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Geotechnical Evaluation of Quarry Dust Suitability as Construction Material in Abuja and Environs

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Abstract

The geotechnical properties of quarry dust (mechanical sand) from parts of Abuja and environs have been evaluated with the aim of assessing their suitability and comparative advantage over river sand in the construction. Grain size distribution, water absorption, specific gravity and compaction tests were carried out on fifteen (15) quarry dust samples using the American Society for Testing and Materials (ASTM) recommendations while compressive strength tests were conducted on hollow blocks made from quarry dust and river sand from the study area using the Portland Cement Association recommended percentages of concrete aggregates and ordinary portland cement. Rockcrete was manufactured using cement, quarry dust and rock chips in the ratio 1:2:4 and water to cement ratio of 6:10 respectively while sandcrete was manufactured using cement and river sand in the ratio 1:6 and water to cement ratio of 6:10 respectively. Grain size evaluation revealed compositional averages of sand (64.75%), gravel (27.39%) and silt (7.86%). Further evaluation of samples revealed an average water absorption of 0.96% and specific gravity of 2.60g/cm^3. Compaction test revealed average maximum dry density (MDD) of 2.1g/m^3 and optimum moisture content (OMC) of 6.99%. The average compressive strength of sandcrete hollow block was 0.7N/mm, 1.4N/mm, and 1.7N/mm while rockcrete hollow block showed average compressive strengths of 1.6N/mm, 2.1N/mm, and 2.3N/mm after 7, 14, and 28 days of curing respectively using ordinary portland cement. Taking study findings into consideration, quarry dust from the study area is recommended for the production of rockcrete hollow blocks using the Portland Cement Association recommended percentages of concrete aggregates and ordinary portland cement. Stakeholders in the construction sector are encouraged to use rockcrete hollow blocks due to its strength, durability, lower capillarity, and minimal humus content for growth of organics over sandcrete hollow blocks especially in the erection of high rising buildings as a strategy in addressing some structural failures arising from poor constructional materials in Nigeria.

Keywords: *Quarry dust, Abuja, Geotechnical Properties, Rockcrete, Sandcrete, Hollow Blocks.*

Introduction

Quarry dust, also referred to as mechanical sand is defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks from quarries to form fine particles with less than 4.75mm diameter. Out of the different quarry wastes, quarry dust is produced in abundance; making up about 25% of the output of each crusher unit (Sarvade and Nayak, 2014).

The African region is full of raw materials suitable for efficient satisfaction of local needs, yet the construction sector is not making optimal use of these materials (Ramachandran, 1983). Escalating population growth in Africa with Nigeria toping the list, has led to increased demand for construction materials to meet both housing and transportation needs. The overuse and dependence on river sand as the popular choice of fine aggregate for construction has led to environmental concerns and a concomitant price increase. This can be solved by replacing river sand with quarry dust in concrete. Fine aggregates reduce excess voids in the concrete mix while coarse aggregate and rods provide improved load bearing capacity. This concept has been used successfully in recent times in the production of hollow blocks usually referred to as "Rockcrete" with 4/8" rock chips augmenting the gravel ratio in quarry dust while the term "Sandcrete" was used for conventional river sand blocks made exclusively from sand sized grains. Quarry dust has been proposed as an alternative to river sand that gives additional benefit to concrete as it is known to increase the strength of concrete over concrete made with equal quantities of river sand, thou it causes a reduction in the workability of concrete (Ukpata et al*.,* 2012).

Location and Accessibility

Abuja, Nigeria's capital city is strategically located at the middle of the country. The Federal Capital Territory has a land area of 8,000 square kilometres. It is bounded on the north by Kaduna state, on the west by Niger state, on the east and south-east by Nasarawa state and on the south-west by Kogi state. Abuja falls within latitude 7° 25' and 9° 20' north of the equator and longitude 5° 45' and 7° 39' east. The topography of Abuja is varied with the lowest elevation located at the extreme south-west floodplains of the River Gurara (76 m above sea level) while the highest elevation is located at the north-east highlands with many peaks above 760 metres above sea level. Fifteen sample locations were selected for this study (Table 1) spread around Abuja and environs.

