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Quarry Dust as a Partial Replacement of Coarse Aggregates in Concrete Production

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Abstract: *This study is an attempt to investigate the suitability of quarry dust as a partial replacement of coarse aggregates in concrete making. Samples of concrete cubes were made with varying proportions of quarry dust replacing the coarse aggregate. It was foreseen that the utilization of quarry dusts as partial replacement of coarse aggregates in concrete will be more beneficial due to the relative ease of inclusion that will be achieved as opposed to batching them separately as fine aggregates. Since they are produced from the production of coarse aggregates, they could, therefore, be better included, transported, and batched as coarse aggregates.This promises to be a more sustainable option, preserving the global natural resource base as well as save construction costs significantly. A total of 150 cubes were cast. Some physical properties of the concrete constituent materials that are relevant to the experiments were determined. The mix design of 1:2:4 was adopted and two brands of Ordinary Portland cement (OPC) were used for comparative purposes. Particle size distribution analysis, slump test, and compressive strength test were carried out on the materials, the fresh concrete, and the cured concrete cubes respectively. The quarry dust sample was found to be well graded and the concrete mixes had true slumps with decreasing consistency as the quantity of quarry dust increased. The results disclosed that replacing 10% of the required amount of gravel with quarry dust and using the Ibeto brand of Portland cement yielded the highest amount of compressive strength of 32.3N/mm^2. It was also observed that using the Ibeto brand of OPC, the concrete cubes made with inclusion of quarry dust up to 25% all performed better than the zero replacement level in terms of their compressive strengths. The strengths achieved with the Dangote brand of OPC were satisfactory up to 15% replacement level. This suggests that the quarry dust can be utilized as a partial replacement of the coarse aggregates in concrete within the satisfactory levels. The study further showed that variations in the properties of Portland cement brands can result in significant differences in the performances of concretes made with them.*
Keywords: *concrete, quarry dust, compressive strength, coarse aggregates, partial replacement*

I. Introduction

Concrete is one of the most used building materials globally. They are produced by mixing aggregates, which are inert materials, in fixed proportions with a cementing material and water to produce concrete (Singh 2008). Aggregates are responsible for strength, hardness and durability of concrete. Aggregates are either coarse (gravel and stones) or fine (sand). It is desirable that aggregates consist of particles with adequate strength and resistance to exposure conditions. For a workable, durable and economical concrete mix, aggregates are expected to be resistant to abrasion, and stable to chemical attacks. The particle size distribution and surface texture of aggregates are also of great importance. Coarse aggregates are aggregates that are more than 4.75mm in size (Shetty, 2005). They range from10mm to 20mm in size with a bulk density of about 1430kg/m^3. Gravel and crushed stones are some examples. For effective performance, they must be clean, hard, tough, strong, durable, inert, free from dust and well graded (Akeem *et al*, 2013).

Coarse aggregate which is the strength component of the concrete have been found to be relatively high in demand and price. In the recent past, several attempts have been made towards the replacement of natural aggregates with other cheap materials in concrete. This quest for alternative construction materials is due to the global sustainability concern as it relates to the preservation of the environment and non-renewable natural resources which has been depleting in quality and quantity as a result of many human activities of which Civil Engineering constructions are major contributors. Reuse of various industrial by-products such as flyash, silica fume, rice husk ash, foundry waste, quarry dust, et cetera as substitutes to the conventional construction materials in construction has been argued to be a possible way forward towards achieving an environmentally friendly construction (Nwachukwu *et al*, 2012; Neville, 2002; Gambhir, 1995). Based on this, this study attempts to study the effects of quarry dust addition on the strength characteristics of concrete and to assess the rate of compressive strength development for replacement of coarse aggregate with quarry dust. Quarry dust, a by-product from the crushing process during quarrying activities is one of those materials that have recently gained attentions to be used as concreting aggregates, especially as fine aggregates. But the fact that the quarry dust is a by-product of the production of coarse aggregates makes it reasonably utilized as a partial replacement of the same, if found to be suitable. This will make for easy in-the-quarry proportioning instead of batching on site with sand collected from a different source altogether.

Quarry dust has been used for different activities in the construction industry such as in road construction and manufacture of building materials such as light weight aggregates, bricks, plastering material and tiles. According to Sivakumar and Prakash (2011), quarry dust,which used to be a waste obtained during quarry process, has very recently gained good attention to be used as an effective filler material instead of fine aggregate. Neville (2002), Zain et al. (2000), and Gambhir (1995) also demonstrated in their studies how quarry dust can be suitably used as concrete aggregates, especially as fine aggregates. Nwachukwu et al (2012) explained that quarry dust is a cohesionless sandy material. He agreed that the material could be acquired either naturally (which is rare) or artificially by the mechanical disturbance of parent rocks (blasting of rocks) for the purpose of producing coarse aggregates used for construction. The particles of quarry dust have diameters ranging from 0.05mm to 5.00mm. Agbode and Joel (2001) found in their study on the suitability of quarry dust as partial replacement for sand in hollow block production, that quarry dust is cheaper than river Benue sand even during rainy season, due to the fact that they were seen as inferior materials.

