) like rounded and irregular gravel or crushed rock which is mostly angular in shape.

Neville, 1981 [8], rightly observed hat concrete is among the most commonly used structural materials alongside steel. The knowledge of the properties of concrete makes possible the selection of a more suitable economic mix. The strength of the concrete is of quintessence. It is the maximum load (stress) that the concrete can carry (Jackson and Ravindra, 1996) [3]. As the strength of concrete increases, its other properties usually improve. Tests for strength, particularly in compression, are easily performed; concrete compressive strength is commonly used in the construction industry for the purpose of specification and quality control. The Engineer knows his target flexural strength and will express it in terms of compressive strength. Several factors affect the compressive strength of concrete. The coarse aggregate which is the largest component of the concrete, needs to be seriously taken into consideration as it would doubtlessly play a major role in the strength improvement of the concrete.

III. MATERIALS AND METHODS

The fine aggregate used for this research work was river bed sand collected from the Amansea river, Awka North Local Government Area of Anambra State. Three types of coarse aggregate namely; crushed granite, washed gravel, and unwashed gravel. The gravels were sourced from a quarry at Abagana in Idemili South Local Government Area of Anambra State. The Crushed granites used were bought from the marketed chippings in Awka, which were actually sourced from Auchi quarries, in Esako Local Government Area of Edo State. The maximum size of the aggregates was 20mm.

The Dangote Brand of Ordinary Portland cement was used in the work. It is marketed in most cement shops within Awka. The cement was taken to the laboratory in 50kg bags and was carefully kept away from dampness to avoid lumps. Portable water supplied at the Concrete Technology laboratory of Reynold's Construction Company plant located at Nteje in Oyi local Government of Anambra State was also used throughout the research work. The Particle Size Distribution of the coarse and fine aggregates was carried out after they were air dried as well as their Specific gravity tests.

The batching of the concrete was by weight and a mix ratio of 1:3:6 was adopted for a target mean strength of 15N/mm^2 as presented by Salihu, 2011 [11] which is in accordance with BS 812(1975, 1986, and 1995) [16]. Water/cement ratio of 0.6 was employed. Four cubes were cast for each aggregate type for a particular age at curing, namely; 7 days, 14 days, 21 days, and 28 days. In other words, 12 concrete cubes (150mm x 150mm x 150mm) were cast for each aggregate type, making a total of 48 cubes. The fresh concrete was thoroughly tampered in the mould with steel rod and reference numbers were given to the moulds for easy identification of the concretes made with the same type of coarse aggregate. The moulds were removed after 24hours and the ponding method of curing, in which the cubes were totally immersed in water throughout the curing period, was adopted. The water in the curing pond was kept at an average laboratory temperature of 28^{0}C (82.4^{0}F) to prevent thermal stresses that could result in cracking, just as James *etal*, 2011 [4] suggested.

Four cubes were removed from each set of cubes at each maturity age. The cubes were weighed and crushed using the Danison crushing machine in the Concrete Technology laboratory of Reynold's Construction Company, Nteje, Anambra State. The ratio of the crushing loads to the surface area of the cubes gave the compressive strengths of the cubes which were averaged for each aggregate type at each curing age.

IV. RESULTS AND DISCUSSION

Particle Size Distribution

Figure 1 is the sieve analysis carried out on both the fine aggregate and the coarse aggregates in accordance with the guidelines specified by BS 1377; Part 2,1990 [17]. The figure shows that the river sand used for the experiment was well graded with a maximum size of 3mm. The maximum and minimum sizes of the coarse aggregates (granite, washed gravel and unwashed gravel) were 20mm and 3mm respectively. This is proper for coarse aggregates to be used in construction works.

