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A Comparative Study of the Methods of Concrete Mix Design Using Crushed and Uncrushed Coarse Aggregates

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Abstract: The study aims at comparing two methods of concrete mix design; The British Department of Environment Method and The American Concrete Institute Method, using the crushed and uncrushed coarse aggregates at various target strengths. A total of Forty-Five cubes were produced. Fifteen concrete cubes were produced with crushed aggregates (Granite) using the DOE method. Another fifteen cubes were produced with uncrushed coarse aggregates (Gravel) using the DOE method, while the remaining fifteen concrete cubes were produced with crushed aggregates using the ACI method. Each of these cube were produced at different mix strength M20, M30 and M50, according to IS 456:2000 and tested at different curing days; 7days, 14days and 24days respectively. The compressive strength values were determined at ages 7, 14 and 28 days curing periods respectively. Results obtained showed that the uncrushed aggregates gave a higher 28-days compressive strength compared to that obtained from the crushed aggregates, but the reverse was the case for M50 were the result obtained using the crushed aggregate gave a higher strength than that obtained from uncrushed aggregate. It was also found that using the DOE method, the overall result obtained gave some low and high strength values at some point or the other. The same goes also for the ACI method, an average of 36.2N/mm2 for M20, 45.6N/mm2 for M30 and 67.7N/mm2 for M50 was obtained at 28-days using the DOE method and an average of 33.9N/mm2for M20, 46.9N/mm2 for M30 and 73.35N/mm2 for M50 using the ACI at 28-days. The ACI did not make provision for uncrushed aggregate in its design method, implying that comparison could not be made in that regard.

1.0 Introduction

Concrete is the second most consumed material worldwide by man after food and water [1]. It is obtained by mixing cement, fine aggregate, coarse aggregate and water in required proportions. The mixture when placed in forms and allowed to set hardens like rock. This hardening is caused by the chemical reaction between the water and the cement which results to concrete growing stronger with age.

The strength, durability and other characteristics of concrete depend upon the properties of the constituent materials, proportion of mix, the methods of compaction and other controls during placing, compaction and curing. Concrete mix design, involves the determination of the proportions of the given constituents of concrete namely, cement, water, fine aggregates, and coarse aggregate and admixtures if any [2-7]. It is the process of specifying the mixture of the ingredients required to meet anticipated properties of fresh and hardened concrete [8]. This proportioning is governed by the performance of concrete in two states, namely, the plastic (fresh) state and the hardened state. If the plastic concrete is not workable, it cannot be placed and compacted, hence the property of workability becomes of very vital importance. Secondly, the compressive strength of the hardened concrete is generally considered to be an index of its other properties, depending upon many other factors, namely, quality and quantity of cement, water and aggregates, mixing, placing, compaction and curing.

Concrete mix design is a well-established practice around the world. All developed countries as well as many developing countries, have standardized their concrete mix design methods. These methods are mostly based on empirical relations, charts, graphs and tables developed as an outcome of extensive experiments and investigations of locally available materials and all of those standards and methods follow the same basic trial and error principles.

Some of the prevalent concrete mix design methods available are: ACI mix design method, USBR mix design method, British or DOE mix design method, ISI recommended guidelines.

The British Department of Environment (DOE) method of concrete mix design is used in the United Kingdom and many other parts of the world including Nigeria. The method originates from the "Road-note" which was published in Greek Britain in 1950. The DOE method utilizes British test data obtained at the building research institute, the Transport and Road Research Institute and the British Cement Association. The aggregates used in the test conform to BS 812 [9] and the cements to BS 12 [10].

The American Concrete Institute (ACI) mix design method is one of the numerous methods of concrete mix design available today. It is widely used in US and is continually updated. Both methods are somehow similar, but with major difference in the method of estimating the relative proportions of fine and coarse aggregates.

The British Department of Environment (DOE) and the American Concrete Institute (ACI) methods are two different methods of concrete mix design amidst other methods, for construction work (Highways & Building) [11-12]. The aim of this research work is to examine the similarities and differences (if any) between the ACI and the DOE methods of concrete mix design, using crushed and uncrushed coarse aggregate at various target strength, and to determine how the different design methods affects overall results.

2.0 Materials and Method

Cement

The cement used in this study was obtained from Eagle Cement Company, Rivers State, Nigeria.