Sivakumar and Prakash (2011) investigated the mechanical properties of quarry dust addition in conventional concrete. They concluded that the addition of the quarry dust improved the strength properties of concrete far above the conventional concrete. Karthicket al (2014), in his study on the usage of quarry dust as a partial replacement for sand in concrete found that the compressive strength of concrete cubes at 28 days of curing was improved as high as 35.26% above the strength of conventional concrete when 40% of the fine aggregate was replaced with quarry dust by weight. A similar study by Paramjeet and Singh (2014) and Ukpata et al (2012)also reported a strength increase of 12% above conventional concrete and encourages the utilization of quarry dust as fine aggregates.

Though no known attempt have been made in the possible replacement of coarse aggregate with quarry dust, prior to this study, the high improvement achieved from these previous studies on fine aggregates points to the possibility of utilizing it as coarse aggregates being that they are of the same source. Besides, quarry dust has rough, sharp and angular particles and as such causes a gain in strength due to better interlocking. The use of quarry dust in concrete is desirable because of its benefits such as useful disposal of by products, reduction of coarse aggregate usage as well as increasing the strength parameters and possible increase in the workability of concrete (Nwachukwu et al, 2012).In a developing country like Nigeria, the use of alternative cheaper local materials or even by-products like the quarry dust as replacement of the coarse aggregate will greatly enhance the production of concrete with desired properties at low cost. It will drastically reduce the cost of production and consequently the cost of construction. By this, the quarry dust will be utilized effectively than allowing it waste with consequential environmental hazard.

II. Materials And Methods

2.1; Materials

The materials used in this project include water, cement, sharp sand, quarry dust and granite. The portable water used for the experiments was taken from the concrete laboratory water thank. Two brands of Portland cement (Dangote and Ibeto) of grade 42.5 were used for the research. They were sourced from Local cement dealers at Ama-achara in Enugu state. The quarry dust as well as the gravel was obtained from Isiagu quarry, while the sharp sand used was river bed sand collected from Nyama River both in Enugu State of Nigeria.

2.2; Methods

The Specific Gravity and the Particle Size Distribution Analysis for the samples were carried out in accordance to BS1377. The workability test, casting, and crushing of the cubes were carried out in accordance to BS1881 part 3 (1992). The cubes were cured in accordance with BS8110, Part 1 (1985).

The concrete mix was batched by weight and mixed manually with 1:2:4 mix proportion. Concrete cubes of 150mm × 150mm × 150mm in size were for the casting. The proportion of the gravel was replaced by quarry dust at 0%, 5%, 10%, 15%, 20%, and 25% replacement levels. Three cubes were cast at each replacement level and the average compressive strength gotten at a given curing age. The curing of the concrete was by complete immersion in water.

Table 1 below shows the batching of the materials at different replacement levels.

Table 1; Proportioning of the Constituent Materials.

Replacement %	Cement (kg)	Sand (kg)	Water (kg)	Granite (kg)	Quarry dust (kg)
0	1.073	2.132	0.59	4.263	0
5	1.073	2.132	0.59	4.050	0.213
10	1.073	2.132	0.59	3.837	0.426

15	1.073	2.132	0.59	3.624	0.639
20	1.073	2.132	0.59	3.410	0.853
25	1.073	2.132	0.59	3.197	1.066

III. Results Anddiscussions

3.1; Properties of the Materials

Table 2 below is the summary of the physical properties of the sand, gravel, and quarry dust, used for the experiment. The particle size distribution curves for the three materials are plotted as figure 1 below.

The sand used for the experiment was found to be uniformly graded with a uniformity coefficient of 3.45 while the gravel has sizes ranging between 14mm and 19mm with a uniformity coefficient of 1.35. These are typical of the size ranges used for construction projects in Nigeria and are significantly collected from predominant sources within Enugu State, South-East Nigeria.

Table 2; Index Properties of the Materials

	Sample Designation		
Property	**Sand**	**Gravel**	**Quarry dust**
Specific gravity	2.56	2.71	2.57
% gravel (>4.76mm)	0	99.90	2.80
% sand (<4.76mm to 0.075mm)	99.8	0.01	98.45
% fines (<0.075mm)	2.09	2.02	1.55
Coefficient of Uniformity	3.45	1.35	45.12
Cc	1.02	1.47	1.10

The quarry dust which was the material of concern was found to be composed of varying ranges of particle sizes but predominantly sand. This suggests that the name quarry dust does not connote a material full of fines but points to the fact that the quarry sites have been disposing of the material as unwanted wastes. That makes this investigation a quintessential attempt to assess the extent to which this material can suitability be utilized in concrete works as partial replacement for coarse aggregates.

