Comparison of different forms of gravel as aggregate in concrete

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Abstract

Gradation plays an important role in the workability, segregation, and pump ability of concrete. Uniformly distributed aggregates require less paste which will also decrease bleeding, creep and shrinkage while producing better workability, more durable concrete and higher packing. This attempt looks at the effect of particle size distribution pattern for five types of gravel aggregate forms, angular, elongated, smooth rounded, irregular and flaky as related to the strength of concrete produced. Different forms of naturally existing gravel aggregate were collected from a particular location and tests were carried out on them to determine their gradation. Based on the gradation the aggregates were used to prepare different samples of grade 20 concrete with water-cement ratio of 0.5. The particle size distribution resulted in coefficients of uniformity ranging from 1.24 to 1.44. The granite aggregate, which serves as a reference, had a coefficient of uniformity of 1.47. Tests were conducted on fresh and hardened concrete cube samples. The concrete sample CT5 recorded a slump of 32mm and highest compressive strength value of 21.7 N/mm^2, among the concrete produced from different forms of gravel.

Keywords

Aggregate; Gravel; Particle size; Gradation; Shape; Concrete; Density; Compressive strength

Introduction

This research looks at aggregate characteristics of shapes, texture and grading with respect to its influence on workability, of fresh concrete and how it affects strength, density, and durability of hardened concrete. The bush gravel is a local construction material commonly used by the local populace, but no previous research has been done to determine its properties [1].

The high costs of concrete used in construction arise from the cost of the constituent materials. Such cost can be reduced through the use of locally available alternative material, to the conventional ones normally used in concrete work [2]. The interest of this research is to suggest an alternative material to granite because it is very expensive. The maximum size of a well-graded coarse aggregate of a given mineralogy can have two opposing effects on the strength of normal concrete [3] mentioned that, with the same cement content and consistency, concrete mixtures containing larger aggregate particles require less mixing water than those containing smaller aggregate. On the contrary, larger aggregates tend to form weaker transition zones containing more micro-cracks. They concluded that, the result of these two opposing effects when large aggregates are used is considerably slight.

Some researchers have carried out work on the effect of particle size distribution of coarse aggregates and their impact on compressive strength of concrete produced from them.[4] predicted aggregates' size distribution effect on the compressive strength of concrete, using a probabilistic mechanical model approach. The aggregate diameters were defined as statistical variables and their size distribution functions were identified to the experimental sieve curve. They proposed inter-aggregate failure criterion to describe the compressive-shear crushing of the hardened cement paste when concrete was subjected to uni-axial compression. They used homogenization approach to develop an analytical formula which predicted the effects of cement paste strength and aggregate size distribution and volume fraction on the concrete compressive strength. According to them, an increasing concrete strength for the same cement paste and the same aggregate volume fraction can be obtained by decreasing both aggregate maximum size and the percentage of coarse aggregates.

Combined four granular fractions in different proportions in order to investigate the effect of the particle size distribution of the aggregate on the properties of concrete [5]. Their results revealed that the highest compressive strength was obtained for mixtures without chemical admixture made with a ternary combination of granular fraction and having a maximum size of 25 mm, with a continuous granular size distribution.

Quantified the wall effect of concrete by configuration parameters such as the volume fraction, the specific surface area and the mean free space of the solid phase [6]. They also considered the influences of ellipsoidal particle size distribution, shape and volume fraction of ellipsoidal aggregates on the configuration parameters as evaluated by stereological methods and serial section analysis technique.

The workability of concrete changes significantly with grading, mixture with high void contents requires more paste for a given level of workability [7]. Aggregates strongly influence the freshly mixed and hardened properties of concrete, as well as the mixture proportions and the economy. Consequently, this indicates that the selection of aggregate is an important process.

The effect of shape of aggregate on the quality of concrete used for buildings and pavements was studied by [8]. They varied the proportions of Flakiness and Elongation and conducted tests to evaluate the effect on the compressive strength and flexural strength of concrete.