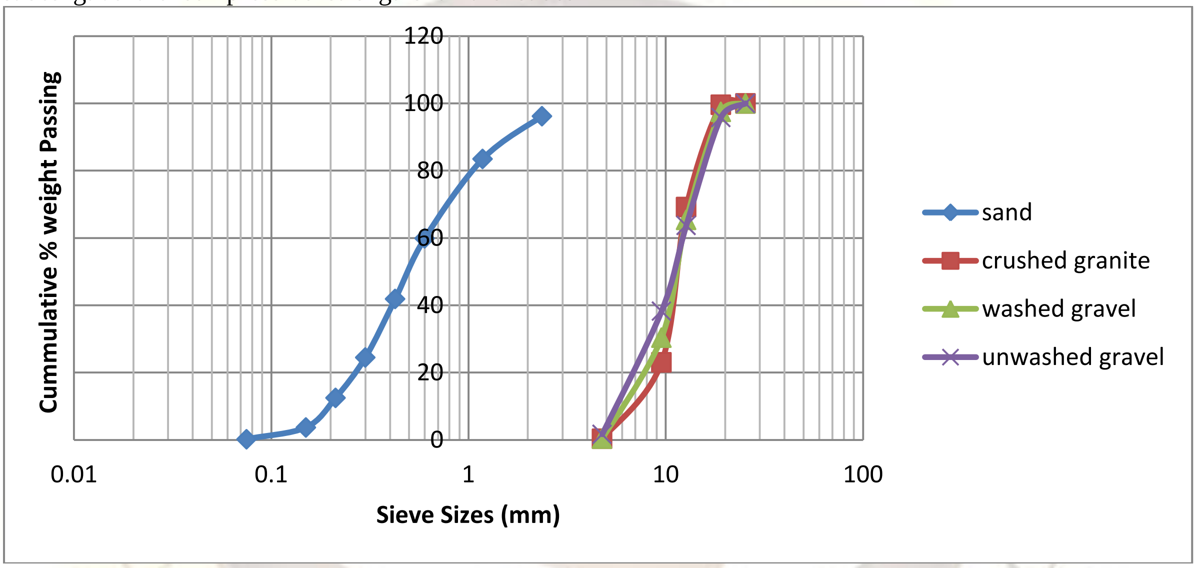

Figure 1: Particle Size Distribution of the fine and coarse aggregates

V. Specific Gravity and Water Absorption of Aggregates

Table 1 reveals the relative Density or Specific Gravity of the aggregates used in the investigation in accordance with the specifications of ASTM (C127 and C128, 2012) [15]. The sand, the crushed granite and the gravel displayed Specific Gravity values of 2.66, 2.24, and 2.89 respectively. The low specific gravity of the crushed granite shows that it is an impervious light weight aggregate. The porosity and the weight of the gravel account for its high specific gravity. The water absorption of the aggregates differs as shown in the table. Granite should have required a smaller quantity of water to achieve the water/cement proportion than the gravel. The fact that the same quantity of water was used in the mixes suggests that larger amount of water was actually employed in the concrete mixes with the gravel.

Table 1: Relative Density and Water Absorption of the Aggregates

Property / Aggregate Type	Specific Gravity (S_g)			Water Absorption (%)
	S_g 1	S_g 2	Mean S_g	
Sand	2.66	2.65	2.66	-
Granite	2.25	2.24	2.24	0.4
Gravel	2.39	3.38	2.89	5.5

VI. Compressive Strength

Tables 2, 3, and 4 as well as figure 2, shows the result of cube crushing at 7, 14, 21, and 28 days respectively. From the result, the compressive strengths of the concrete cubes cast with the three types of coarse aggregates were found to have exceeded the target mean strength after seven days of curing. The compressive strength of the washed and unwashed gravels was very close at the 7th day of curing. The compressive strength of crushed granite at the 7th day exceeded those of the gravel with a significant margin of 5.6 N/mm^2 which is up to 35% variation in strength. Apart from the fact that the unwashed gravel was coated with dirt of clay, silt, and humus, it is the same material with the washed gravel. The closeness of their compressive strengths is, therefore, not a surprise. More strength was gained as the curing age increased. This increase in strength as the curing age increased is in agreement with the findings of James *etal*, 2011 [4] and Joseph *etal*, 2012 [5], though the densities of the cubes decreased with increase in curing age.

In all cases, the compressive strength of the unwashed gravel remained the least, though it was from the same source with the washed gravel and is the same material with it. This variation in strength development could be due to the micro fine coatings of silt, clay and humus which are deterrents to the development of concrete strength. This further supports the opinion of Bloem and Gaynor, 1963 [1] that says that the cleaner the aggregates, the better the strength performance. Indeed cleanliness is an important factor in concrete strength development. The micro fines absorb the water that is made available for the initial hydration of cement and consequently, disrupts the aggregate-cement bond. The effect of this could be more pronounced at larger quantities of the fines.