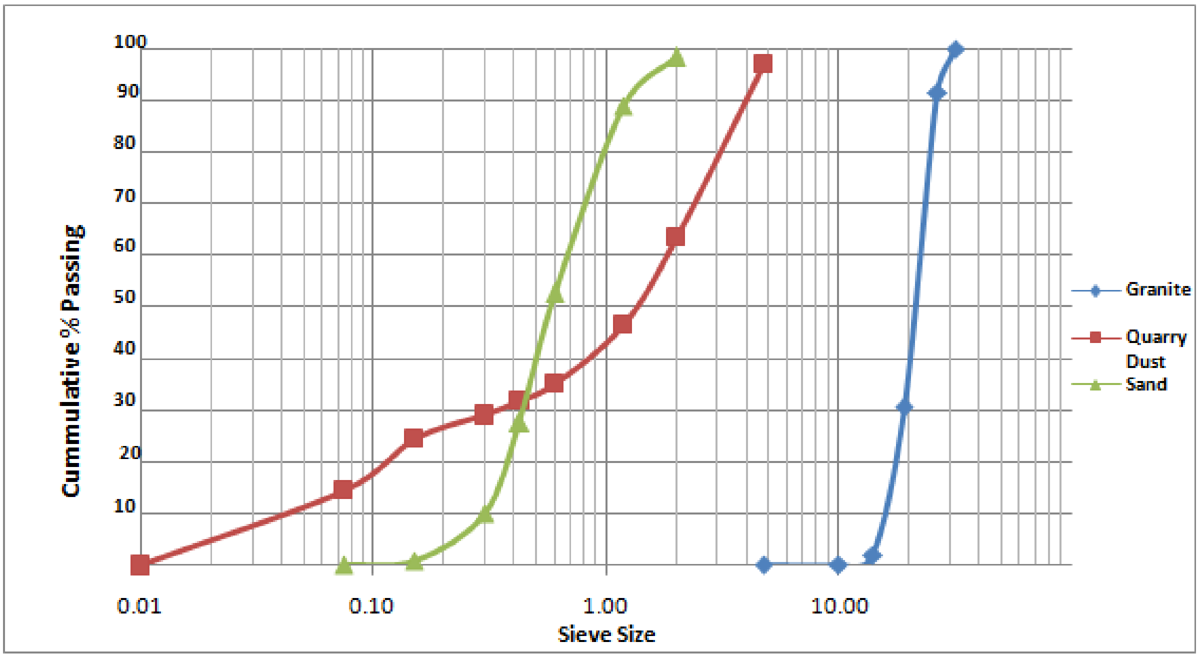

Figure 1: Particle Size Distribution for Gravel, Sand and Quarry Dust.

The specific gravity of the Sharp sand, Quarry Dust and Gravel were found to be 2.56, 2.57 and 2.74 respectively. The specific gravity value for Quarry dust is close to that of the fine aggregate, though slightly higher. As expected, the specific gravity of the coarse aggregate was quite higher than those of sand and quarry dust which shows how denser it is and makes it more necessary to investigate the performance of the concrete if the quarry dust is batched into the concrete mix as coarse aggregate.

3.2; Concrete Consistency with Quarry Dust as Coarse Aggregates

The result of the workability tests carried out with 0.65 w/c ratio for the two brands of Portland cement used, Dangote and Ibeto, have been summarized as Table 4 below. It was observed that in both cases, the workability of the concrete decreased as the percentage of quarry dust increased. In each of the cases, a true slump was achieved which consistently got lesser as the quantity of the quarry dust increased, strongly suggesting that the quarry dust is more water absorbing than gravel.

Table 4: Slump Test Result for Dangote Cement and Ibeto Cement

Dangote Cement			**Ibeto Cement**		
S/n	**Height of Collapse (mm)**	**Slump (mm)**	**S/n**	**Height of Collapse (mm)**	**Slump (mm)**
N0	190	110	**M0**	200.00	100
N5	220	80	**M5**	221.00	80
N10	235	65	**M10**	260.00	40
N15	270	30	**M15**	281.50	20
N20	285	15	**M20**	295.00	5
N25	300	0	**M25**	300.00	0

In as much as the two brands of cement used for this experiments were similar in their workability characteristics in response to the incorporation of the quarry dust, figure 4 below shows that there is noticeable and consistent difference between the workability of Dangote Cement and Ibeto Cement. The workability achieved with the Dangote Cement was higher than the Ibeto cement at all replacement up till 20% where the two are the same. It shows that the use of Dangote cement with quarry dust shows a better workability than with Ibeto cement for w/c ratio of 0.65. From the results, the 25% percent replacement for both cement brands and the 20% replacement for Ibeto cement were found to be inconsistent being that the slump were below 10 which is the minimum specified by BS EN 12350-2:2009. The concrete without quarry dust had class S3 slump, the one with 5% and Dangote 10% were of class S2 slump, while those of 10% Ibeto, 15% replacement for both, as well as 5% replacement for Dangote were of slump class S1.