The influence of aggregate size on the compressive strength of concrete was also studied by [9]. They compared the effect of aggregate size on the compressive strength of normal-weight concrete and lightweight concrete specimens in order to trace the size-effect trend.

The contribution of aggregate size on the compressive strength and void ratio for different binder strengths was investigated by [10]. They concluded that the rate of strength reduction of porous concrete with small aggregate size is found to be higher than that with larger aggregate size. At the same void ratio, the strength of porous concrete with large aggregate is larger than that with small aggregate. Polyurethane Polymer Concrete was studied by [11] for the influence of aggregate shape and distribution on its strength and fracture behaviour. They found out that the aggregate shape and distribution have significant effects on the failure behaviours of the Polyurethane Polymer concrete specimen under loading, in terms of the micro-cracks formation, growth and the failure strength.

This work studied the particle size distribution of five different forms of gravel aggregate and the effect on the workability and strength of concrete produced from them. No previous research has been done on this particular material before, but it’s widely used by the locals, without any scientific basis.

Materials and method

The gravel used for the experiment was obtained from a local settlement located some 3km away from toll gate station at Kpagungu, Minna. Borehole water fit for drinking located close to the concrete laboratory of the Federal University of Technology, Minna was used for the concrete production. The ordinary Portland cement brand, obtained from cement store at Kpagungu, Minna was used as binder for the concrete work. Sieve analysis test [12] for sand, crushed granite, angular gravel, elongated gravel, smooth rounded gravel, irregular gravel and flaky gravel were conducted according to specifications by the British Standard. Slump test [13] and compacting factor test were conducted on the fresh concrete. Samples of hardened concrete cubes prepared, were also tested for density and compressive strength [14].

Proportions of concrete mixture

The concrete mix design was done based on an assumed concrete grade 20 using the procedure for the design of normal weight concrete stipulated in British Standard [15]. Batching by weight method was used to proportion the concrete materials. The reference mix adopted is that produced with crushed granite as coarse aggregate. Five other different types of concrete samples based on the five different types of gradation for angular gravel, elongated gravel, smooth rounded gravel, irregular gravel and flaky gravel, were also produced. The quantities of cement, sand, water and the coarse aggregate were kept constant for all the mix samples, the only variant is the gradation of the coarse gravel-aggregate. The details of the concrete mix proportion are shown in Table 1 below.

Table 1. Concrete samples and the proportions of their constituent materials

Conc. sample W/C = 0.5	Qty of ingredients in kg/m^3			
	Aggr.	Sand	Cement	Water
CT1	1389	672	202	101
CT2	1406	672	202	101
CT3	1396	672	202	101
CT4	1408	672	202	101
CT5	1411	672	202	101
CT6	1410	672	202	101

CT - concrete type; CT1- crushed granite concrete sample; CT2 - rounded gravel concrete sample; CT3 - elongated gravel concrete sample; CT4 - irregular gravel concrete sample; CT5 - angular gravel concrete sample; CT6 - flaky gravel concrete sample

Results and discussion

The results for the particle size distribution for crushed granite, angular gravel, elongated gravel, smooth rounded gravel, irregular gravel and flaky gravel are summarized and presented in Table 2 below. Particle size distribution for sand, crushed granite, angular gravel, elongated gravel, smooth rounded gravel, irregular gravel and flaky gravel shown in Figures 1 to 7 respectively, indicates that the crushed granite and all the gravel aggregate are uniformly graded. Uniformly graded aggregate, indicates aggregate containing particles of almost the same size [16]. With this grading, aggregates are not well packed, and resulting concrete will require lot of paste. For better understanding of the gradation of aggregate, two types of coefficient are usually employed, Coefficient of uniformity (Cu) and coefficient of curvature (Cc). For a well graded coarse aggregate, coefficient of uniformity (Cu) must be greater than 4 while coefficient of curvature (Cc) lies between 1 and 3. The particle size analysis gave the values of coefficient of uniformity Cu for angular, elongated, smooth rounded, irregular and flaky gravel aggregates as 1.38, 1.44, 1.4, 1.44 and1.24 respectively, while the Cc recorded are 0.92, 1.01, 1.03, 0.92, and 1.06 respectively.