Table 1: Summary of sample locations and name of quarry

S/N	Coordinate	Quarry Name	Sample Name
1	09°08'54.4" 007°28'54.4"	ICC Quarry	TOM 1
2	9°08'54.9" 007°28'35.5"	Arab Contractors Quarry	TOM 2
3	09°10'45.4" 007°30'60.9"	Perfect Stone Quarry	TOM 3
4	09°09'56.6" 007°30'01.7"	Leenford Quarry	TOM 4
5	09°08'12.3" 007°29'06.5"	Julius Berger Quarry	TOM 5
6	09°10'50.4" 007°22'41.6"	Istanbul Concrete LTD.	TOM 6
7	09°11'20.0" 007°22'38.3"	Venus Quarry	TOM 7
8	09°12'46.2" 007°23'58.8"	CGC Quarry	TOM 8
9	09°12'26.8" 007°24'26.3"	SCC Quarry	TOM 9
10	09°09'42.2" 007°18'39.3"	Zebercerde Quarry	TOM 10
11	09°05'55.7" 007°14'53.6"	Dantata & Sawoe	TOM 11
12	08°57'09.3" 007°24'17.8"	Tigong Quarry	TOM 12
13	08°55'04.4" 007°25'51.3"	Pioneer Quarry	TOM 13
14	08°55'04.4" 007°17'22.4"	DiaJinJia Quarry	TOM 14
15	08°55'51.4" 007°17'46.3"	Granite & Marble Ltd.	TOM 15

Literature Review

In most villages, mud and clay materials are still used as construction materials with their acceptability as last alternative for the poor with high levels of inefficiency, especially in areas of high flooding potential (Nwanga, 2005). In urban settlements however, sands serve as the most acceptable aggregate for both concrete slabs and block making. Shanker and Ali (1992) studied the engineering properties of quarry dust and reported that quarry dust can be employed as alternative material to river sand in concrete based on grain size analysis. Rao and Anda (1996) discovered improved compaction characteristics of rockcrete consisting of quarry dust and coarse aggregate (rock chips) over river sand moulds (sandcrete). Soosan et al. (2001) observed that quarry dust exhibit high shear strength which improves the geotechnical properties of moulds in which they are employed. Nisnevich et al. (2003) confirmed the acceptance and utilization of quarry rock dust as building material in industrially advanced countries of the west for the past three decades based on its geotechnical properties. Ilangovan et al. (2008) carried out a comparative study of the physical properties of quarry dust and natural sand in India. His findings revealed that quarry rock dust posses higher relative bulk density as well as fine particles less than 0.075mm which act as filler matrix in moulds. This, he attributed to have resulted in a 10-12% improved strength property of rockcrete over the convectional sandcrete moulds. Hameed and Sekar (2009) demonstrated that rockcrete made from quarry dust are of higher advantage than sandcrete moulds in water logged areas due to lower capillary action and minimal humus content for growth of organics. Research had shown that quarry dust can be advantageously used in reinforced earth retaining walls, reinforced soil beds and reinforced flexible pavements as a fill material due to its stability, free draining nature and good frictional characteristics with synthetic reinforcement (Satyanarayana et al., 2013). The choice of quarry dust as replacement for sand has also been supported by Manassa (2010) showing up to 20% of sand being effectively replaced by quarry dust in traditional concrete.

The quantity of quarry dust varies from site to site, depending on many variables including rock type, the size of the operation, the extraction process and available outlets for the material (Ghazireh et al., 2011). The geology of the study area is generally classified as basement complex comprising gneisses, migmatites, granites, schists, phyllites and quartzites (Fig. 1). The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). According to Obaje (2009), these rocks may have been modified by at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African cycles (600 Ma). The first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization.

