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INFLUENCE OF COARSE AGGREGATE GRADING TYPES ON THE COST OF CONCRETE

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Abstract

The effects of grades of coarse aggregates on the cost of concrete was studied. Several times in real life practice, the engineer at construction site is faced with the problem of not having the required grade of coarse aggregate for a given project. . This could be caused by several reasons such as; non-availability of desired grade, the different grades of coarse aggregate being obtained as a left over from a sister project, etc. In Nigeria, coarse aggregate for concrete is very expensive and thus, the engineer will think of how to use the available grade of coarse aggregate in his concrete mix design to achieve the desired results instead of discarding it. In this study, seven different grades of coarse aggregate were investigated. The fineness modulus of the fine aggregate and bulk densities of the various grades of coarse aggregate were determined. The results were used together with tables from American Concrete Institute (ACI) code to carry out concrete mix design on all the various grades of coarse aggregate to calculate the quantities of the different elements of concrete. From the mix design, the cost of the materials for producing one cubic meter of concrete was determined. The result showed that the Well graded aggregate had the highest bulk density of 1717Kg/m^3 while uniformly graded retained on 10mm sieve had the least bulk density of 1580Kg/m^3. Uniformly graded aggregate retained on 10mm sieve required the highest cost of N58,278.81 to produce a cubic meter of grade 25 concrete while the cost was least at N56,242.52 when uniformly graded retained on 20mm sieve and Gap-graded without 5mm size were used. This suggests that the larger the size of coarse aggregate (within the size limits studied) the less the cement paste required and hence the less the cost.

1.0 INTRODUCTION

The increase in population of human beings in the world has given rise to a corresponding increase in the demand for shelter and other developmental infrastructures [1]. Concrete is a major construction material used in building shelter and developmental infrastructures such as; bridges, highways, dams. tunnels, etc. [2]. Concrete is an amalgamated material made up of; binding agent (cement, bitumen, pozzolans, etc.), aggregates, water and admixtures which are at times added to enhance the properties of concrete [3], [4], [5]. Aggregates are further classified into fine and coarse aggregates [6]. When the binding agent is Portland cement, the concrete produced is called 'Portland Cement Concrete'. On the other hand, if the binding agent is bitumen, the resulting concrete is called 'Bituminous Concrete' or 'Asphaltic Concrete'. It has been discovered that the aggregates used in producing concrete largely determine the strength of the concrete [7]. Aggregates used in concrete greatly affect the properties of both fresh and

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hardened concrete due to the fact that aggregates occupy about 75% of the entire concrete volume [8].

It is well known that the way the particles of aggregates fit together with one another within the concrete mix greatly determines the properties of the fresh and hardened concrete [3]. Coarse aggregate for normal concrete production comes in the following standardized size ranges; 5mm-15mm, 15mm-22mm and 22mm-40mm [9]. Aggregate grading has a very great influence on the workability of concrete. In a given concrete mix, a well graded aggregate produces less voids which leads to higher availability of cement paste in the mix resulting to better lubrication and workability of the mix [10]. Well graded aggregate implies when a given sample of aggregate contains all the basic sizes of the aggregate in the right proportion in a way that the sample has minimum voids. This sample with minimum voids will demand less quantity of paste to fill up the voids, and hence less amounts of cement and water in the mix, this will result to concrete with improved economy, high strength and durability and less shrinkage [11].

However, in real life situations, aggregates come from quarries in size distributions which do not represent the well grading due to the cumbersome tasks involved in sieving and mixing proportionately. This usually results in aggregates being gap graded. Sometimes again the challenge could be a situation whereby a particular size of aggregate is available in large quantity at the site, making it an economic waste to purchase more in a bid to have all sizes of well graded aggregate. In the former case, the engineer is faced with the challenge of how best to combine the gapped grading, knowing sizes to be made predominant and the ones to be made less prominent in order to achieve optimum results of concrete strength; in other words, to find out the size gaps whose absence in the aggregate becomes more detrimental to the concrete compressive strength. In the latter case, the engineer will require knowledge of anticipated strength variation resulting from the use of the available uniform aggregate and hence put measures in place to ensure overall performance of the concrete does not fall below minimum requirement. The problem for the engineer may be a balance between economy and performance; the assurance that the material available at the site is qualified for use to achieve required objective or, if not, to purchase what is expedient even when there could be unused materials for work.