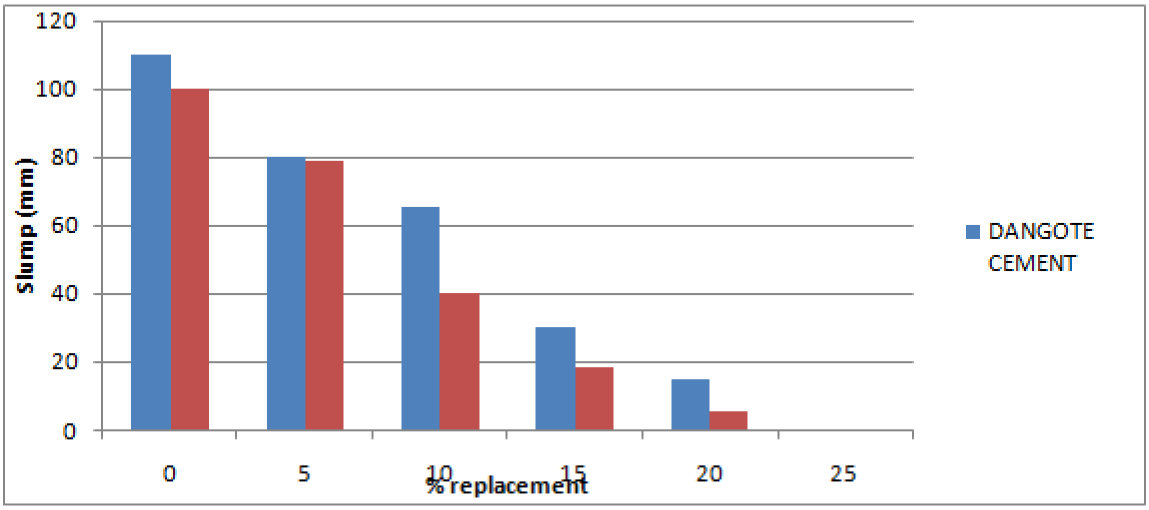

Figure 2: Workability of the Concrete mixes with the Two Portland Cement brands

3.3; Compressive Strength Result of Concrete with Different Proportions of Quarry Dust

The Compressive Strength results of the concrete cubes, at different curing ages, made with Dangote as well as Ibeto cement are tabulated as Table 5 and Table 6 below respectively.

Table 5: Summary of Compressive Strength for Dangote Cement

S/N	**7 DAYS (N/mm²)**	**14 DAYS (N/mm²)**	**21 DAYS (N/mm²)**	**28 DAYS (N/mm²)**	**56 DAYS (N/mm²)**
N0	14.12	14.30	15.26	20.88	21.31
N5	12.16	14.41	15.42	21.32	22.57
N10	10.37	11.25	13.81	14.59	20.10
N15	12.10	14.10	14.17	15.78	18.35
N20	11.58	11.79	12.10	13.78	21.57
N25	9.99	10.73	11.01	12.62	20.42

Table 6: Summary of Compressive Strength for Ibeto Cement

S/N	7 Days (N/mm²)	14 Days (N/mm²)	21 Days (N/mm²)	28 Days (N/mm²)	56 Days (N/mm²)
M0	11.81	16.77	18.31	20.50	22.91
M5	19.77	21.76	23.91	24.46	29.73
M10	23.19	26.68	30.09	32.30	32.47
M15	18.22	20.22	21.62	24.49	26.51
M20	18.46	19.97	20.79	21.92	22.54
M25	21.26	21.79	22.79	24.04	26.99

This result is illustrated graphically in figures 3 and 4 below. Generally, the compressive strengths increased with curing age as expected. Being that the 1:2:4 mix proportion was adopted, a concrete of grade M15 was expected, which implies that any specimen with compressive strength of 15N/mm^2 and above at 28 days of curing would be satisfactory. Therefore, all the cubes cast with the Ibeto cement were all found to be satisfactory whereas those made with Dangote cement up to 15% replacement were also found to be satisfactory. Besides, all the cubes achieved a compressive strength above 15N/mm^2 at 56 days of curing. Which supports the fact that concrete gains strength with age at curing.