Aggregates

The fine aggregate used for this work was sharp river dredged sand, obtained from one of the building construction sites within the University of Port Harcourt Campus. The crushed coarse aggregates (Granites) was also obtained from the same construction sites, while the uncrushed coarse aggregates (Gravels) was obtained from a local building site at Oyigbo, Rivers State.

Water

The water used for this study was obtained from the tap. It was colourless, odourless, tasteless and free from organic materials.

Sieve Analysis: This test was aimed at separating the aggregate obtained from one source into their constituent size ranges. The aim was to determine the relative proportion of the grain sizes present in a given mass of aggregate. The coarse aggregates used for this study, was tested for particle size grading.

Specific Gravity: This test was carried out to compare density of the soil mass to the density of an equal volume of water.

Slump Test: This test was carried out to determine the consistency, wetness or fluidity of fresh concrete.

Compressive Strength Test: This test was conducted to determine the hardness of concrete relative to its flexural and compressive strength. The compressive strength was determined from concrete cubes obtained using different mix proportions and then tested for 7 days, 14 days and 28 days respectively. Mixing of measured quantities was achieved manually using a shovel, and the concrete mixture was turned over and over until a homogenous mix was obtained. A total of Forty-five (45) cubes was

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produced, 15 from each of the methods Two (2) cubes each were tested at every 7 and 28 days curing periods for every target strength, one (1) was crushed on the Fourteenth (14) day and the average of the two taken as the compressive strength of the concrete at that age.

RESULTS AND DISCUSSION

3.1 Result of Sieve Analysis

Below is the result of the sieve analysis carried out on the coarse aggregate used for the experiment

Mass of Soil = 500g

Table 1: Sieve Analysis for Crushed Coarse Aggregate

Sieve No:	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Retained	Cumulative % Retained	% Passing
½	12.5		500	0	0	100
5/16	8.0	4	496	0.8	0.8	99.2
4	4.75	9	487	1.8	2.6	97.4
8	2.36	32	455	6.4	9.0	91.0
16	1.18	47	408	9.4	18.4	81.6
30	0.6	126	282	25.2	43.6	56.4
50	0.3	178	104	35.6	79.2	20.8
100	0.15	94	10	18.8	98.0	2.0
200	0.075	3	7	0.6	98.6	1.4

From Table 1,
Total cumulative %retained up to 150µm sieve = 251.4%
Total %retained up to 150µm sieve = 98%
Fineness modulus = Total cumulative % retained up to 150µm sieve/100%
Therefore; FM = 251.4/100=25.14 ≈ 25.1