The proportions of fine and coarse aggregates in a given aggregate sample will determine the grading of the aggregate sample and hence, the properties of the resulting concrete [12]. Variations in the grading of aggregate influences the demand by the mix for cement paste which affects the cost, strength, workability and density of the resulting concrete. In a given volume of concrete mix, if the aggregate is well graded there will be less voids which makes more cement paste available for thorough mixing and lubrication of the mix. Among all the three major constituents namely; cement, aggregates and water, cement is the most expensive, thus in order to reduce the cost of concrete, researchers and engineers strive to design concrete mix that will produce concrete with enhanced properties and require less amount of cement for a given target strength.

Eme and Nwaobakata [13] carried out research on the effect of grading of aggregate on the flexural strength and workability of concrete. In their work, they produced concrete with well graded aggregate and gap graded aggregates, they observed that the well graded aggregate concrete had less workability, higher flexural strength and requires less cement content than the gap graded aggregate concretes. Ikponmwosa *et al.* [14] used local materials and different water-cement ratios in different mix ratios to produce high performance concrete and observed that concrete mixes with smaller particles of aggregates has lower slump but reduced compressive strength than their counterparts with larger aggregate sizes. Ukala [15] varied the following sizes of coarse aggregate; 12.7mm, 25.4mm, 38.1mm and 50.8mm to create different grades of coarse aggregate while maintaining a constant fine aggregate grading and constant water – cement ratio in the concrete mix and he observed that the workability of the concrete decreases as bigger sizes of coarse aggregates was introduced into the mix.

Thus, a good knowledge of the right proportions of the constituent materials to achieve the target strength will help engineers in taking right decisions when they have a certain grade of coarse at the site. This work will also assist engineers in giving the right advice to their clients with regard to the grade of aggregate they will use to save cost and also achieve the target strength. To this end the objectives of this work are;
(i) To carryout detail concrete mix design using the various grades of coarse aggregate to calculate the quantities of the constituents of concrete to meet the target strength.
(ii) To determine the cost of materials required to produce one cubic meter of concrete using the various grades of aggregate.

2.0 MATERIALS AND METHODS

2.1 Materials

The various materials used in this work and the laboratory apparatus used to realize the set goals of this research includes:

(i) Fine Aggregate of 4.75mm maximum size (River Sharp Sand free from deleterious materials) and obtained from a dredging site at River Nun, Yenagoa, Bayelsa State Nigeria;

(ii) Crushed granite obtained from a granite quarry at Auchi, Edo State, Nigeria. The various grades of coarse aggregates studied are described in Table 1.

Table 1: Various grades of aggregates

S/N	Notation	Description	Size Range (mm)
1	W.G.	Well graded Aggregates	5 – 25
2	U.G. 20	Uniformly graded aggregates retained on 20mm sieve	20 – 24
3	U.G. 15	Uniformly graded aggregates retained on 15mm sieve	15 – 19
4	U.G. 10	Uniformly graded aggregates retained on 10mm sieve	10 – 14
5	G.G. 15	Gap graded aggregates – 15	5 – 24 (except 15-19)
6	G.G. 10	Gap graded aggregates – 10	5 – 24 (except 10-14)
7	G.G. 5	Gap graded aggregates – 5	5 – 24 (except 5 - 9)

(ii) Ordinary Portland Cement (OPC) grade 42.5N manufactured by Dangote Nigeria Limited.

(iii) British Standard (BS) sieves of various sizes.