Tests results for consistency of the fresh concrete gave slump value of 27mm for CT2 sample, 38mm for CT3, 30mm for CT4, 32mm for CT5, and 38mm for CT6. The crush granite concrete sample which serves as control gave slump value of 33mm. All the slump values obtained, lies within the range 10-40mm which is categorized as True Slump according to [12]. The compacting factor test results gave 0.8 for CT2 sample, 0.91 for CT3, 0.8 for CT4 0.86 for CT5 and 0.86 for CT6. The crush granite concrete sample which serves as control gave compacting factor value of 0.88. BS 1881: part 103; [17] prescribes for normal weight concrete, compacting factor value range of 0.8 to 0.92. The summary of workability tests results for fresh concrete samples are presented in Table 3 below.

The hardened concrete samples were tested for density and compressive strength. The density of concrete cubes samples for CT1, CT2, CT3, CT4, CT5 and CT6 at 28 days hydration period are 2458, 2416, 2417, 2401,2443 and 2410kg/m^3 respectively, while the concrete cubes compressive strength values are 22.8, 17.1, 17.1, 17.1, 21.7 and 17.2N/mm^2. The variation of density and compressive strength with age are represented in Figure 8 and Figure 9 respectively. The density of the produced concrete cubes samples falls within the range 2400 to 2460kg/m^3.

Table 2: Particle size distribution for aggregate

Sieve size (mm)	% Passing					
	Granite	Rounded Gravel	Elongated Gravel	Irregular Gravel	Angular Gravel	Flaky Gravel
37.5	100	100	100	100	100	100
28.0	99.2	97.9	83.4	93.6	98.4	70
20.0	56.9	53.1	37.5	37.8	42.3	25.4
14.0	11.1	6.1	6.7	3.6	1.0	6,8
10.0	1.5	0	2.9	1.3	0	2.8
6.3	0.1	0	0.9	0.4	0	0.9
5.0	0	0	0	0	0	0

Sieve size mm % of sand										
Sieve size mm	5	3.35	2	1.18	0.85	0.6	0.45	0.3	0.15	0.075
% of sand	100	99.1	95.6	88.8	80.6	61.1	33.9	14.4	1.6	0.4