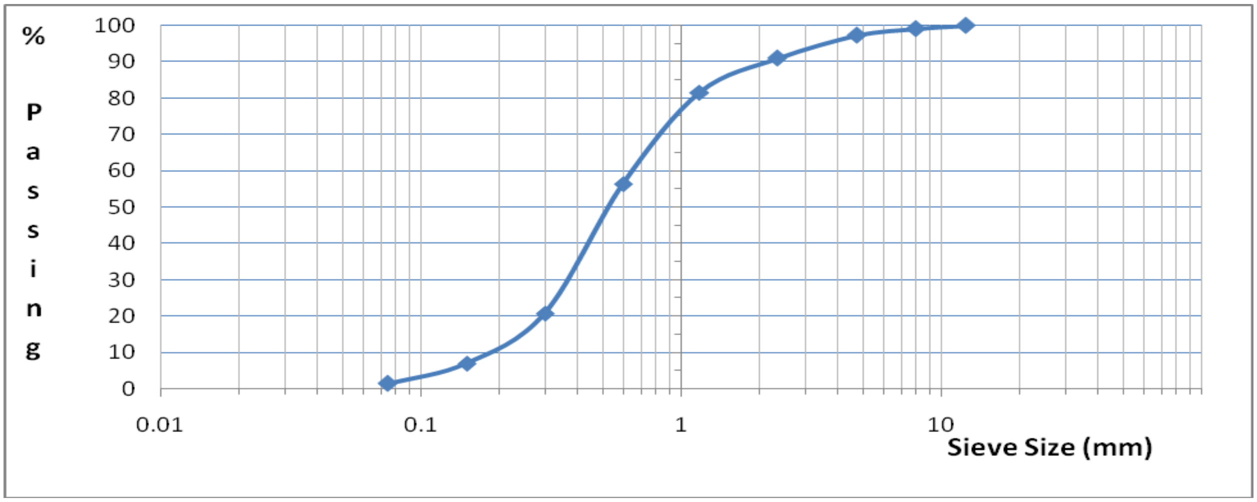

Figure 1: PSD Curve for Crushed Coarse Aggregate

From the PSD curve in Fig .1, we have:-

$D_{10} = 0.18$, $D_{30} = 0.37$, $D_{60} = 0.75$

Coefficient of Uniformity, $C_u = D_{60}/D_{10} = 0.75/0.18$
$= 4.17$

Coefficient of Curvature, $C_C = (D_{30})^2/(D_{60} \text{ X } D_{10})$
$= 0.37^2/(0.75*0.18)$
$= 1.01$

Mass of Soil = 500g

Table 2: Sieve Analysis for Uncrushed Coarse Aggregate

Sieve No:	Sieve Size (mm)	Mass Retained (kg)	Mass Passing (kg)	% Retained	Cumulative % Retained	% Passing
½	12.5	-	500	-	-	100
5/16	8.0	-	500	-	-	100
4	4.75	2	498	0.4	0.4	99.6
8	2.36	26	472	5.2	5.6	94.4
16	1.18	36	436	7.2	12.8	87.2
30	0.6	131	305	26.2	39.0	61.0
50	0.3	190	115	38.0	77.0	23.0
100	0.15	90	25	18.0	95.0	5.0
200	0.075	23	2	4.6	99.6	0.4

From Table 2,
total cumulative %retained up to 150µm sieve = 229.8%
total %retained up to 150µm sieve = 95%
Fineness Modulus = Total cumulative %retained up to 150µm sieve/100.
Therefore; FM = 229.8/100
= 22.98

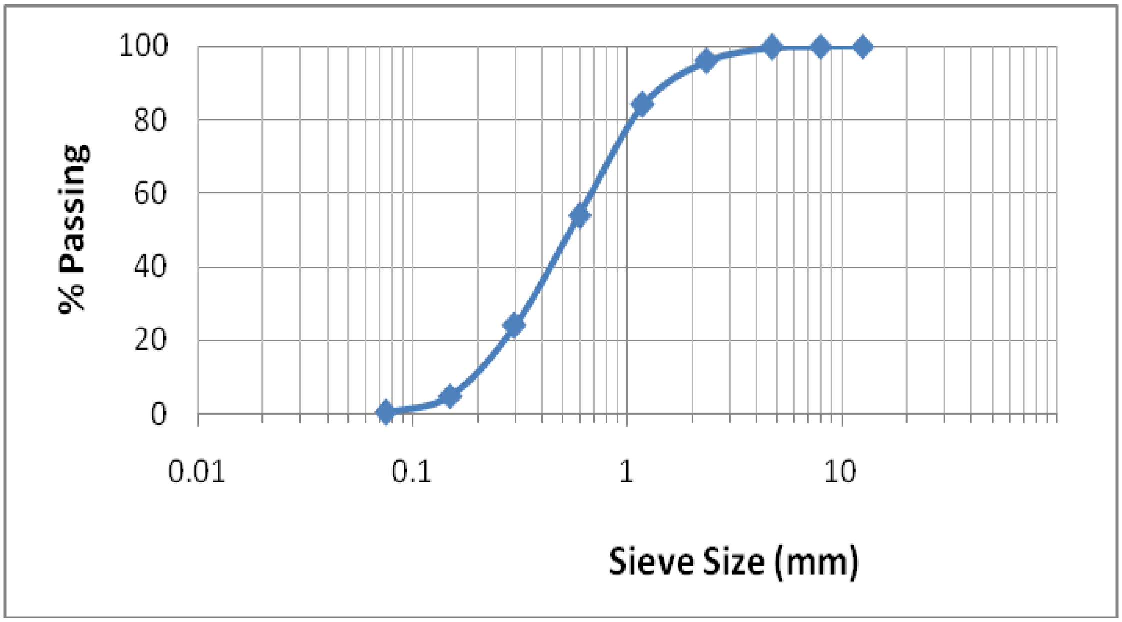

Figure 2: PSD Curve for Uncrushed Coarse Aggregate

From the PSD curve in Fig .2, we have:

$D_{10} = 0.17$, $D_{30} = 0.35$, $D_{60} = 0.69$

Coefficient of Uniformity, $C_u = D_{60}/D_{10} = 0.69/0.17$
$= 4.06$

Coefficient of Curvature, $C_C = (D_{30})^2/(D_{60} \text{ X } D_{10})$
$= 0.35^2/(0.69*0.17) = 1.04$

3.2 Result of Specific Gravity Test:

The result of the specific gravity conducted on the coarse aggregates used for the project work is as shown below:

Table 3: Specific Gravity for Crushed and Uncrushed Aggregates.