(iv) Miniature concrete mixer of 200kg capacity, Concrete cube moulds, Universal testing machine, Slump cone, Tamping rod, Trowel, weighing Scale, Electronic balance, brush, Riffle box, Cylindrical metal measure of known volume and Scoop.

2.2 Methods

1) Sieve analysis

Sieve analysis was carried out on the river sharp sand following the procedures described in [16] to calculate the particle size arrangement of the aggregates and the results are shown on Table 6. Fineness modulus of the fine aggregates (which is a requirement in the American Concrete Institute (ACI) method of concrete mix design) were determined from the results of sieve analysis using the formulae shown in Equation (1).

$$\text{Finess Modulus, FM} = \frac{\text{Total sum of mass of samples retained on the standard sieves}}{100} \quad (1)$$

The different sizes of coarse aggregates were isolated in the required quantities by collecting quantities retained in the corresponding sieves. After this, the isolated coarse aggregate sizes where blended in proportions typical of their various gradation types.

2) Bulk density (Dry rodded density) of coarse aggregates

Following the specifications of BS 812 :Part 2 [17] the bulk densities of the various coarse aggregate grading configurations were then determined for use in the mix design. For the well graded aggregate, 5-10mm and 10-25mm aggregates samples were combined in equal measures to get the well graded coarse aggregate sample and then sundried to constant mass. The cylindrical metal measure was weighed on the electronic scale and recorded. The coarse aggregate sample was then scaled down to the required quantity with the use of the riffle box and filled in the cylindrical metal measure in nearly equal three layers. 25 evenly distributed strokes of the tamping rod were applied to each layer surface, making sure that the rod did not hit the bottom of the metal measure during rodding or penetrate the first and second layers during rodding of the second and third layers respectively.

The metal measure was then weighed with the filled and rodded aggregates and the weight also recorded. Let;

$$\text{Weight of cylindrical metal measure} = \text{A} \quad (2)$$

$$\text{Weight of aggregate sample} + \text{cylindrical mearsure} = \text{B} \quad (3)$$

$$\text{Volume of Cylindrical measure} = \text{C} \quad (4)$$

Weight of aggregate sample (D) is given as;

$$D = B - A \quad (5)$$

Bulk Density ρ is given as;

$$\rho = \frac{D}{C}\ kg/m^3 \quad (6)$$

Following the same procedure, the bulk densities of the various grades of aggregates were determined and the results shown on Table 7.

3) Concrete mix design

Applying the ACI method of concrete mix design prescribed in Li [18] and, ACI 325.14R-17 [19] and ACI 211. 1-91 [20]. The concrete mix was designed as follows:

Step One: The target mean strength was calculated from the following the expression;

$$\text{F}_{\text{m}} = \text{F}_{\text{min}} + \text{K} * \text{S} \quad (7)$$

Where; F_m is the target mean strength; F_{min} is the specified design strength = 25N/mm^2 ; K is a constant = 1.64 (Assuming that 5% of results are allowed to fall below specified design strength); S is standard deviation of the statistics taken as = 4 for the purpose of this study.

Therefore, upon substitution;

$$\text{F}_{\text{m}} = 25 + (1.64 * 4) = 31.56\ N/mm^2 \quad (8)$$

Step Two: The water/cement ratio was calculated thus:

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Table 2: Relation between w/c and average compressive strength of concrete, according to ACI 211. 1-91 [20]

Average Compressive Strength at 28 days (MPa)	Effective Water/Cement Ratio (by mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	-
40	0.43	-
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Source: Li [16]

Since ordinary Portland cement was used and concrete is non-air entrained, from Table 2, for a target strength of 31.56MPa after 28 days curing, effective water-cement ratio (by mass), w/c after interpolation is given as;

$$^{w}/_{c} = 0.53 \quad (9)$$

Step Three: Cement content.

