TECHNICAL SCIENCES

USE OF KUTA GRAVEL AS COARSE AGGREGATE FOR SUSTAINABLE CONCRETE PRODUCTION

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Abstract

Continuous rise in the world's population has resulted in increase in the demand for shelter and consequently, higher demand for concrete. By occupying three-quarter of concrete volume, the demand for aggregates has also increased. Processes involved in the manufacture of the commonly used crushed aggregates are major sources of environmental pollution. There is need therefore, to find alternative sources of aggregates to cater for the high demand and also solve the problem of environmental pollution. This study investigated the properties of coarse aggregate obtained from Kuta all-in aggregate and its compressive strength when used in producing concrete. The coarse aggregate was separated from the all-in aggregate using 4.75mm BS standard sieve. Properties of the coarse aggregate (mechanical and physical) were determined in accordance with relevant parts of BS 812. Five concrete mixes were made with varying values of Water/Cement (W/C), Coarse Aggregate/Total Aggregate (CA/TA) and Total Aggregate/Cement (TA/C) ratios. Three (3) 150×150×150mm concrete cubes were cast for each mix and checked for compressive strength at 28 days. The properties of Kua gravel determined showed that it has a specific gravity value of 2.60, water absorption value of 0.60%, flakiness index of 26%, elongation index of 29%, AIV of 16.45%, ACV of 25.82%, percentage air void (uncompacted) of 41.5%, uncompacted and compacted bulk densities of 1523.47kg/m^3 and 1640.52kg/m^3 respectively. The particle distribution falls within the limit for graded aggregates between 20mm-5mm.The properties of Kuta gravel so determined, fall within the acceptable limits for properties of natural coarse aggregates used in producing concrete. Concrete mix with a combination of W/C=0.4, CA/TA=0.55, TA/C=3 yielded the maximum compressive strength of 26.8N/mm^2. It was concluded that Kuta gravel is suitable for use as coarse aggregate in producing structural concrete requiring a strength of 25N/mm^2 or less.

Keywords: Characterisation, Concrete, Coarse aggregate, Kuta gravel, Compressive strength, Sustainability.

1. INTRODUCTION

Over the years, the world has witnessed a significant rise in its population. The world's population has increased from 4 billion in 1987 to 7 billion in 2011 [1]. This number has risen to 7.8 billion by 2020 and is estimated to reach 9.8 billion by the year 2050 [2]. Critical needs that are key to the survival of the human race are regarded as physiological needs [3]. Shelter is listed among the physiological needs of man. It has become imperative therefore, to provide affordable shelter for the world's teeming population.

For several years, concrete has been the primary material used in the construction of buildings [4]. It is regarded as the most popular material used for building [5]. With the increase in population therefore, there is consequent increase in the demand for concrete. Concrete is a construction material basically formed from water, cement and aggregates.

Aggregates make up about 70-80% of the absolute concrete volume [6], [7]. With this, they can be regarded as the most essential element of concrete. The properties of these aggregates determine durability characteristic of concrete they are made with. This is corroborated by Neville and Brooks [8] that the characteristic properties of concrete are influenced by the physical, chemical, mechanical and thermal properties of the aggregates it is made from. For a concrete with the most desirable properties therefore, aggregates must be properly selected and controlled. The determination of aggregate properties (characterization) is therefore, very important if concrete with desirable properties is sort.

According to source, aggregates are grouped as natural and synthetic (manufactured) aggregates [9]. Over time, researchers have focused on trying to find alternatives to the commonly used crushed (manufactured) aggregates. This has become necessary, since crushed aggregates are not available in some localities and transporting them to such localities for use in concrete increases the overall cost of construction [10]. Also, the processes that are involved in the manufacture crushed aggregates are major contributors to environmental pollution. This is corroborated by Njoku *et al.* [11] that noise, brought about by excavation of aggregate materials and significant dust from the quarry sites are unavoidable especially in situations where explosives are used. Harmful chemicals that are detrimental to the well-being of people living around the quarry sites are also expelled from these activities. Besides the problems of environmental pollution, the world, in recent times, has witnessed an aggravated increase in demand for concrete to be used in regular construction, consequently resulting in a greater demand for alternative construction materials [12]. It is clear therefore, that the continuous use of manufactured (crushed) aggregates is not sustainable.