S/N	DESCRIPTION	MASS in kg, (CRUSHED)	MASS in kg, (UNCRUSHED)
1	Weight of empty density bottle (W_1)	24.00	24.00
2	Weight of Bottle + Soil (W_2)	76.98	76.92
3	Weight of Bottle + Soil + Water (W_3)	123.43	122.57
4	Weight of Bottle + Water (W_4)	90.74	89.39
5	Weight of Water = (W_4 - W_1)	66.74	65.39
6	Weight of Soil + Water = (W_3 – W2)	46.45	45.65
7	Weight of Soil = (W_2 - W_1)	52.88	52.92
8	Weight of Displaced Water = ((W_4 - W_1)- (W_3 – W2))	20.29	19.74

From Table 3, we have:

For Crushed aggregate, G_S = SN 7/SN 8
= 52.88/20.29
= 2.61

For Uncrushed aggregate, G_S = SN 7/SN 8
= 52.92/19.74
= 2.68

3.3 Result of Slump Test

Result is as presented below:-

Initial height of concrete (H) = 300mm

Subsided height of concrete (h) = 233

Slump S, = ΔH
= H – h
= 300 – 233
= 67mm

To the nearest 5mm = 65mm

3.4 Result of Compaction Factor Test

Wt. of cylinder alone (W_1) = 3.6kg

Wt. Of partially compacted concrete + Cylinder (W_2)
= 8.3kg

Wt. Of fully compacted concrete + Cylinder (W_3)
= 8.65kg

Therefore, compaction factor (cf) $= \frac{(W2-W1)}{(W3-W1)}$

$= \frac{(8.30 - 3.60)}{(8.65 - 3.60)}$

CF **= 0.93.**

3.5 Result of Cube Test

3.5.1 DOE Method

The result of the cube test obtained from the cubes produced with the values of the constituent elements for DOE crushed and uncrushed aggregates are presented below:

Table 4: Cube Test Result on Crushed Aggregates

M20					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2450	2400	2520	2453	2436
Failure Load (N)	223000	212000	326000	366000	358000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	22.3	21.2	32.6	36.6	35.8
Average Compressive Strength	21.75		32.60	36.20	
M30					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2258	2346	2479	2354	2357
Failure Load (N)	254000	282000	348000	459000	453000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	25.4	28.2	34.8	45.9	45.3
Average Compressive Strength	26.80		34.80	45.60	
M50					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2397	2435	2459	2396	2376
Failure Load (N)	349000	317000	438000	671000	683000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	34.9	31.7	43.8	67.1	68.3
Average Compressive Strength	33.30		43.80	67.70	

ISSN 2229-5518

Table 5: Cube Test Result on Uncrushed Aggregates

M20

Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2435	2479	2513	2470	2503
Failure Load (N)	288000	283000	317000	375000	381100
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	28.8	28.3	31.7	37.5	38.11
Average Compressive Strength	28.55		31.70	37.81	

M30

Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2311	2343	2378	2421	2454
Failure Load (N)	321000	298000	354000	472000	483000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	32.1	29.8	35.4	47.2	48.3
Average Compressive Strength	30.95		35.4	47.75	

M50

Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2349	2351	2417	2512	2458
Failure Load (N)	363000	395000	481000	643000	631000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	36.3	39.5	48.1	64.3	63.1
Average Compressive Strength	37.90		48.10	63.70	

3.5.2 From the ACI Method

ISSN 2229-5518

The result of the cube test obtained from the cubes produced with the values of the constituent elements for ACI crushed aggregates are presented below:

Table 6: Cube Test Result on Crushed Aggregates

M20					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2510	2630	2615	2679	2565
Failure Load (N)	317000	306000	325000	337000	341000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	31.7	30.6	32.5	33.7	34.1
Average Compressive Strength	31.15		32.50	33.90	
M30					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2450	2512	2540	2587	2573
Failure Load (N)	351000	374000	405000	477000	461000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	35.1	37.4	40.5	47.7	46.1
Average Compressive Strength	36.25		40.50	46.90	
M50					
Age of Concrete (Days)	7		14	28	
Date of Manufacturing	14/01/2015		14/01/2015	14/01/2015	
Date of Crushing	21/01/2015		28/01/2015	11/2/2015	
Area of Cube (mm^2)	10,000		10,000	10,000	
Weight of Concrete (g)	2712	2723	2618	2650	2723
Failure Load (N)	486000	511000	573000	730000	737000
Compressive Strength of Concrete = Failure Load/Area (N/mm^2)	48.6	51.1	57.3	73	73.7
Average Compressive Strength	49.85		57.30	73.35	

ISSN 2229-5518

Table 7: Summary of Cube Test Results Obtained at Various Curing Age.

Concrete Grade	DOE, crushed			DOE, uncrushed			ACI, crushed		
	Days								
	7	14	28	7	14	28	7	14	28
M20	21.75	32.60	36.20	28.55	31.70	37.81	31.15	32.50	33.90
M30	26.80	34.80	45.60	30.95	35.40	47.75	36.25	40.50	46.90
M50	33.30	43.80	67.70	37.90	48.10	63.70	49.85	57.30	73.35

These results can also be summarized in Figure 3-8 below

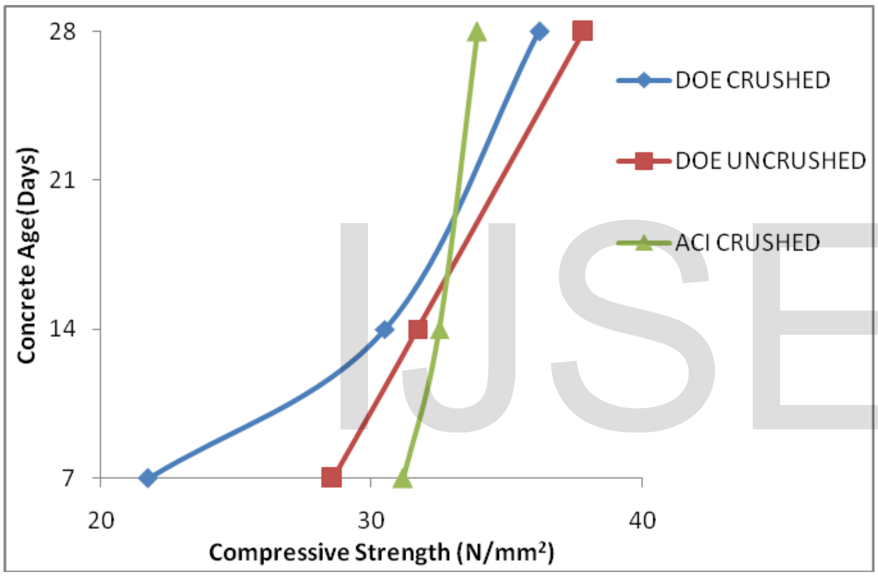

Figure 3: Relationship between Compressive Strength and Concrete Age at M20.

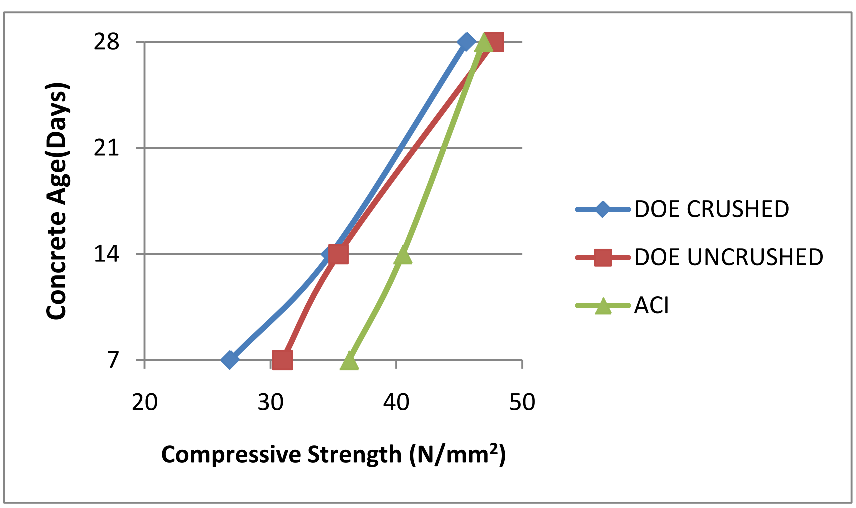

Figure 4: Relationship between Compressive Strength and Concrete Age at M30.