The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by faulting and

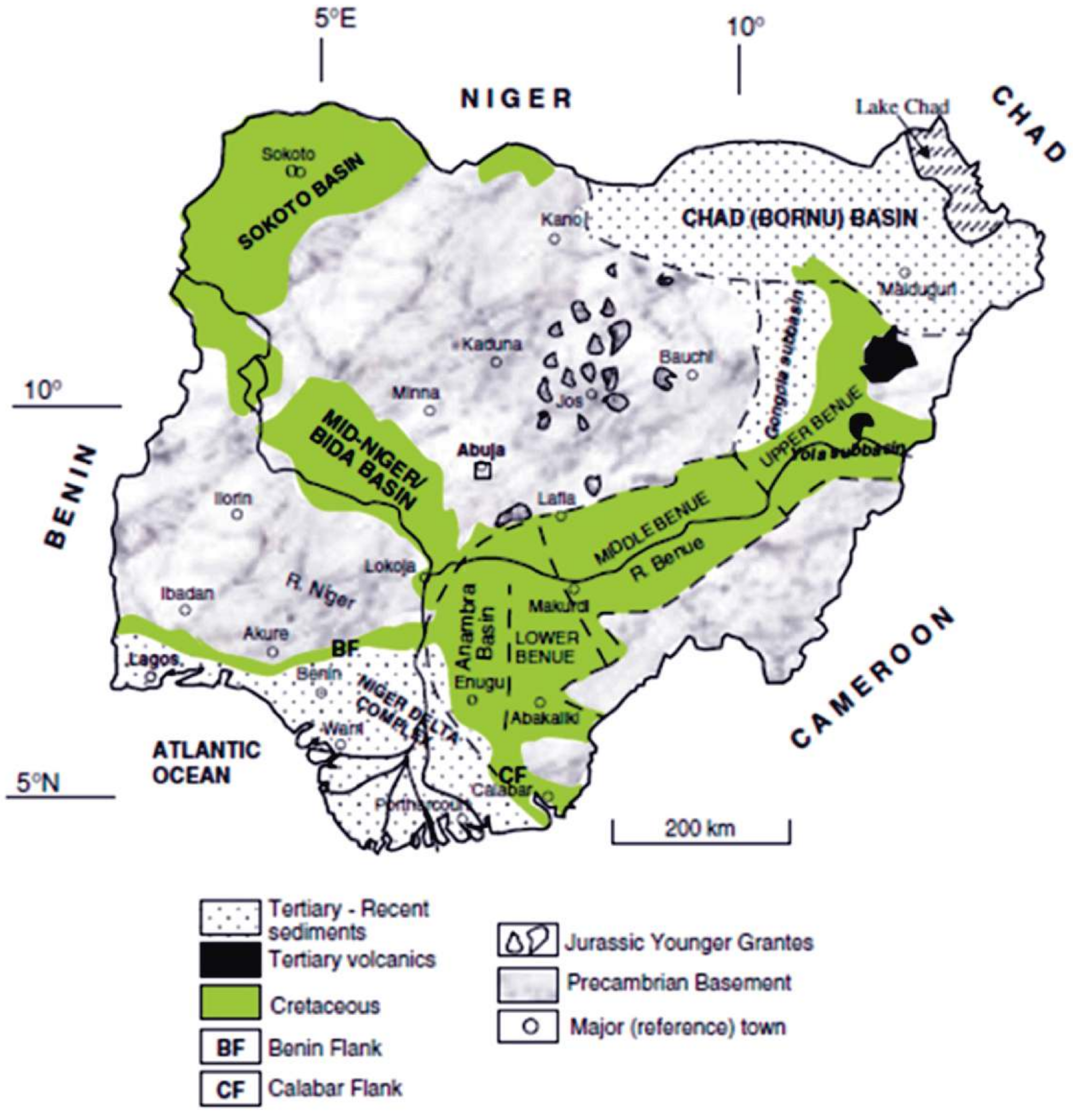

Fig. 1: Geologic map of Nigeria showing the study area (After Obaje, 2009)

fracturing (Gandu *et al*., 1986; Olayinka, 1992). The fore-listed cycles of intense deformation may have affected the mineralization and structural properties of basement rocks in northcentral Nigeria.

Methods of Study

The scope of study comprises geotechnical evaluation of the suitability of quarry dust as construction material in Abuja and environs while the adopted methodology comprises:

Geologic Fieldwork and Sample Collection

Fifteen samples were collected from identified sample locations (quarry sites) and labelled appropriately (Table 1).

Preparation and Analysis

Collected samples were prepared for laboratory analysis using guidelines of the American Society for Testing and Materials (2012). These analysis include grain size distribution, specific gravity, water absorption, optimum moisture content (OMC) and maximum dry density (MDD) determination from compaction tests. Compressive strength test was also carried out on hollow blocks made from the samples (both rockcrete and sandcrete) cured for seven (7), fourteen (14) and twenty eight (28) days using ordinary portland cement. Rockcrete produced for this study was made with the Portland Cement Association (2006) recommended standard concrete mix ratio of 6% air, 10% cement, 16% water, 26% fine aggregate and 42% coarse aggregate.

For quality control, concise and uniform representative of samples collected were used for the analysis. This was achieved by using a jig jaw device. Other controls include the use of clean and uncontaminated sample bowls, avoiding contamination from touching different samples with unwashed hands, and observing error due to parallax in equipment reading.

Data Analysis and Interpretation

Data generated from the fore-mentioned analysis were analysed using Microsoft Excel and Microsoft PowerPoint softwares. Graphic illustrations were presented and discussed in relation to referenced standards.