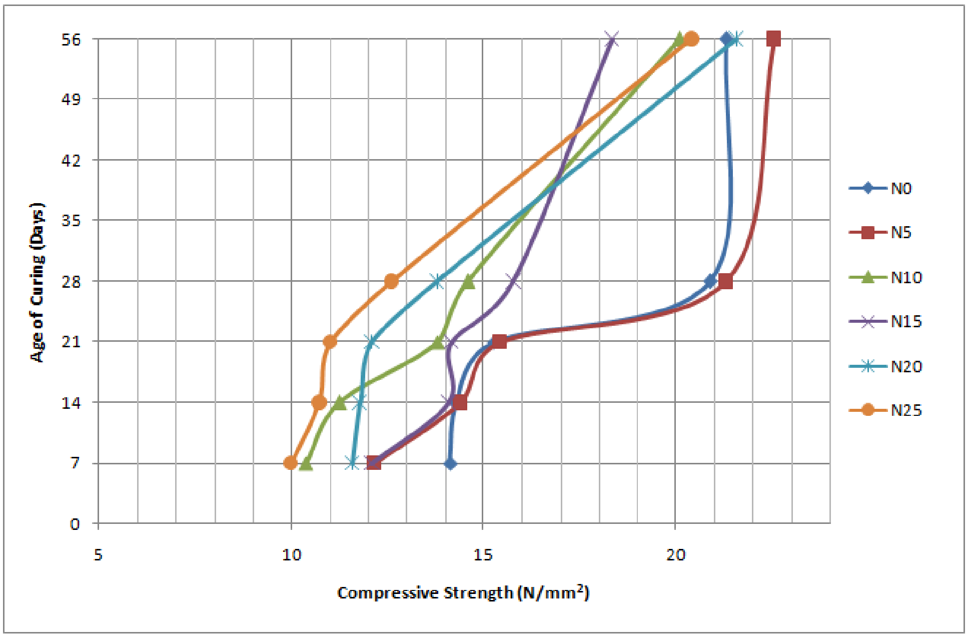

Figure 3: Increase in Compressive Strength with Age of Curing Dangote

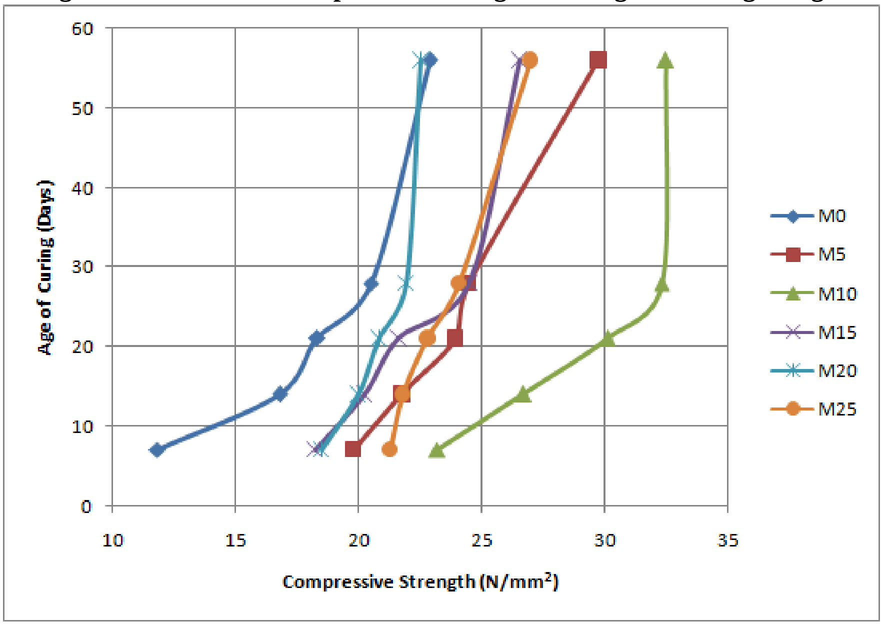

Figure 4: Increase in Compressive Strength with Age of Curing Ibeto

Figure 5 is the graph of the 28th day strengths achieved at different replacement levels of the coarse aggregate with quarry dust. Concrete with Quarry dust show an increasingly compressive strength. In other words, compressive strength of concrete made with replacement of coarse aggregate with Quarry dust ranges from 18.35N/mm^2 to 22.57N/mm^2 for Dangote Cement and 22.54N/mm^2 to 32.47N/mm^2 for Ibeto cement. Dangote cement is maximum at 5% replacement (N5) and the compressive strength is 22.57N/mm^2. Other replacements however showed a declining compressive strength. Looking at the various replacements: N5 showed a steadily rapidly strength gain. Other replacements however show a similar strength gain at 56 days but are comparatively smaller. Ibeto Cement showed an early compressive strength gain with replacement of coarse aggregate with Quarry dust for all the replacements. Its Compressive Strength ranges from 22.54 N/mm^2 up to 32.47 N/mm^2 after 56 days and reaches its peak value at 10% replacement (M10). At M10, the compressive Strength is 32.47 N/mm^2 (29.44% more than that of the conventional concrete of 0% replacement) for 56 days. For 7 days, 14 days, 21 days and 28 days, the strength is also higher than the conventional concrete of 0% replacement (49.07%, 37.14%, 39.15%, 36.53%) respectively.

The Ibeto brand of cement shows better compressive strength than Dangote Cement: from the result and analysis, it was seen that the compressive strength of concrete made by replacing coarse aggregate with Quarry dust is higher with the use of Ibeto cement. For 5% replacement, the compressive strength of the concrete made with Ibeto cement is about 38.49%, 33.78%, 35.51%, 12.84%%, 24.08% for 7 days, 14 days, 21 days, 28 days and 56 days respectively more than that of Dangote, for 10% replacement, Ibeto was still higher (about 55.28%, 57.83%, 54.10%, 54.83%, 38.10% more than Dangote for 7 days, 14 days, 21 days 28 days and 56 days respectively). For 15% it is still more than that of Dangote Cement (about 33.59%, 30.27%, 34.46%, 35.67%, 30.78% for 7 days, 14 days, 21 days 28 days and 56 days respectively). For 20% replacement, it is still higher though at 56 days, the Strength difference is low about 4.30%, (for other days i.e 7 days, 14 days, 21 days and 28 days, Ibeto Cement is about 37.27%, 40.96%, 41.80%, 37.14% more than that of Dangote cement). While for 25% replacement, it is higher (about 53.01%, 50.76% 51.69%, 47.50%, 24.34% more than that of Dangote Cement). And these show very high difference between the two for all replacement. The difference between the two would have been as a result of the difference in the composition of the two brands of cement.