ISSN 2229-5518

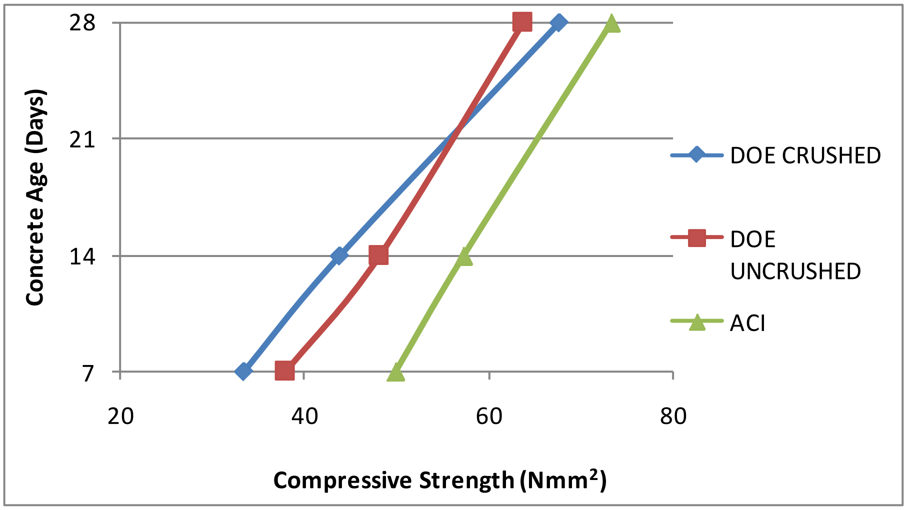

Figure 5: Relationship between Compressive Strength and Concrete Age at M50.

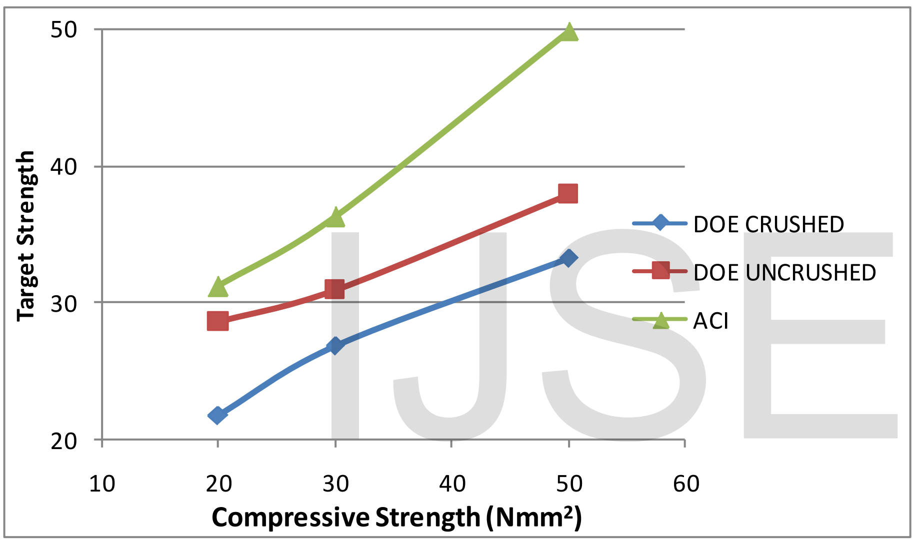

Figure 6: Relationship between Compressive Strength and Target Strength at Age 7days.