Results and Discussions

Geology

The study area is underlain by Precambrian rocks of the Nigerian Basement Complex, which generally comprise the Migmatite-Gneiss Complex and the Older Granites. Specific mapped rock units in the study area comprise biotite granite, quartzite-quartzy schist, banded gneiss-biotite gneiss and migmatite (Fig. 2). The rocks in the area have witnessed fracturing and faulting arising from the Pan African orogeny. Veins extending significant distances were mapped generally trending NE-SW. It is to note that quarry sites in the study area were predominantly situated on gneiss and granites.

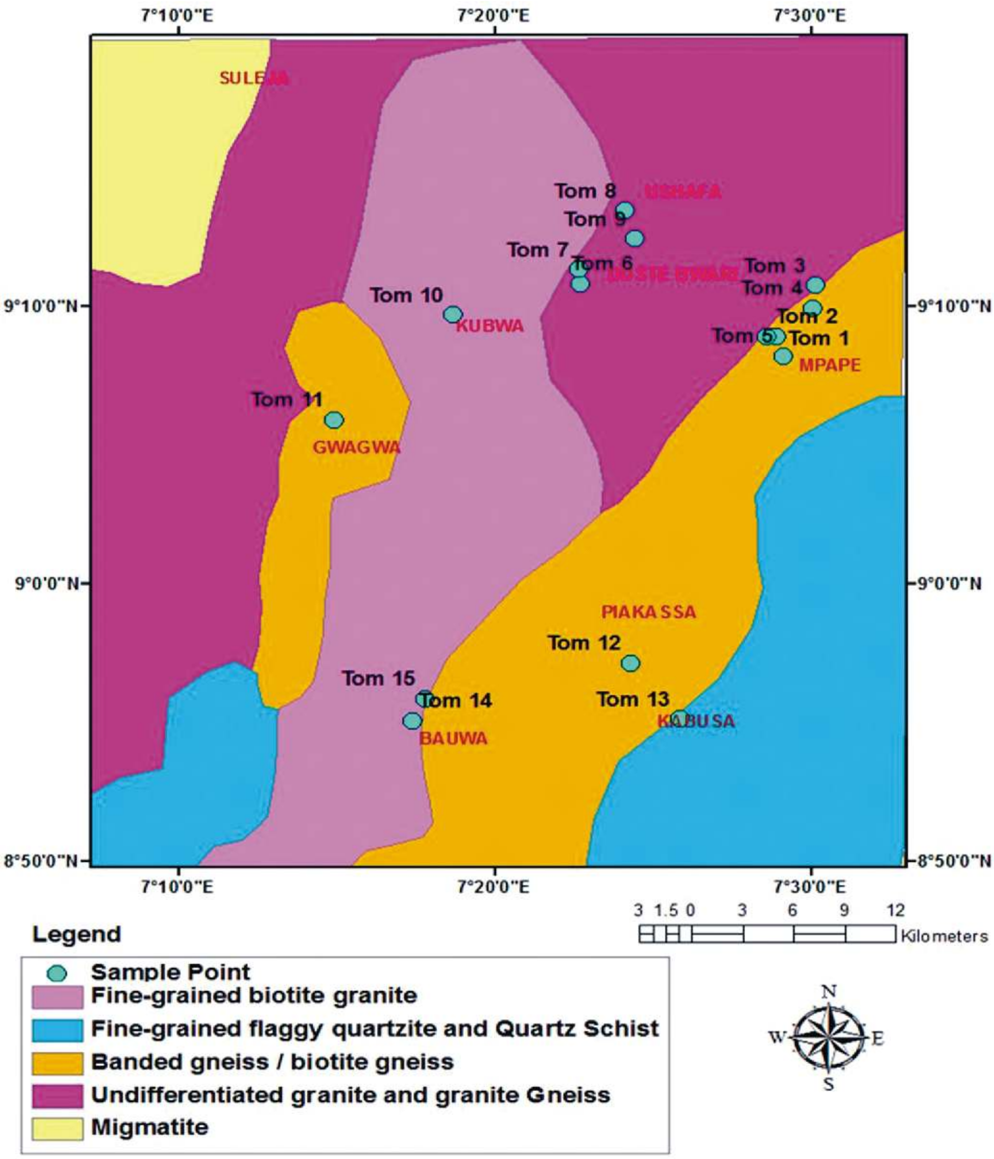

Fig. 2: Geological map of the study area showing sample locations.

Geotechnical Analysis

Results from geotechnical analysis of study samples are presented in Table 2-3 and interpreted in Fig. 3-8 below.

Water Absorption

Water absorption analysis of samples from the study area showed an average of 0.96% with TOM 6 and Tom 14 having the highest and lowest values of 1.207% and 0.759% respectively (Figure 3).