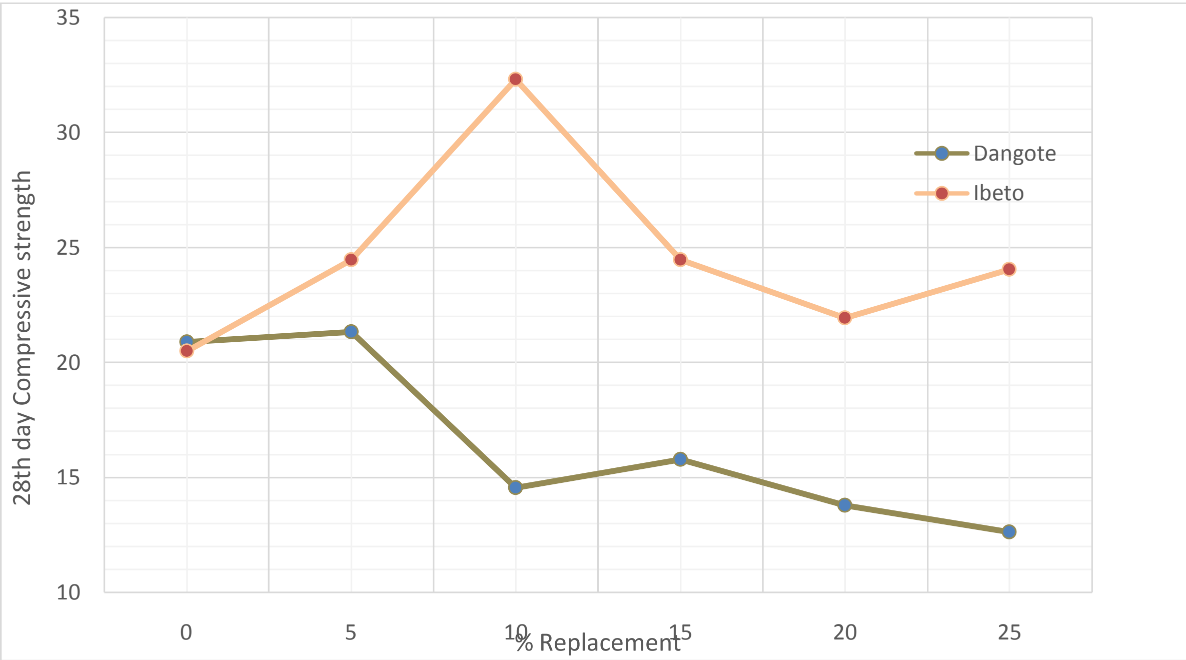

Figure 5; Variation in Compressive Strength of the Concretes at 28th Day of Curing

These results suggest that the slump test for workability and consistency of mix has no practically significant information to give about the final strength of the concrete. It only points to the ease of placing and smoothness of the finished product than to the strength gain. This opinion is based on the fact that the fresh concrete mixes with the Dangote cement tended to be more workable than those made with the Ibeto cement, but the cubes from the Ibeto cement were significantly stronger.

3.4; Relationship between Density and Compressive Strength

Figures 6 and 7 show the average observed densities of the concrete cubes before they were crushed. The results of the average densities gotten are shown below:

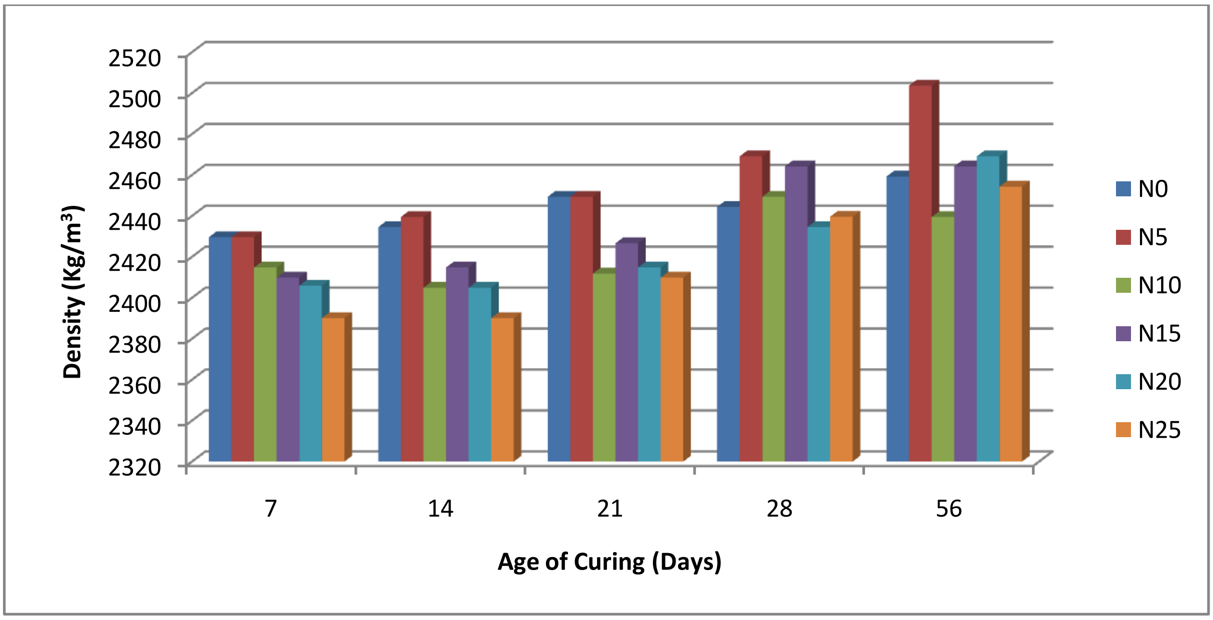

Figure 6: Density Result for all days of curing with Dangote Cement

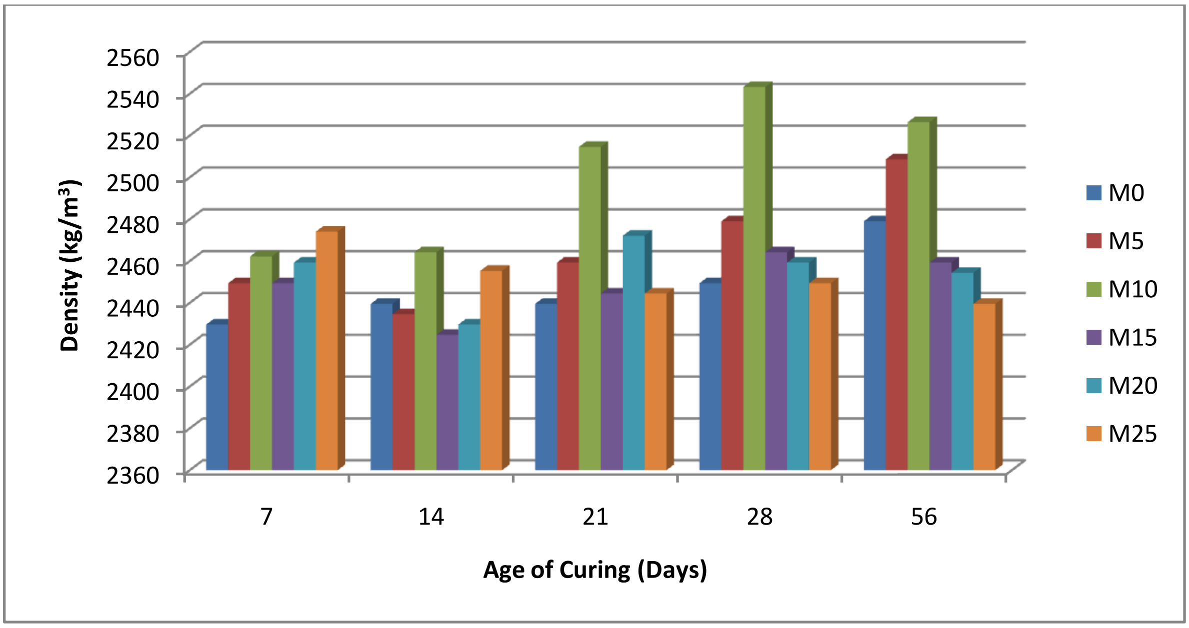

Figure 7: Density Result for all Days of Curing with Ibeto Cement

For the Dangote cement, at 15% replacement, the density was found to be lowest (2360.49kg/m^3) while the maximum (2503.70kg/m^3) was at 5% replacement at 56 days which coincidentally is the maximum compressive strength observed.