The establishment of dredging sites in the farthest reaches of the world in recent years have resulted in the availability of a significant volume of river-based aggregates. These aggregate particles have sizes ranging between 4.75 and 25mm [12]. Given this size distribution, these aggregates can be classified and utilized in concrete making [13]. Kuta all-in aggregate is a natural deposit of all-in aggregate sourced from Kuta, Niger state. It can be separated into fine and coarse aggregates. Its use in making concrete has gained popularity among the locals in Niger state, Nigeria. However, this aggregate has not been characterized for concrete use and there is limited study on the characteristics of the aggregate.

Compressive strength is contestably the most functional and most significant concrete property [14]. It is easy to use the compressive strength as a measure for other strength parameters including flexure, modulus of elasticity, shear and tension. This is corroborated by Kabir *et al*. [15] that most mechanical properties of concrete can be estimated using simple formulas when the compressive strength is known. In engineering structures, concrete is used principally to resist compressive stresses. For this reason, proportioning of most concrete constituents are done with respect to compressive strength. The strength developed by concrete for a properly placed and workable mixture of cement, water and aggregate are influenced by the cement to water quotient, cement to aggregate quotient, maximum size of aggregate, surface texture, shape, grading, strength and stiffness of aggregates [13].

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this investigation are:

2.1.1 Portland Limestone Cement (PLC)

Portland Limestone Cement of grade 42.5N was employed for this investigation. The cement was obtained from a retail outlet in Minna.

2.1.2 Fine Aggregates (Sand)

The fine aggregate utilized for the research is river sand obtained from Kuta, Niger state. The sand is clean, sharp and free from organic matter. The sand used conforms with the requirements of BS EN 12620 [16].

2.1.3 Coarse Aggregates (Kuta Gravel)

Kuta gravel acquired from Kuta, Niger state, was the coarse aggregate used in this study. The aggregate conforms to BS EN 12620 [16] specifications for aggregates used for concrete.

2.1.4 Water

Potable water sourced from Federal University of Technology, Minna was used for mixing and curing of the concrete. The water is free from inorganic matter, suspended particles, salts and any form of impurities. This type of water requires no testing before usage in producing concrete according to BS EN 1008 [17].

2.2 Methods

2.2.1 Separation of the all-in aggregate

The all-in aggregate was first, sieved through the 20mm BS standard sieve to obtain a maximum aggregate size of 20mm. To separate the fine aggregates from coarse aggregates, the all-in aggregate was sieved through the 4.75mm BS standard sieve. Materials retained on the 4.75mm sieve were utilized as aggregates (coarse) for this study. Figure 2.1 shows the unprocessed and processed Kuta gravel.

Figure 2.1: Kuta gravel

2.2.2 Characterization of Kuta Gravel

Physical and mechanical property tests were done in order to characterize the gravel for concrete use. Elongation index, specific gravity, water absorption, sieve analysis, bulk density, flakiness index and Aggregate Impact Value (AIV) were determined in accordance to BS 812-105.2 [18], BS 812-2 [19], BS 812-2 [19], BS 812-103.1 [20], BS 812-2 [19], BS 812-105.1 [21] and BS 812-112 [22] respectively.

2.2.3 Testing of Fine Aggregates

Specific gravity, water absorption and bulk density were determined for the fine aggregate in accordance to BS 812-2 [19] while sieve analysis was done in accordance to BS 812-103.1 [20].

2.2.4 Factor Setting

Factor setting for the design was carried out using Central Composite Design. It is one of the most employed fractional factorial design in the response surface methodology (RSM). It involves measuring the effect of changing one or more factors at a time on the response (performance characteristics). This process provides the designer an opportunity to understand how various design factors affect the response and therefore, results in high quality prediction of interactions [23].