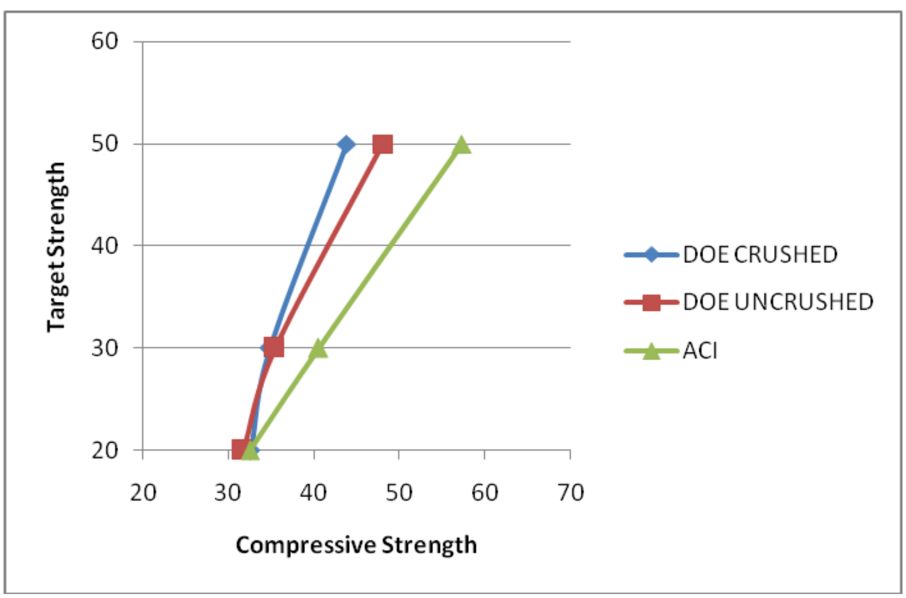

Figure 7: Relationship between Compressive Strength and Target Strength at Age 14days.

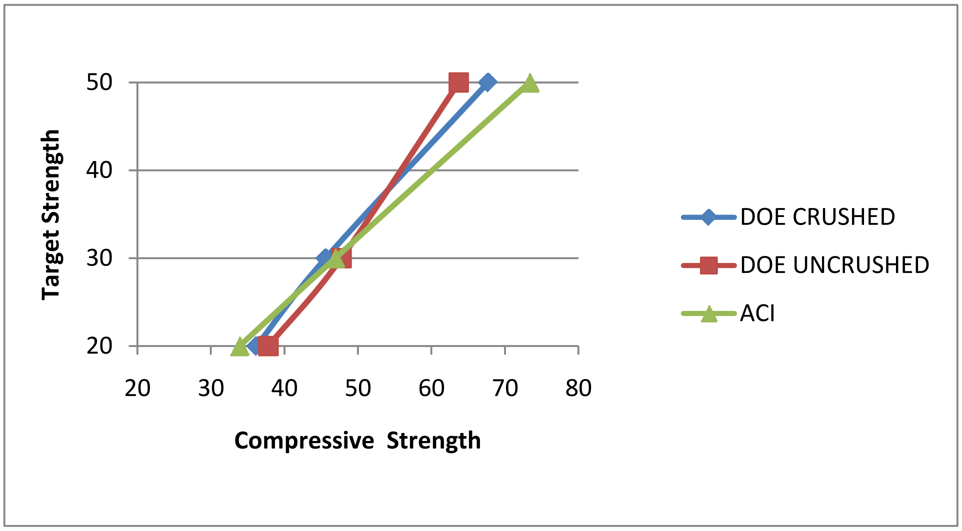

Figure 8: Relationship between Compressive Strength and Target Strength at Age 28days.

3.6 Discussion of Results

The analyses of results in Table 1 and 2, gave a fineness modulus, of 25.6 and 23.0 respectively for the crushed and uncrushed coarse aggregates. Also, from the PSD curve (Fig. 1 and 2), the coefficient of uniformity, C_U and coefficient of curvature, C_C of both aggregates are greater than 4.0 and 1.0 respectively, showing that both aggregates are well graded. The specific gravity result was 2.61 for the crushed and 2.68 for the uncrushed aggregates respectively. The compressive strength values obtained using the British Department of Environment (DOE) method for crushed aggregates has a fluctuating value, it is high at some point and low at other point, but it is not so with the American Concrete Institute, ACI method.