Table 3: Approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates, according to ACI 211. 1-91 [20]

Slump and Air Content	Water Content (Kg/m^3) of concrete for indicated maximum aggregate Size							
	10	12.5	20	25	40	50	70	150
	Non – Air – Entrained Concrete							
Slump								
30 – 50 mm	205	200	185	180	160	155	145	125
80 – 100mm	225	215	200	195	175	170	160	140
150 -180mm	240	230	210	205	185	180	170	-
Approximate entrapped air content (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air – Entrained Concrete							
Slump								
30 – 50 mm	180	175	165	160	145	140	135	120
80 – 100mm	200	190	180	175	160	155	150	135
150 -180mm	215	205	190	185	170	165	160	-
Recommended average total air content (%)								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5[a]	1.0[a]
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5[a]	3.0[a]
Extreme exposure[b]	7.5	7.0	6.0	6.0	5.5	5.0	4.5[a]	4.0[a]

Source: Li [16]

From Table 3, for a slump of 80mm, 25mm maximum aggregate size and no entrained air, mixing water content, W_W

$$W_w = 195\, Kg/m^3 \quad (10)$$

Therefore, the cement content, C_c is given as;

$$C_C = \frac{Mixing\ water}{Water-Cement\ ratio} = \frac{195}{0.53} = 367.92 \text{kg/m}^3 \quad (11)$$

Step Four: Weight of Coarse Aggregate.

From Table 4, for 25mm maximum aggregate size of coarse aggregate and fineness modulus of 3.0, the dry rodded bulk volume of coarse aggregate = 0.65

Therefore weight of coarse aggregate, $W_{C.A}$ is given as;

$$W_{CA} = 0.65 * bulk\ desity = 0.65 * 1717 = 1116.05\, \text{kg}/m^3 \quad (12)$$

Table 4: Bulk volume of rodded coarse aggregate per unit volume for different fineness module

Maximum Aggregate Size (mm)	Dry bulk volume of coarse aggregate per unit volume for different fineness module			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Source: Li [16]

Table 5: Bulk volume of rodded coarse aggregate per unit volume for different fineness module

	First Estimate of Density (Unit Weight) of Fresh Concrete	
Maximum Aggregate Size (mm)	Non – Air Entrained	Air Entrained
	Kg/m^3	Kg/m^3
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Source: Li [16]

Step Five: Density of Fresh Concrete.

From Table 5, for 25mm maximum aggregate size and non-air entrainment, First Estimate of Density of fresh concrete = 2375kg/m^3 (13)

Hence, weight of fine aggregate W_{FA} is given as;

$$W_{FA} = 2375 - (195 + C_C + W_{C.A})$$
$$= 2375 - (195 + 367.92 + 1116.05) = 696.03\ Kg/m^3 \quad (14)$$

Thus, the mix proportion for Well graded aggregate (WG) for 1m^3 of concrete is given as;

$$Cement : Fine\ Aggregate : Coarse\ Aggregate = 367.92 : 696.03 : 1116.05 \quad (15)$$

$$Mix\ Ratio = 1 : 1.89 : 3.03 \quad (16)$$

Using the same procedure, the mix proportions for the various grades of aggregates were determined. The resulting mix proportions from the mix designs per cubic meter of concrete and the costs of constituent materials are presented in Tables 8 to 14. This cost analysis is based on the current prices of concrete materials as at 17th December, 2023 as per survey conducted in Yenagoa, Bayelsa state, Nigeria. Table 15 shows a summary of the total cost of constituent materials for a cubic meter of concrete for the various grades of coarse aggregates.

3.0 RESULTS AND DISCUSSIONS

3.1 Results

Table 6: Sieve analysis result of the fine aggregate

Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
Average weight of the Sample (g) = 1000.			
10	0.0	0.0	100.0
5	2.2	0.2	99.8
2.36	9.4	0.9	99.1
1.18	49.3	4.9	95.1
0.6	204.5	20.4	79.6
0.3	768.9	76.9	23.1
0.15	970.8	97.1	2.9
0.075	994.0	99.4	0.6
<0.075	1000		

From Table 6, the finess modulus was obtained as;

$$FM = \frac{(0+0.2+0.9+4.9+20.4+76.9+97.1+99.4)}{100} = \frac{299.8}{100} = 3.0 \quad (17)$$