The relative ratios of the concrete constituents were assigned values and considered as independent variables in the design. The following were used as independent variables

$$W/C = 0.4, 0.5, 0.6 \quad (2.1)$$
$$CA/TA = 0.55, 0.6, 0.65 \quad (2.2)$$
$$TA/C = 3, 4.5, 6 \quad (2.3)$$

Where: W/C= Water/Cement quotient, CA/TA=Coarse aggregate/Total Aggregate quotient, TA/C= Total Aggregate/Cement quotient and TA= Total Aggregate = FA+CA

The CCD has three factor levels. These are: the lower level, centre point and the upper level, which are assigned coded values of -1, 0 and 1 respectively. Apart from these three factor levels, there are two axial (star) points making a total of five points and thereby giving the design flexibility. These axial points denoted by –α and α, are dependent on the number of factors (variables) in the design.

$$\alpha = 2^{\frac{k}{4}} \quad (2.4)$$

Where K= number of design factors.

In this study, three variables are being considered, therefore, $\alpha = 2^{\frac{3}{4}} = 1.682$

The five coded factor levels for this study are: -1, 0, 1, -1.682 and 1.682.

The RSM in Minitab was used to generates twenty (20) coded values for each of the design variables. Five of the twenty coded values were selected and utilized for the investigation. These coded values are converted to real values (uncoded values) of the design variables. To convert coded values to uncoded values, equation (2.5) was used.

$$x_{uncoded} = \frac{x_{min}+x_{max}}{2} \pm \alpha\left(\frac{x_{min}-x_{max}}{2}\right) \quad (2.5)$$

Where: α= coded value, x_{min}= initial lower limit of the design variable, x_{max}=initial upper limit of the design variable.

2.2.5 Design of Concrete Mix Composition

The absolute volume method was used in preparing the concrete mix composition.

The absolute volume equation is given as

$$\frac{W_W}{1000} + \frac{W_c}{1000SG_C} + \frac{W_{FA}}{1000SG_{FA}} + \frac{W_{CA}}{1000SG_{CA}} + AV = 1 \quad (2.6)$$

Where:

W_W=Weight of water, W_C=Weight of cement, W_{FA}=Weight of fine aggregate, W_{CA}=Weight of Kuta gravel, SG_C=Specific gravity of cement, SG_{FA}=specific gravity of fine aggregate, SG_{CA}=Specific gravity of Kuta gravel and AV=air void=2%=0.02

To incorporate the variables of the design, the weights of fine aggregates as well as the coarse aggregates were expressed in terms of the CA/TA and TA/C ratios and weight of water was expressed in terms of W/C ratio.

$$W_w = W_c \times \left(\frac{W_W}{W_c}\right) \quad (2.7)$$

$$W_{FA} = \left(\frac{W_{TA}}{W_C}\right) \times \left(1 - \frac{W_{CA}}{W_{TA}}\right) \times W_c \quad (2.8)$$

$$W_{CA} = \left(\frac{W_{TA}}{W_C}\right) \times \left(\frac{W_{CA}}{W_{TA}}\right) \times W_c \quad (2.9)$$

The cement weight, W_c for a cubage unit of concrete can be derived from equation (2.6) and substituting equation (2.7), (2.8) and (2.9) into (2.6)

$$W_C = \frac{1-AV}{\frac{\left(\frac{W_W}{W_C}\right)}{1000} + \frac{1}{1000SG_C} + \frac{\left(1-\frac{W_{CA}}{W_{TA}}\right)\left(\frac{W_{TA}}{W_C}\right)}{1000SG_{FA}} + \frac{\left(\frac{W_{TA}}{W_C}\right)\left(\frac{W_{CA}}{W_{TA}}\right)}{1000SG_{CA}}} \quad (2.10)$$

Equation 2.10 was used in calculating the proportions of concrete constituents needed for $1m^3$ of concrete mix for the five selected points. Combinations for the five selected coded points and their uncoded values as well as the constituent proportions are as set out in Table 2.1.