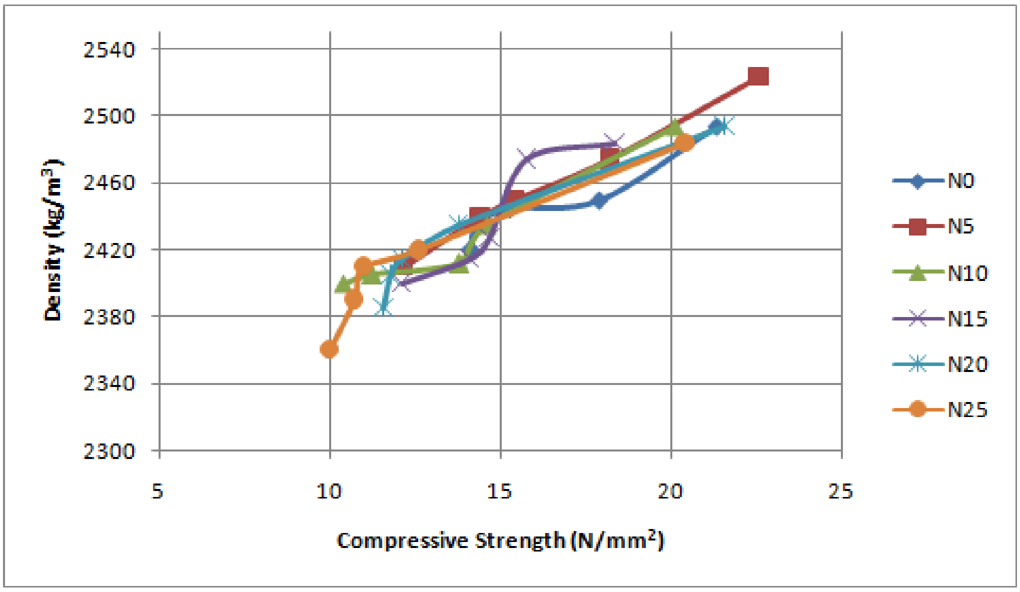

Figure 8: Variation of Compressive Strength with Density with Dangote Cement

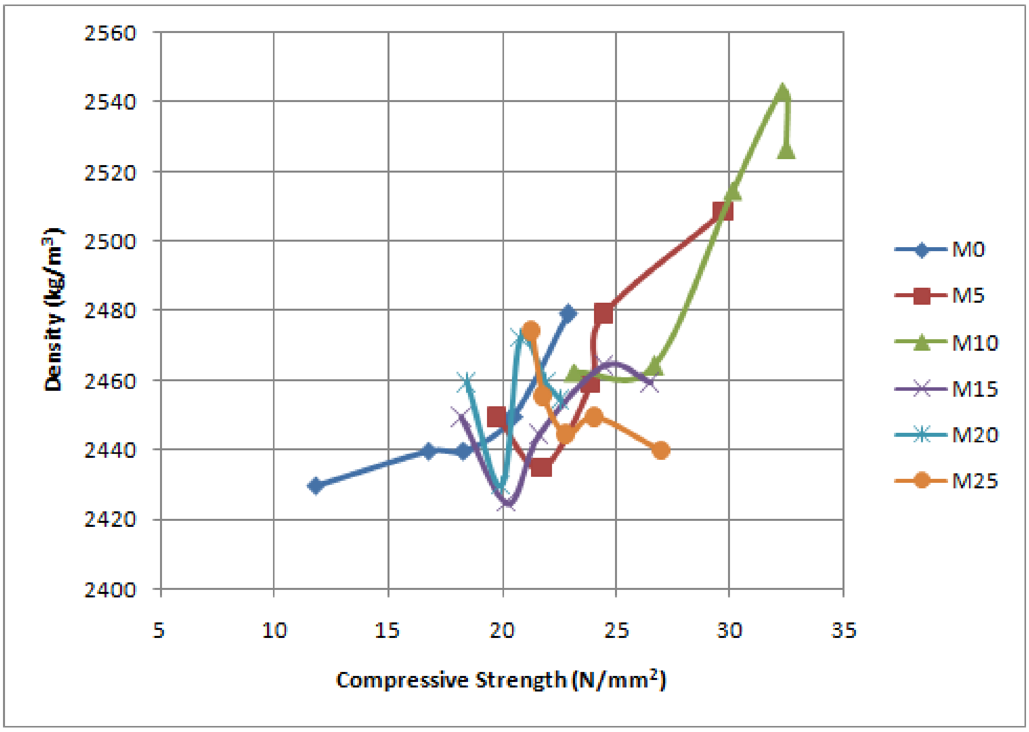

Figure 9: Variation of Compressive Strength with Density with Ibeto Cement

From the figure 8 and 9 above, it could be seen that the densities of the cubes increased with increase in their compressive strength. The variation is not uniform neither are the relationships perfectly linear, by observation of the curves, but the result of the Pearson correlation coefficients (0.9 and 0.8 for Dangote and Ibeto respectively) suggest a positive negative correlation between density and compressive strength of concrete. This further suggests that as the density of the concrete specimen increases, the compressive strength of the same is also expected to increase in like manner.

IV. Conclusion And Recommendation

Based on this experimental investigation on the possible replacement of coarse aggregate with Quarry Dust in Concrete, it could be concluded that the workability of concrete decreases with increasingly percentage of Quarry Dust in the mix and workability test being a pointer to the consistency of the mix does not imply the final strength characteristics of the same.

This study shows that replacing 10% of the required amount of gravel with quarry dust and using the Ibeto brand of Portland cement yielded the highest amount of compressive strength of 32.3N/mm^2. It was also observed that using the Ibeto brand of OPC, that the concrete made with inclusion of quarry dust up to 25% all performed better than the zero replacement level in terms of their compressive strengths. In contrast, the concrete cubes made with the Dangote cement performed less with the inclusion of the quarry dust. Besides, the strengths achieved were satisfactory up to 15% replacement level. This suggests that the quarry dust can be utilized as a partial replacement of the coarse aggregates in concrete within the satisfactory levels. Hence, the variations in the properties of Portland cement brands can result in a significant difference in the performance of concretes made with them.

From the observed densities of the concrete made by replacing coarse aggregate with Quarry dust, the concretes fall in category of normal weight concrete. Based on the Pearson's correlation coefficients gotten from the experimental data, there is a strong positive relationship between the Density and the Compressive Strength of concrete. This suggests that as the density increases with the compressive strength.

The main foreseen benefits of the utilization of quarry dusts as partial replacement of coarse aggregates in concrete is the relative ease of inclusion as opposed to batching them separately as fine aggregates. They are produced from the production of coarse aggregates and could better be included, transported, and batched as coarse aggregates. This promises to be a more sustainable option, which will preserve the global natural resource base as well as save construction costs significantly.

It is recommended, therefore, that quarry dust be batched into concrete mixes as partial replacement of gravel instead of fine aggregates as recommend by most researchers. Crushing of concrete test cubes before placing such for the main structures is very necessary. This will give information about the target compressive strength from such a mix, as the variations in Portland cement brands can affect the final performance of the concrete members.

V. Further Studies

Investigation into the properties of different brands of Portland cement that would result in variations in concrete strength performance is recommended for further studies.

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