Table 7: Bulk densities of the various grades of aggregates

S/N	Notation	Description	Size Range (mm)	Bulk Density (Kg/m^3)
1	W.G.	Well graded Aggregates	5 - 25	1717
2	U.G. 20	Uniformly graded aggregates retained on 20mm sieve	20 - 24	1610
3	U.G. 15	Uniformly graded aggregates retained on 15mm sieve	15 - 19	1610
4	U.G. 10	Uniformly graded aggregates retained on 10mm sieve	10 - 14	1580
5	G.G. 15	Gap graded aggregates - 15	5 – 24 (except 15-19)	1670
6	G.G. 10	Gap graded aggregates - 10	5 – 24 (except 10-14)	1670
7	G.G. 5	Gap graded aggregates - 5	5 – 24 (except 5 - 9)	1610

Table 8: Cost of materials for 1m^3 of grade 25 concrete made from well graded coarse aggregate **(W.G)**

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	367.9	40,469.00
Fine Aggregate	River sharp sand	4.20	696.05	2,923.41
Coarse aggregate	Angular granite	12.00	1116.05	13,392.6
Total Cost				**56,785.01**
Mix Ratio	Cement : Fine Aggregate : Coarse Aggregate = **1 : 1.89 : 3.03**			

Table 9: Cost of materials for 1m^3 of grade 25 concrete made from 20mm uniformly graded coarse aggregate (**U.G 20**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	367.9	40,469.00
Fine Aggregate	River sharp sand	4.20	765.6	3,215.52
Coarse aggregate	Angular granite	12.00	1046.5	12,558.00
Total Cost				**56,242.52**
Mix Ratio	Cement : Fine Aggregate : Coarse Aggregate = **1 : 2.08 : 2.84**			

Table 10: Cost of materials for 1m^3 of grade 25 concrete made from 15mm uniformly graded coarse aggregate (**U.G 15**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	377.36	41,509.6
Fine Aggregate	River sharp sand	4.20	807.44	3,391.25
Coarse aggregate	Angular granite	12.00	970.20	11,642.4
Total Cost				**56,543.25**
Mix Ratio	Cement : Fine Aggregate : Coarse Aggregate = **1 : 2.14 : 2.57**			

Table 11: Cost of materials for 1m^3 of grade 25 concrete made from 10mm uniformly graded coarse aggregate (**U.G 10**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	405.66	44,622.60
Fine Aggregate	River sharp sand	4.20	855.88	3,594.69
Coarse aggregate	Angular granite	12.00	838.46	10,061.52
Total Cost				**58,278.81**
Mix Ratio	Cement **:** Fine Aggregate **:** Coarse Aggregate = **1 : 2.11 : 2.07**			

Table 12: Cost of materials for 1m^3 of grade 25 concrete made from 15mm Gap graded coarse aggregate (**G.G 15**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	367.9	40,469.00
Fine Aggregate	River sharp sand	4.20	729.81	3,065.20
Coarse aggregate	Angular granite	12.00	1082.29	12,987.48
Total Cost				**56,521.68**
Mix Ratio	Cement **:** Fine Aggregate **:** Coarse Aggregate = **1 : 1.98 : 2.94**			

Table 13: Cost of materials for 1m^3 of grade 25 concrete made from 10mm Gap graded coarse aggregate (**G.G 10**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	367.90	40,469.00
Fine Aggregate	River sharp sand	4.20	726.60	3,051.72
Coarse aggregate	Angular granite	12.00	1085.50	13,026.00
Total Cost				**56,546.72**
Mix Ratio	Cement **:** Fine Aggregate **:** Coarse Aggregate = **1 : 1.97 : 2.95**			

Table 14: Cost of materials for 1m^3 of grade 25 concrete made from 5mm Gap graded coarse aggregate (**G.G 5**)

Material	Type	Unit rate(₦)	Quantity (kg)	Amount (₦)
Cement	O.P.C.	110.00	367.9	40,469.00
Fine Aggregate	River sharp sand	4.20	765.6	3,215.52
Coarse aggregate	Angular granite	12.00	1046.5	12,558.00
Total Cost				**56,242.52**

Mix Ratio	Cement : Fine Aggregate : Coarse Aggregate = **1 : 2.08 : 2.84**

Table 15: Cost of Materials for Producing 1m^3 of Concrete.