Table 2.1

Proportions of Concrete Constituents for $1m^3$ of Concrete Mix

Mix	Coded Values			Uncoded Values			Proportions of Constituents			
	W/C	CA/TA	TA/C	W/C	CA/TA	TA/C	Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)
A1	-1.68	0.00	0.00	0.33	0.60	4.50	136.32	410.83	739.49	1109.24
A2	-1.00	-1.00	-1.00	0.40	0.55	3.00	209.03	522.57	705.48	862.25
A3	0.00	0.00	1.68	0.50	0.60	7.02	138.93	277.87	780.55	1170.82
A4	1.68	0.00	0.00	0.67	0.60	4.50	240.58	360.06	648.11	972.16
A5	0.00	0.00	0.00	0.50	0.60	4.50	191.89	383.77	690.79	1036.19

2.2.6 Workability Test

Slump test was done on the fresh concrete to determine its workability in consonance with specifications of BS EN 12350-2 [24].

2.2.7 Curing

The concrete cube specimens were cured in line with specifications of BS EN 12390-2 [25]. The immersion method of curing using curing tank was used.

2.2.8 Compressive Strength Test

Compressive strength of the hardened concrete was measured at 28 days of age. Three (3) samples were prepared for every mix proportion.

For the compressive strength test, concrete cube samples (150mm) were prepared. The hardened concrete cube samples were tested in line with BS EN 12390-3 [26] for testing hardened concrete. Samples of cube specimen is shown in Figure 2.2.

Figure 2: Crushing of cube specimen

3. RESULTS AND DISCUSSIONS

3.1 Characterisation of Kuta Gravel

The properties of the Kuta coarse aggregate are summarized in Table 3.1. The properties, as determined are observed to be within permissible boundaries for coarse aggregates used in concrete production. Further discussions on the characterisation of Kuta gravel are presented in the following sub-sections.

Table 3.1

Physical and Mechanical Properties of Kuta Gravel

Property	Result	Specification
Specific gravity	2.60	2.5-2.8 [9]
Water absorption	0.6%	0.5-1% [13]
Aggregate Impact Value (AIV)	16.45%	< 25, 30 or 40% depending on application [8]
Bulk density (uncompacted)	1523.47 kg/m^3	1520 -1680 kg/m^3 [27]
Bulk density (compacted)	1640.52 kg/m^3	1200-1750 kg/m^3 [28]
Uncompacted and Compacted Void Ratios	41.5% and 36.9% respectively	30-45% [29].
Particle size distribution	Graded	Limit for graded aggregates of aggregates between 20mm to 5mm [30]
Aggregate Crushing Value (ACV)	25.82%	< 45% [31]
Flakiness Index	26%	<50% [16]
Elongation Index	29%	<35% [32]

3.1.1 Specific Gravity

A specific gravity value of 2.60 was determined as presented in Table 3.1. This value is same as 2.6 obtained by [33] for crushed granite and compares favourably with 2.65 obtained by [34] for natural aggregate obtained from the Bida basin and 2.74 obtained by [35] for coarse aggregate. The coarse aggregate extracted from Kuta all-in aggregate is therefore, suitable for use in concrete since specific gravity for natural aggregates ranges from 2.5 to 2.8 [9].

3.1.2 Water Absorption

An average water absorption of 0.60% was determined for the coarse aggregate as displayed in Table 3.1. This value is close to 0.9% reported by [12] for water absorption of river stone. Water absorption shall not exceed 0.8% for natural coarse aggregate [32]. Corroborating the above finding, Shetty [13] opined that coarse aggregates typically have water absorption between 0.5 to 1%.

BS 8007 [36] postulates that water absorption of aggregates must not be greater than 3% to ensure acceptable strength, density and durability of concrete. Therefore, the water absorption values obtained for the Kuta coarse aggregate satisfies this requirement.

3.1.3 Aggregate Impact Value (AIV)

Table 3.1 also reflects the result for the AIV of Kuta gravel. The average AIV is 16.45%. The value so determined, is acceptable for aggregate used in concrete for all purposes. For aggregates used in concrete prone to surface wearing, AIV shall not be more than 30%, while for concrete excluding wearing surfaces, AIV shall not exceed 45% [13]. Corroborating this, Neville and Brooks [8] stated that, for aggregates used in concrete for pavement wearing surfaces, heavy floors, and in other concretes, AIV must be limited to 30, 25 and 45% respectively.