The water available in a concrete mix affects the workability of the batch. If the water content of the concrete mixture is not kept constant, the water-cement ratio will vary from batch to batch affecting other properties, such as the varying compressive strength and workability from batch to batch. The average water absorption value for quarry dust from the study area is 0.96% which falls within the A.A.S.H.T.O recommended range of 0.2% to 2%. Workability is one of the physical parameters of concrete which affects the strength, durability and the appearance of the finished surface.

Specific Gravity

Specific gravity evaluation of quarry dust samples from the study area revealed an average of 2.60g/cm^3 with sample locations TOM 11 and TOM 14 having the highest and lowest specific gravity values of 2.676g/cm^3 and 2.454g/cm^3 respectively (Figure 4).

Table 2: Geotechnical properties of samples from study area

S/N	Sample Name	Water Absorption (%)	Specific Gravity (G/M^3)	Grain Size Distribution			Compaction	
				GRAVEL (%)	SAND (%)	SILT (%)	OMC (%)	MDD (G/M^3)
1	TOM 1	0.836	2.547	31.37	60.38	8.25	7.3	2.10
2	TOM 2	0.903	2.592	26.12	67.23	6.65	7.6	2.12
3	TOM 3	0.790	2.570	22.94	70.24	6.82	6.6	2.09
4	TOM 4	0.826	2.623	33.53	57.24	9.23	7.7	2.11
5	TOM 5	1.048	2.581	25.68	63.16	11.16	7.5	2.00
6	TOM 6	1.207	2.659	28.87	65.11	6.02	7.8	2.11
7	TOM 7	1.139	2.664	29.98	62.91	7.11	6.2	2.12
8	TOM 8	0.993	2.653	27.40	63.13	9.47	7.0	2.14
9	TOM 9	0.804	2.657	28.72	60.48	10.80	6.3	2.11
10	TOM 10	0.907	2.548	31.91	60.63	7.46	7.3	2.12
11	TOM 11	0.974	2.676	18.63	72.35	9.02	7.4	2.15
12	TOM 12	1.203	2.551	23.76	71.77	4.47	7.0	2.09
13	TOM 13	1.065	2.662	20.87	72.05	7.08	6.4	2.13
14	TOM 14	0.759	2.454	28.08	62.05	9.87	7.4	2.10
15	TOM 15	0.913	2.596	32.93	62.56	4.51	5.3	2.13

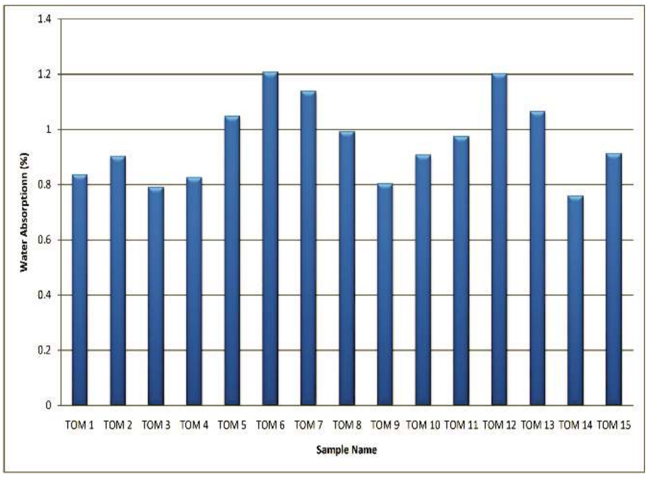

Fig. 3: Water absorption of study area samples

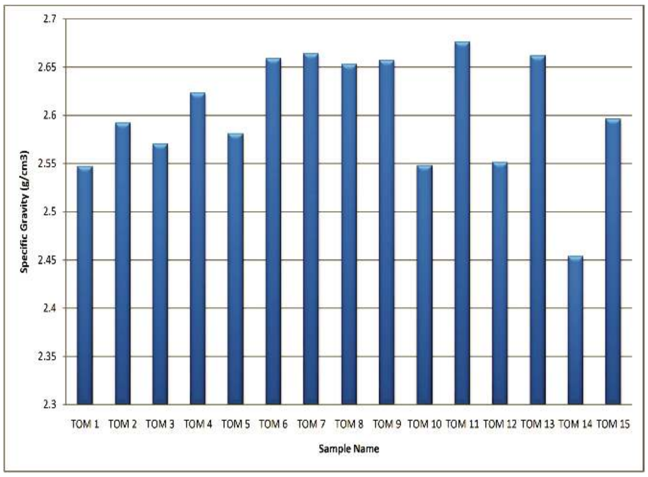

Fig. 4: Specific gravity of study area samples

The average specific gravity of the study samples fall within the A.A.S.H.T.O recommended range of natural construction aggregates of 2.60 g/cm^3.