Table 2; Compressive Strength of Concretes made with Crushed Granite

Age at Curing	Cube Reference	Crushing Loads (KN)	Compressive Strength (N/mm^2)	Mean Compressiv Strength (N/mm^2)
7TH Day	CG 1	490	21.8	22.1
	CG 2	503	22.4	
	CG 3	498	22.1	
	CG 4	495	22.0	
14TH Day	CG 1	520	23.1	23.5
	CG 2	530	23.6	
	CG 3	525	23.3	
	CG 4	536	23.8	
21ST Day	CG1	540	24.0	23.9
	CG2	538	23.9	
	CG3	540	24.0	
	CG4	531	23.6	
28TH Day	CG 1	575	25.6	25.1
	CG 2	568	25.2	
	CG 3	545	24.2	
	CG 4	568	25.2	

Age at Curing	Cube Reference	Crushing Loads (KN)	Compressive Strength (N/mm^2)	Mean Compressive Strength (N/mm^2)
7TH Day	U 1	336	14.9	15.5
	U 2	360	16.0	
	U 3	360	16.0	
	U 4	340	15.1	
14TH Day	U 1	369	16.4	16.6
	U 2	375	16.7	
	U 3	370	16.4	
	U 4	374	16.6	
21ST Day	U1	376	16.7	16.8
	U2	378	16.8	
	U3	378	16.8	
	U4	378	16.8	
28TH Day	U 1	378	16.8	16.9
	U 2	390	17.3	
	U 3	378	16.8	
	U 4	379	16.8	

Table 3; Compressive Strength of Concretes made with Washed Gravel

Table 4; Compressive Strength of Concretes made with Unwashed Gravel

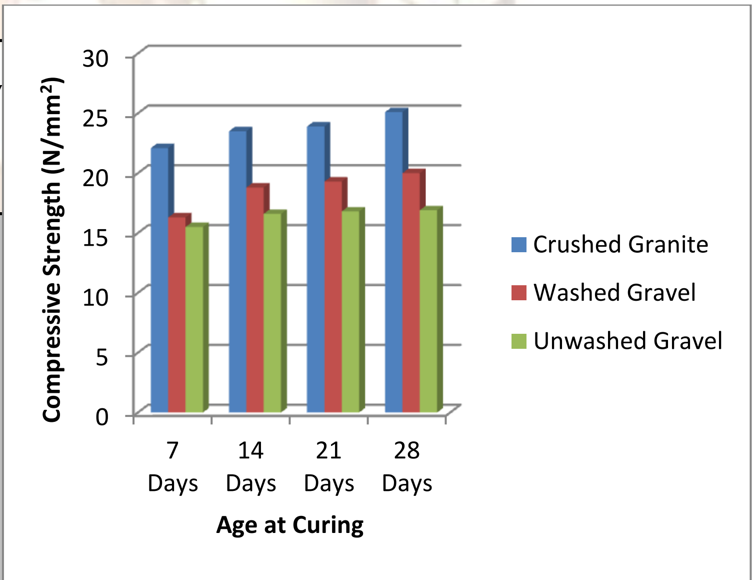

Figure 2; Variation of Compressive Strength with Aggregate Type and Age at Curing

VII. CONCLUSIONS AND RECCOMENDATIONS

Based on the results of this investigation which have been discussed above, the following conclusions can be drawn:

- Concretes made with crushed granite performed best in compression than those made with natural gravels of similar grading.

- Concretes made with unwashed gravel had the least compressive strength. This is in agreement with the findings of Kaplan, 1959 [6], Soroka, 1993 [12], Young and Sam, 2008 [14], among others. This, therefore, reaffirms that variation in concrete strengths is due to factors like; surface nature, cleanliness and internal structure of the aggregate materials.

It is, therefore, recommended that;

1. The investigation should be extended to the effect of different sizes of coarse aggregates on the compressive strength of concrete.
2. Proper compaction of the concretes must be ensured, as compaction is observed to improve the strength of concrete.
3. Coarse aggregates if sourced with impurities must be washed before use.
4. Lightweight but strong aggregates like crushed granite should be used (notwithstanding the cost) in high rise buildings and other massive structures in which high factors of safety for the strength of concrete is required.
5. For smaller structures, the natural gravels can be more economical.

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