3.1.4 Bulk Density

Average uncompacted and compacted bulk densities of 1523.47 and 1640.52 kg/m^3 respectively were determined for the coarse aggregate. The results are as presented in Table 3.1. The values so determined, are close to 1528.7 kg/m^3, 1686.35 kg/m^3 and 1752.0 kg/m^3 for bulk densities of coarse aggregates reported by Kabir *et al.* [15]. ASTM C33 [27] specifies uncompacted bulk density values from 1520 to 1680 kg/m^3 for normal weight aggregates used in concrete. ACI [28] prescribes compacted bulk density values ranging between 1200 to 1750 kg/m^3 for aggregates meant for casting normal concrete.

Uncompacted and compacted percentage void ratios of 41.5% and 36.9% respectively were determined for the Kuta gravel. The result so obtained, fall within the acceptable range. Void content of coarse aggregate ranges between 30 to 45% [29].

3.1.5 Sieve Analysis

The findings for the sieve analysis of Kuta gravel is presented in Figure 3.1. From the particle size distribution curve, Kuta coarse aggregate falls within the limit for graded aggregates between 20mm to 5mm [30].

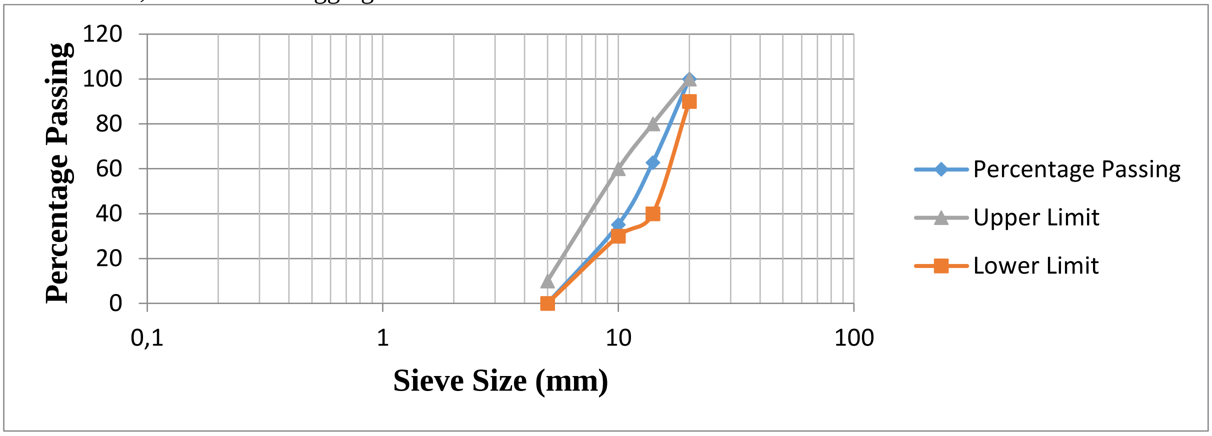

Figure 3.1: Particle size distribution of Kuta gravel

3.1.6 Aggregate Crushing Value (ACV)

The aggregate crushing value (ACV) is presented in Table 3.1. The ACV was determined to be 25.82%. This falls within the permissible limit and hence, the aggregate is considered good for use as concrete constituent. An ACV less than 45% is allowed for producing concrete according to limits for material and workmanship by the Federal Ministry of Works [31].

3.1.7 Flakiness Index

Table 3.1 shows the results of flakiness index of Kuta gravel. Flakiness Index is a function of the aggregate's shape. Generally, the aggregate shape affects the mobility, workability, and strength of the concrete so produced. Flaky aggregates are detrimental to the desirable properties of concrete.

A flakiness index of 26% was determined for the coarse aggregate extracted from the Kuta all-aggregate. Flakiness index for coarse aggregate shall not exceed 50% [16]. BS 882 [30] specifies a flakiness index limit of 40% for crushed aggregates and 50% for natural gravel.

3.1.8 Elongation Index

Table 3.1 also shows the result for elongation index of Kuta gravel. The elongation index was determined to be 29%. For natural aggregates, the elongation index is limited to 35% [32]. The coarse aggregate therefore, is appropriate for use as coarse aggregate in concrete as the elongation index falls within acceptable limit.