From Tables 4 to 7 and Figures 3 to 8 it can be observed that, the 28-days compressive strength for M20, M30and M50 using the DOE and ACI methods were 36.2N/mm^2, 45.6 N/mm^2, 67.7 N/mm^2 and 33.9 N/mm^2, 46.9 N/mm^2, 73.35 N/mm^2 respectively for crushed aggregates, but when uncrushed aggregate was used, the result obtained at 28-days were; 37.81 N/mm^2, 47.75 N/mm^2 and 63.70 N/mm^2 respectively.

5.0 Conclusion

From the study the following conclusions can be drawn.

Both DOE and ACI methods are based on the empirical relations and derived from extensive experiments done in each of the countries with locally available materials, implying that both methods extensively uses tables and graphs during the design process, and follow logical determination of the ingredients, by establishing the targeted strength for trial batch. Such trial batch strength is derived from the required design strength of the structural concrete and the statistical analysis to ensure that the mix design meets or exceeds the design strength, which is related to statistics of the quality control.

Once the target strength is established, both methods advance the process with the determination of the water/cement ratio. It is also common to both methods that the cement content is determined from a relationship of two parameters; the w/c ratio and the amount of water and is checked against limited values in order to satisfy durability requirement. While the DOE method uses 28 days cube strength to arrive at the target strength, the ACI method uses 28 days cylindrical strength.

Though both methods utilize the standard deviation to calculate the target strength, the technique employed by both methods is absolutely different. While the DOE method suggests the value of the standard

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deviation, the ACI method recommends empirical values to determine the standard deviation.

While the British DOE method uses the compaction factor as a measure of workability, the American ACI method uses the slump. Though the DOE method discusses the air entrainment, the selection of the w/c ratio is a sole function of the target strength, whereas in the ACI method, the determination of the w/c ratio, is a combination of both the target strength and the type of concrete (whether Air entrained or Non Air entrained).

In the DOE method, determination of the water content is dependent on the target strength, whereas in the ACI method, water content could be determined independent of the target strength. The DOE method considers whether the coarse aggregate used is crushed or uncrushed, but in the ACI method, consideration is not made for uncrushed aggregate.

Generally, it could be seen that at lower target strength, the DOE method gives a higher compressive strength than the ACI method, but the reverse was the case at M50. Also on the basis of comparison based on age of concrete, from Figures 7 and 8, it could be seen that the ACI method gave a higher compressive strength ($46.9Nmm^2$) at day 14 and day 28 respectively as against the DOE method of 45.6 N/mm^2 and 67.7 N/mm^2 respectively for 14 and 28 days respectively.

References

[1] Krishnaswami, B. N. (2009). Concrete Mix Design. Civil Engineers & Architects Association, Kumbakonam.

[2] Kett, I. (2^{nd} Edition). (2010). Engineered concrete: Mix design and Test methods. CRC press, New York.

[3] Durocrete. (2012). Mixed design manual.

[4] Nwofor, T.C. & Eme, D.B. (2010). Stability of concrete work with partial substitute of rice husk ash (RHA) for cement in Nigeria. *Journal of Chemical, Mechanical and Engineering Practice*, 1(2&3), 42-47

[5] Sule, S. & Nwofor, T.C. (2011). Analytical models for prediction of mechanical properties of rice husk ash concrete. *International Journal of Current Research*, 3(11), 368-370

[6] Nwofor, T.C. & Sule, S. (2012). Stability of groundnut shell ash (GSA)/ordinary Portland cement (OPC) concrete in Nigeria. *Advances in Applied Science Research*, 3(4), 2283-2287.

[7] Nwofor, T.C. & Sule, S. (2014). Investigating geometric characteristics of cement concrete materials. *International Journal of Innovative Research in Advanced Engineering*, 1(9), 74-82.

[8] Amarjit, S. and Kamal, G. (2005). Comparison of IST and ACI methods for absolute volume concrete mix design. 30^{th} conference on our world in concrete and structures, Singapore.

[9] BS 812: Part 1 (1975). Methods of Determination of particle size and shape.

[10] BS 12 (1978). Specification for Portland cement. British Standards Institution.

[11] Kumbhar, P. D. (2012). Assessment of the suitability of existing mi design methods of normal concrete for designing high performance concrete. International Journal of Civil and Structural Engineering. Vol.3.

[12] Bhattacharjee, B. Mix Design of Concrete: British (DOE) method, CEL 774 Construction practices, Civil Engineering Department, IIT, Delhi.