Grain Size Distribution

Grain size evaluation of quarry dust from the study area revealed compositional averages of gravel (27.39%) sand (64.75%) and silt (7.86%) (Figure 5). Sample TOM 4 showed the highest percentage of gravel size aggregate (33.53%) while TOM 11 and TOM 5 showed the highest percentage of sand and silt sized aggregate of 72.35% and 11.16% respectively.

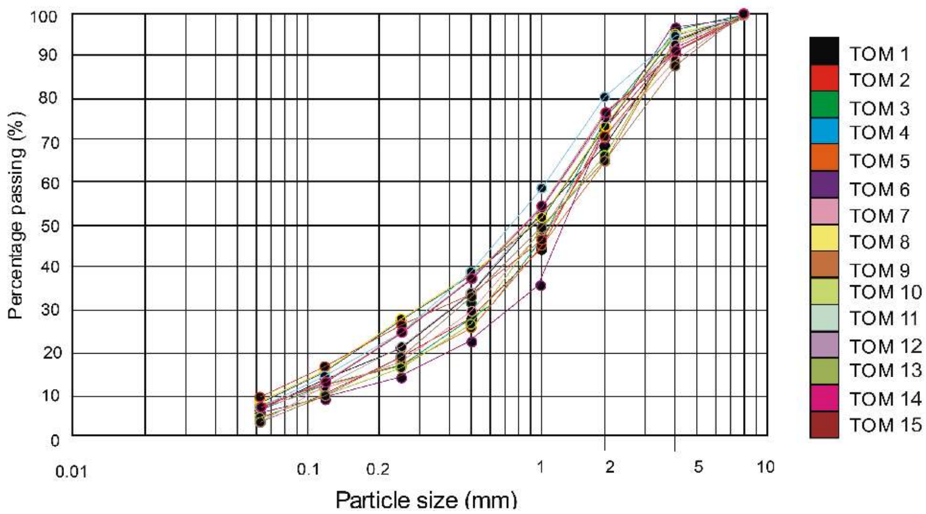

Fig. 5: Grain size distribution chart of quarry dust samples from study area

Morphological and grain size evaluation of river sand and quarry dust revealed that river sand contain mostly sand sized particles which are somewhat round shape, with insignificant amounts of silt whereas quarry dust posses rougher, more irregularly shaped particle shape with more silt sized particles. The average percentage of fines passing 300 µm (No. 50 sieve) from samples in the study area is 25.8%. This falls within the A.A.S.H.T.O recommendation of 5% - 30%. These morphological and geotechnical properties of quarry dust enable good stability, free draining and good frictional characteristics with synthetic reinforcement as seen in compression test.

The disadvantage of quarry dust grain size distribution is the fact that it cannot be used exclusively for the production of efficient moulds because it does not always conform to the Portland Cement Association recommendation for aggregate percentage in concrete. This can be taken care of by the introduction of rock chips to augment the coarse aggregate percentage in concrete.

Compaction Test

Results drawn from compaction test revealed average optimum moisture content of 6.99% and average maximum dry density of 2.11 g/m^3. Sample TOM 6 has the highest optimum moisture content of 7.8% while sample TOM 8 has the highest and maximum dry density of 2.14g/m^3 (Figure 6 and Figure 7).

Compressive Strength Test

Compressive strength test was carried out on sandcrete and rockcrete with geological materials from the study area after 7, 14 and 28 days of curing. Results are presented in Table 3 below.

Compressive Strength Test

Compressive strength test was carried out on sandcrete and rockcrete with geological materials from the study area after 7, 14 and 28 days of curing. Results are presented in Table 3 below.

Test on sandcrete revealed that 7 days moulds posed average compressive strength and density of 0.7N/mm^2 and 117 Kg/dm^3 respectively. Samples cured for 14 days posed average compressive strength and density of 1.4 N/mm^2 and 110 Kg/dm^3 while those cured for 28 days posed average compressive strength and density of 1.7 N/mm^2 and 108 Kg/dm^3 respectively as illustrated in Figure 8.