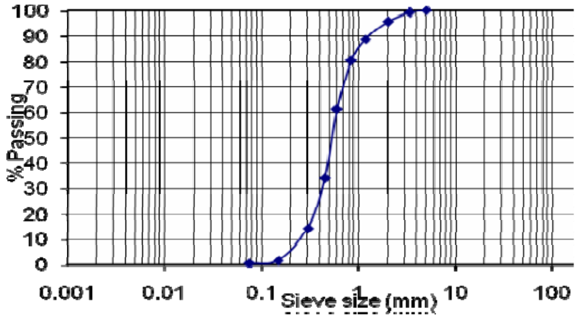

Figure 1. Particle size distribution for sand

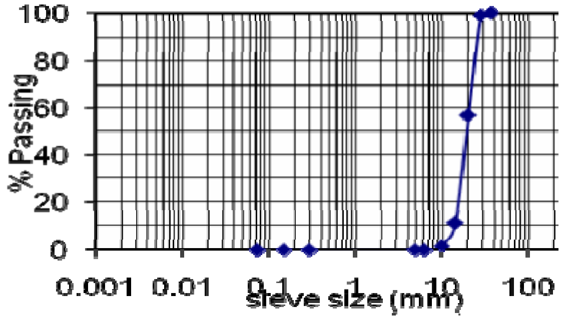

Figure 2. *Particle size distribution for granite*

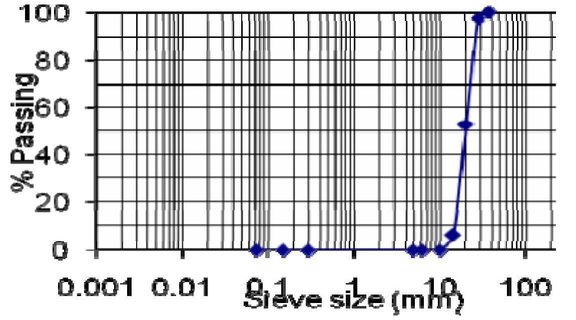

Figure 3. *Particle size distribution for rounded gravel*

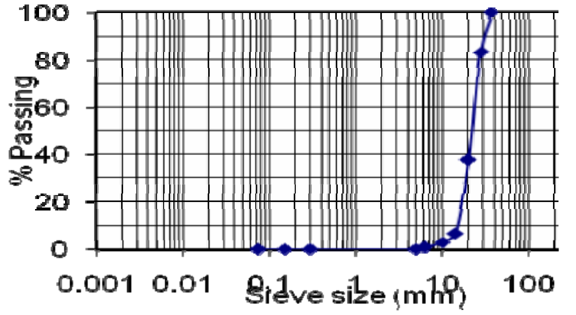

Figure 4. *Particle size distribution for elongated gravel*

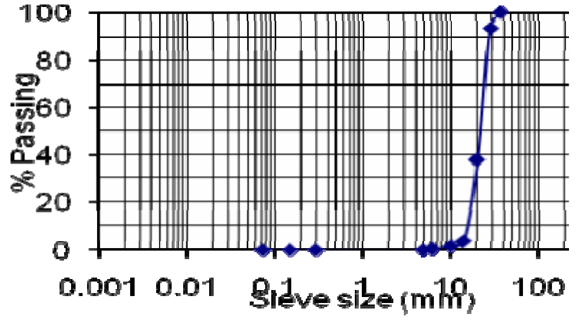

Figure 5. *Particle size distribution for irregular gravel*

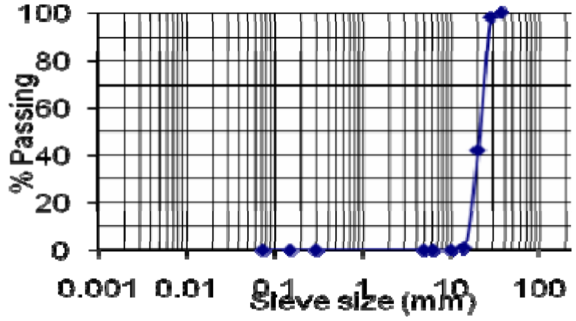

Figure 6. *Particle size distribution for angular gravel*

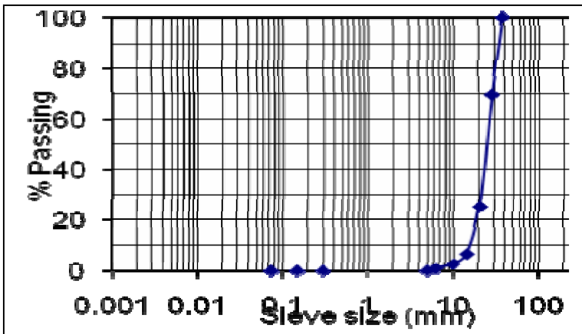

Figure 7. *Particle size distribution for flaky gravel*

Table 3. Results of workability test for fresh concrete

Concrete sample	Slump	Workability	Compacting factor
CT1	33	Medium	0.88
CT2	27	Low	0.80
CT3	38	Medium	0.91
CT4	30	Low	0.80
CT5	32	Medium	0.86
CT6	38	Medium	0.86