S/N	Notation	Mix Ratio	Total Cost (N)
1	W.G.	1 : 1.89 : 3.03	56,785.01
2	U.G. 20	1 : 2.08 : 2.84	56,242.52
3	U.G. 15	1 : 2.14 : 2.57	56,543.25
4	U.G. 10	1 : 2.11 : 2.07	58,278.81
5	G.G. 15	1 : 1.98 : 2.94	56,521.68
6	G.G. 10	1 : 1.97 : 2.95	56,546.72
7	G.G. 5	1 : 2.08 : 2.84	56,242.52

3.2 Discussions

From Table 7, it is observed that the well graded aggregate with particle size range of 5 – 24mm has the highest bulk density of 1717Kg/m^3. This is because, the well graded aggregate has all the various particle sizes evenly distributed within the mix, the smaller particle sizes will fill in the voids created by the larger sizes [21]. This makes the entire aggregate mass to be closely packed, leading to reduction in void ratio and increase in bulk density. Conversely, the uniformly graded aggregate (U.G. 10) having particle size range of 10 -14mm has the least bulk density. This is due to the fact that in this grade, there are no smaller particles to fill the voids created by the large particle, thus making it to have a higher void ratio and as a result, a lower bulk density.

From Tables 8 – 15, it can be deduced that it costs most to prepare grade 25 concrete from 10mm Uniformly graded coarse aggregate (U.G 10) with a total amount of N58,278.81er cubic meter of concrete. This is due to the fact that U.G.10 has smaller particle sizes which creates a larger surface area for cement paste to coat, thus demanding more cement. This leads to high cost since cement is the costliest element of concrete. This is followed by W.G with a total amount of N 56,785.01 per cubic meter of concrete; then G.G 10 with a total amount of N56,546.72per cubic meter of concrete; then G.G 15 with a total amount of N56,543.25 per cubic meter of concrete; then U.G 15 with a total amount of N56,521.68 per cubic meter of concrete; while it costs least to produce concrete from 20mm Uniformly graded coarse aggregate (U.G 20) and Gap graded aggregate of 5mm gap (G.G 5) with a total cost of N56,242.52 each.

This outcome can be explained with the fact that the use of larger particle sizes as in U.G 20 and G.G. 5 resulted in reduction in surface areas of aggregates to be coated with cement paste. Thus, use of larger aggregate sizes in U.G. 20 and G.G. 5 resulted in less demand for cement in the concrete mix hence, making the cost of materials less since cement is the costliest element of concrete [22]. The reduction in cement requirement is a major reason for the reduction in cost to achieve same concrete grade. Table 15 shows that different mix ratios are required to achieve the same grade of concrete using the different grades of coarse aggregate. Thus, all the different grades of coarse aggregates are suitable for the production of concrete grade 25 but at different costs and mix ratios.

4.0 CONCLUSIONS

It is observed from this study that when well graded aggregate which has all the various particle sizes evenly distributed within the mix (5mm to 40mm) is used in concrete, the smaller particle sizes will fill in the voids created by the larger sizes. This makes the entire aggregate mass to be closely packed, leading to reduction in void ratio and increase in bulk density. The use of larger aggregate sizes in concrete creates smaller surface area required to be coated with cement paste, thus making more cement paste available for lubrication of the mix, hence improving the workability of the concrete. Thus, there is less demand for cement in the concrete mix, making the concrete cheaper. All the grades of coarse aggregate studied can be used to produce the desired grade of concrete but at different costs and mix ratios.

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