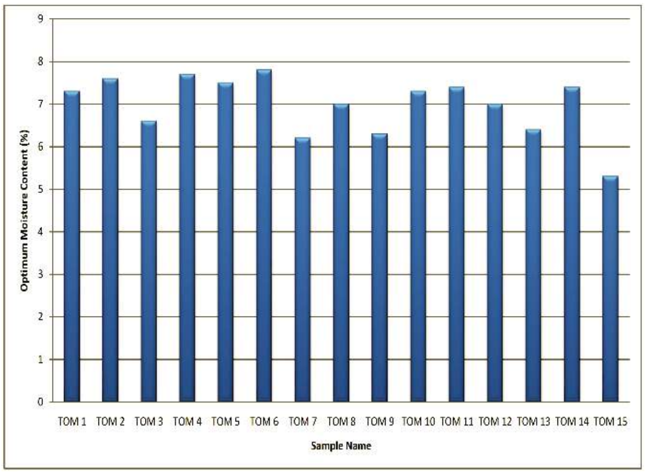

Fig 6: Optimum moisture content of study area samples

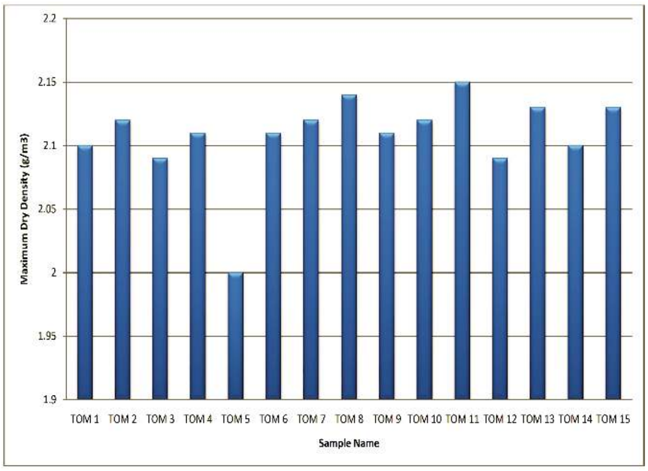

Fig. 7: Maximum dry density of study area samples

Table 3: Compressive strength result of sandcrete and rockcrete moulds from study area using ordinary portland cement.

Mould Type	Days	Average Weight (kg)	Average Density (kg/dm^3)	Average Crushed At (KN)	Average Strength (N/mm)
Sandcrete	7	17.679	117	45	0.7
	14	16.724	110	100	1.4
	28	16.375	108	114	1.7
Rockcrete	7	18.5462	122	122	1.6
	14	17.9634	118	146	2.1
	28	17.7590	117	160	2.3

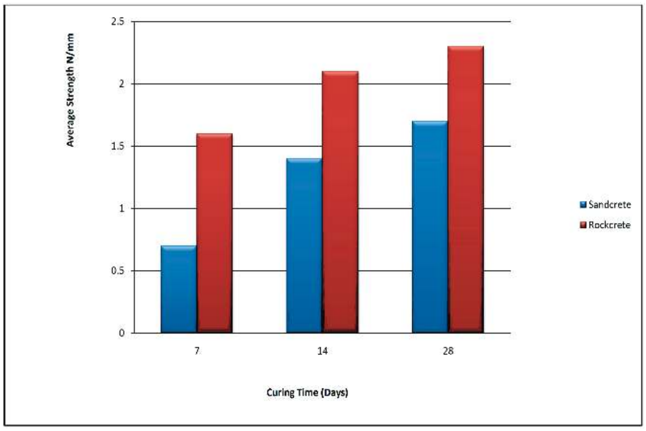

Fig. 8: Compressive strength of sandcrete and rockcrete moulds

On the other hand, test on rockcrete revealed that moulds cured for 7 days had average compressive strength and density of 1.6 N/mm^2 and 112 Kg/dm^3 respectively. Samples cured for 14 days possessed average compressive strength and density of 2.1 N/mm^2 and 118 Kg/dm^3 while those cured for 28 days had average compressive strength and density of 2.3 N/mm^2 and 117 Kg/dm^3 respectively as illustrated in Figure 8. Rockcrete hollow moulds attained greater compressive strength after curing for seven (7) days than sandcrete hollow moulds cured for fourteen (14) days (Fig. 8). This trend is also consistent for rockcrete cured for fourteen (14) days and sandcrete cured for twenty eight (28) days. This validates the comparative advantage of rockcrete over sandcrete hollow moulds in relation to stability, frictional characteristics and free drainage of individual grains in the mould. Furthermore, rockcrete do not contain humus and soil required for the sustenance of plant growth. This make them suitable for construction in water-logged areas characterized by wall wetting and algae growth.