3.2 Physical Properties of the Sand (Fine Aggregate)

Table 3.2 shows the results for the physical properties of the sand used. All the properties measured fall within the allowable boundaries for natural normal weight aggregate for concrete. The graph of particle size distribution pictured in Figure 3.2 reveals that the fine aggregate particle distribution falls within the overall limit of well graded sand used in producing concrete [30].

Table 3.2

Physical Properties of the Sand (Fine Aggregate)

Property	Result	Specification
Specific gravity	2.58	2.5-2.8 [9]
Bulk density (compacted)	1601 kg/m^3	1597-1700 kg/m^3[37]
Fineness modulus	3.10	≤ 3.2 [13]
Water absorption	0.79%	<2.0 [27]

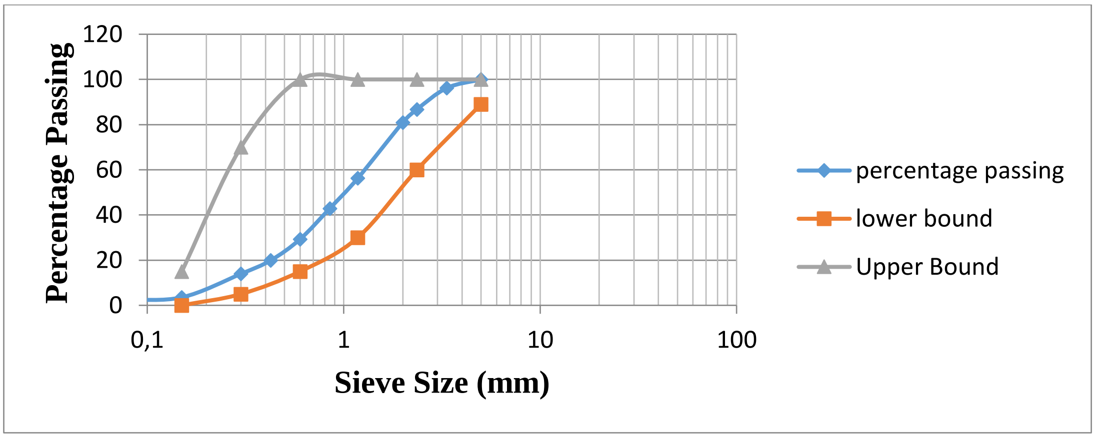

Figure 3.2: Particle size distribution of the fine aggregate

3.3 Slump

Table 3.3 shows the result of slump test on the fresh concrete and the compressive strength of the hardened concrete.

Concrete mix A1 and A3 yielded 0mm and 5mm slump respectively. The concrete mixes are harsh and not workable. Zero slump in mix A1 is due to low water content while that of A3 is on the account of a higher TA/C compared to the W/C ratio.

Mix A2 has a slump of 30mm. This can be classified as low slump under slump class S1 [38].

Mix A5, having a slump of 50mm can be classified under slump class S2 [38].

Concrete mix A4 resulted in the concrete mix with the highest slump of 180mm. This is obviously in consequence to the high-water content. This type of slump is classified under class S4 [38].

Generally, with constant total aggregate to cement ratio, slump increases with increase in water/cement quotient while slump decreases with increase in total aggregate/cement quotient when the water to cement quotient is kept constant [39].

3.4 Compressive Strength

The compressive strength for the concrete mixes is as set out in Table 3.3 and Figure 3.3. The minimum compressive strength ($12.6N/mm^2$) was observed with W/C=0.5, CA/TA=0.6 and TA/C=7.02. This is due to a reduction in cement quantity. The high value of TA/C is thus, responsible for the low compressive strength. The total aggregate/cement quotient is inversely proportional to the concrete compressive strength [40].

High compressive strengths of $25.9N/mm^2$ and $26.8N/mm^2$ were observed for W/C=0.5, CA/TA=0.6, TA/C=4.5 and W/C=0.4, CA/TA=0.55, TA/C=3 respectively. This is due to lower TA/C and reasonable W/C, resulting in a thicker paste due to more cement content.