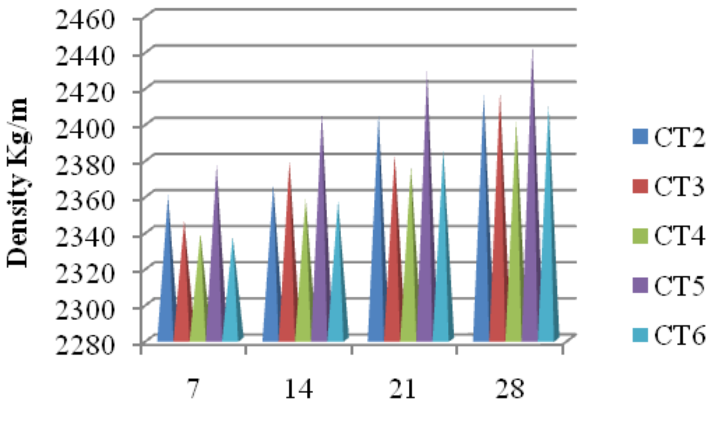

Figure 8. *Density of concrete cube samples and variation with age*

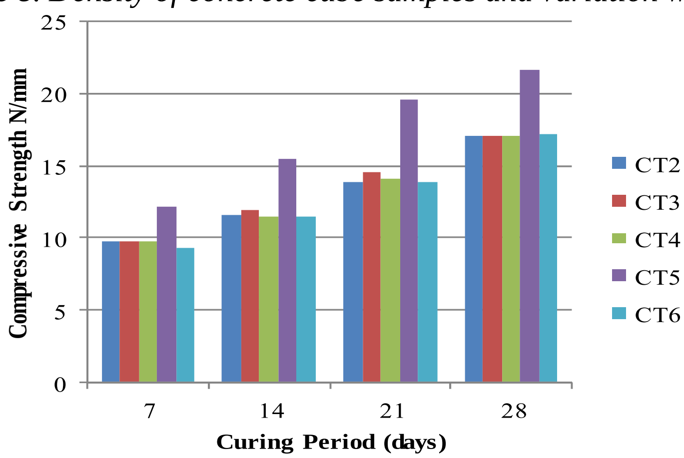

Figure 9. *Compressive strength of concrete cube samples and variation with age.*

Concrete cubes made with normal weight aggregate have density range of 2200kg/m^3 to 2600kg/m^3 [16]. It can be deduced from this result, that all the gravel aggregates, and the crushed granite used as control are normal weight aggregate. The crushed granite concrete gave compressive strength value of 22.8 N/mm^2 close to the value of 21.7N/mm^2 obtained for concrete sample CT5 made of angular shape gravel aggregate and the highest among all the gravel aggregate shapes considered. This value also falls within the strength range for normal weight concrete [16]. There are several reasons for choosing compressive strength as representative index for concrete. First, concrete is used in a structure to resist compression force. Second, the measurement of compressive strength is easier and lastly, other properties can be related to it [18]. Some researchers also worked on similar area of research, but not the same topic, also got some comparable outcome. [19] Evaluated the concrete strength of five types of sandstone while [20] determined the effect of aggregate shape on the mechanical properties of concrete.

Conclusions

The gradation of gravel aggregate based on their shapes, workability of fresh concrete produced using these aggregates, density and strength of the hardened concrete has been successfully evaluated.

- The concrete sample CT5 made of angular shape gravel aggregate gave highest value of compressive strength, 21.7N/mm^2 very close to 22.8 N/mm^2 obtained for crush granite concrete sample CT1 which serves as reference.
- Based on the findings from this research the local populace can be further advised on the best way to use the naturally existing gravel. More importantly, the cost of this naturally occurring gravel is 50% cheaper than crushed granite.
- The angular shape gravel aggregate satisfy the guidelines requirements and specifications for normal weight aggregate.
- The angular shape gravel aggregate with average size of 18mm Ø can be used for concrete production where concrete strength required is below 21N/mm^2, in line with the global trend of sustainability and cost control in construction materials.
- The cost of construction can be reduced through the use of locally available alternative

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material, to the conventional ones normally used in concrete work. The world wide consumption of coarse aggregate in concrete production is very high, and several developing countries have encountered some difficulties in the supply of this aggregate in order to meet the increasing needs of infrastructural development in recent years, hence the need for research about alternative materials.

Acknowledgements

The author hereby acknowledge the contribution of laboratory Technician, Mohammed Umoru, undergraduate students Ramot Saa'du, Tayyib Mohammed and Stephen Arinola for materials collection and other contributions towards the success of this research. The authorities of Federal University of Technology, Minna are also appreciated for providing the necessary equipments and tools used for the research.

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