Conclusion

Critical evaluation of the geotechnical properties of quarry dust in Abuja and environs revealed that they fall within acceptable limits for construction aggregates by the American Association of State Highway and Transport Officials A.A.S.H.T.O. Further compressive strength evaluation of hollow rockcrete and sandcrete moulds produced using the Portland Cement Association recommended percentages of concrete aggregate and ordinary portland cement revealed that rockcrete is comparatively advantageous over sandcrete hollow moulds. This was drawn from the improved compressive strength and faster curing time of rockcrete over sandcrete hollow moulds.

This can be applied as a strategy for addressing some structural failures arising from poor construction materials in Nigeria, especially in the erection of high rising buildings.

References

Abaa, S.I (1983). The structure and petrography of alkaline rocks of the Mada Younger Granit Complex, Nigeria. Journal of African Earth Sciences. Vol. 3. pp 107–113.

ASTM C 136. Standard test method for sieve analysis of fine and coarse aggregates. Annual Book of ASTM Standards, 2012.

ASTM C 1585. Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes. Annual Book of ASTM Standards, 2012.

ASTM C 231. Standard test method for air content freshly mixed concrete by the pressure method. Annual Book of ASTM Standards, 2012.

ASTM C 39. Standard test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM Standards, 2012.

ASTM C 403. Standard test method for time of setting of concrete mixtures by penetration resistance. Annual Book of ASTM Standards, 2012.

ASTM C 642. Standard test method for density, absorption, and voids in hardened concrete. Annual Book of ASTM Standards, 2012.

Black, R. (1980.) Precambrian of West Africa. Episodes 4. pp 3–8.

Gandu, A.H., Ojo, S.B., Ajakaiye, D.E (1986). A gravity study of the Precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. Tectonophysics 126:181–194.

Ghazireh, N., Ghataora, G., Chaddock, B., and Blackman, D., (2011). The use of quarry dust in road foundation materials: Performance of high dust unbound sub-base MA/7/G/6/00 Project report. Tarmac Ltd and Partners.

Hameed, M. S., and Sekar A.S.S. (2009). Properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregates. ARPN Journal of Engineering and Applied Science. Vol. 4 No. 4.

Ilangovan, R., Mahendran, N., and Nagamani, K. (2008). Strength and durability properties of concrete containing quarry rock dust as fine aggregates. ARPN Journal of Engineering and Applied Science. Vol. 3 No. 5.

Manassa J., (2010). Use of crushed granite fine as replacement to river sand in concrete. Leonardo Electronic Journal of Practices and Technologies. Issue 17.

Nisnevich, M., Sirotin, G., and Eshel, Y. (2003). Light weight concrete containing thermal power station and stone quarry waste. Magazine of Concrete Research, Vol. 13.

Nwanga, H. A. (2005). Comparative analysis of quality and cost of sandcrete blocks and blocks made with quarry dust in Ebonyi state. Post graduate thesis, Department of Building, Nnamdi Azikiwe University, Awka.

Obaje, N. G. (2009). Geology and Mineral Resources of Nigeria. Springer Verlag, Heidelberg (Germany), 240pp.

Olayinka, A.I. (1992). Geophysical sitting of boreholes in crystalline basement areas of Africa. Journal of African Earth Sci. Vol. 14: pp 197–207.

Portland Cement Association (2006). Design and Control of Concrete Mixtures EB001. P.C.A Publishers, Skokie, Illinois. Chapter 9.

Ramachandran, A. (1983). Appropriate building materials for low cost housing in Africa. A Symposium Proceeding in Nairobi.

Rao, G.T. and Anda, 1 .T. (1996). A Study on behaviour of concrete with stone sand replacing river sand. National Conference on Alternate Construction Materials in Civil Engineering, Hamirpur.

Sarvade, P.G. and Nayak, S. (2014). Studies on the utilization of quarry dust to improve the geotechnical properties of lithomargic clay. International Journal of Advanced Structures and Geotechnical Engineering, Vol. 03, No.1.

Satyanarayana, P.V.V., Raghu, P., Kumar, R.A., and Pradeep, N. (2013). Performance of crusher dust in high plastic gravel soils as road construction material. Journal of Mechanical and Civil Engineering. Vol. 10, No.3.

Shankar, N.B. and Ali, M.D. (1992). Engineering properties of rock flour. National Journal on Cement and Building Materials from Industrial Waste.

Soosan, T.G., Jose, B.T. and Abraham, B.M. (2001).Use of crusher dust in embankment and highway construction. Proceedings of Indian Geo-Technical Conference, Indore.

Ukpata J. O., Ephraim M. E. and Akeke G. A. (2012). Compressive strength of concrete using lateritic sand and quarry dust as fine aggregates. ARPN Journal of Engineering and Applied Science. Vol.7. No.1.