TA/C=3 resulted in concrete with the highest compressive strength ($26.8N/mm^2$). The low TA/C ratio in this mix simply means there is higher cement content, thereby enhancing the compressive strength of the concrete. Corroborating this finding, Saloma *et al.* [40] asserts that the total aggregate to cement ratio (TA/C) is inversely proportional to the compressive strength of concrete. However, this assertion is limited to a particular value of the total aggregate to cement ratio. Below a certain threshold value, it is observed that decrease in the TA/C ratio decreases the strength of the concrete.

Table 3.3

Compressive Strength

Mix No.	W/C	CA/TA	TA/C	Slump (mm)	Crushing Load (kN)	Compressive Strength (N/mm2)	Average Compressive Strength (N/mm2)
					392.5	17.4	
A1	0.33	0.6	4.5	**0**	364.7	16.2	**16.4**
					348.5	15.5	
					565.4	25.1	
A2	0.4	0.55	3	**50**	648.7	28.8	**26.8**
					599.3	26.6	
					280.6	12.5	
A3	0.5	0.6	7.02	**5**	302.9	13.5	**12.6**
					263.5	11.7	
					415.5	18.5	
A4	0.67	0.6	4.5	**180**	421.3	18.7	**19.4**
					470.2	20.9	
					602.7	26.8	
A5	0.5	0.6	4.5	**30**	590.5	26.2	**25.9**
					558.3	24.8	

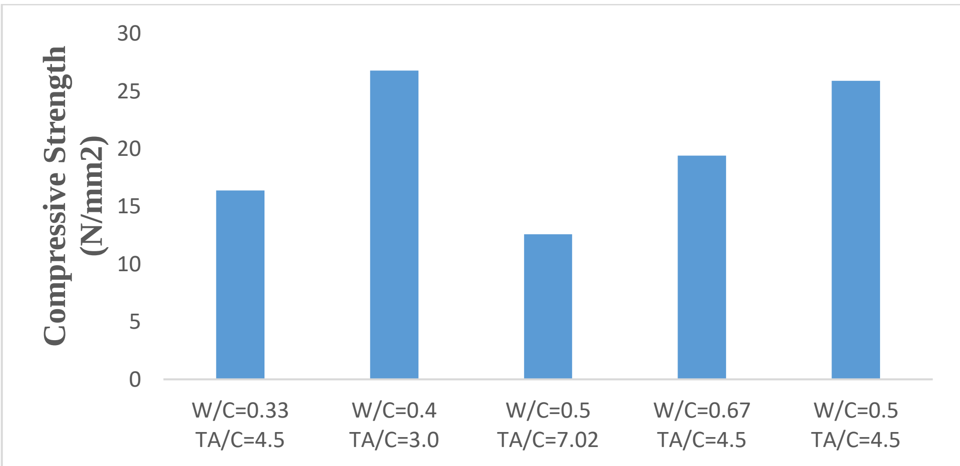

Figure 3.3: Compressive strength for different mixes

4. CONCLUSION

The properties (physical and mechanical) of Kuta gravel as determined, shows that the aggregate has a specific gravity of 2.60, water absorption of 0.60, flakiness index of 26%, elongation index of 29%, AIV of 16.45%, ACV of 25.82%, percentage air void (uncompacted) of 41.5%, uncompacted and compacted bulk densities of 1523.47kg/m^3 and 1640.52kg/m^3 respectively. The particle distribution fall within the limit for graded aggregates between 20mm-5mm.

All the physical and mechanical properties of Kuta gravel determined fall within the acceptable limits for coarse-grained aggregate used in producing concrete.

Kuta gravel is suitable for use as coarse-grained aggregate in concrete production.

Highest compressive strength of 26.8N/mm^2 was achieved with the combination of W/C=0.4, CA/TA=0.55, TA/C=3 while a combination of W/C=0.5, CA/TA=0.6 and TA/C=7.02 gave the lowest compressive strength of 12.6N/mm^2.

Kuta gravel can be used as coarse aggregate in structural concrete requiring a strength of 25N/mm^2 or less.

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