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Engineering Properties of Jakura Marble and Its Suitability for Tiles Production

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Abstract: *Twelve representative marble samples were collected from Jakura and environs and tested for specific gravity, density, compressive strength, porosity, flexural strength, hardness water absorption, soundness or durability and Los Angeles Abrasion to ensure its suitability for use in the production of tiles. The flexural strength, hardness and compressive strength shows its high resistance to crushing and bending effects while the specific gravity and density values proves its ability to bear the impact of the objects that will be placed on it. The soundness and water absorption values makes them suitable for flooring and outdoor cladding due to its resistance to weathering and thawing because of its low rate of water absorption.*
Keywords: *Tiles, Compressive strength, Porosity, Flexural strength, Water absorption.*

I. Introduction

Nigeria, a nation that is blessed with abundant mineral resources has marble reserves put in excess of 5 billion tons of proper, indicated and inferred categories including Jakura marble [1] Despite this abundant reserve, not very much of the country's marble has been properly utilized. This is partly due to lack of comprehensive and reliable geotechnical, geochemical, mechanical and physical data on the marble deposits, which are very important to the choice of any deposit for a particular purpose [2].The exploration for marble started in the year 1970 [3].The Occurrence and exploration of variety of marble deposits found within the Nigerian Basement terrain e.g Burum-Takalafia in the Federal Capital Territory (F.C.T), Abuja; kwakuti in Niger State; Etobe Ajaokuta and Jakuti in Kogi State; Ukpilla in Edo State and Igbetti in Oyo State; Ukpilla in Edo State and Elebu in Kwara State have been studied by many researchers and authors ([1], [4], [5], [6]and [7]). These deposits have various morphologies within the Schist belts and exhibit different physico-chemical characteristics that render them economically attractive.

Jakura Marble deposit located in Kogi state, North Central Nigeria (fig. 1) about 40km along Okene – Lokoja road (Obajana) has been worked mainly for decorative purposes, by Jakura Marble Company. Due to its granular size, extent and purity it also has a potential value in the cement and steel industries. Hence, Dangote Cement Company Obajana has built a factory and is currently working on the deposit located about 7.5km from the Obajana village producing 10.25 million tons per annum as the largest cement factory in Sub – Saharan Africa. Understanding the mineralogy, grain size, texture and weathering states which could be related to the geological processes that form the rock also help in assessing the rock as dimension stone hence determining the rock's suitability and availability for production [8]. For a rock to be considered for dimensional stone such as tiles production, the interlocked grain boundaries will be an important property in economic evaluation of the rock. Marble with high tensile and compressive strengths indicates absolute resilience and durability properties [9]. Marble has numerous applications for structural and decorative purposes.

It is utilized for outdoor sculpture, external walls, floor covering, decoration, stairs, and pavements. The majority of prehistoric monuments were made of marble. Marble has decorated the corridors of palaces and historical places e.g Taj Mahal Palace in India. Marble tiles cover the floors of the affluent and also beautifies the walls of moderate home owners. However, not much has been done in the application of Nigeria's marbles for the manufacture of tiles. Recently, the giant stride taken by the Federal Government of Nigeria by way of placing embargo on the importation of readily finished products in other to give room for the local production at this period is a palpable indication that the production of tiles from marble is a huge area of opportunity to be explored.

Although, the Jakura marble is currently being exploited for cement production, there are however inadequate geotechnical data on the marble for other functional utilization. Hence, the need to investigate the mechanical/engineering potential of the Nigeria marbles and its suitability for industrial application for tiles production and monumental purposes.

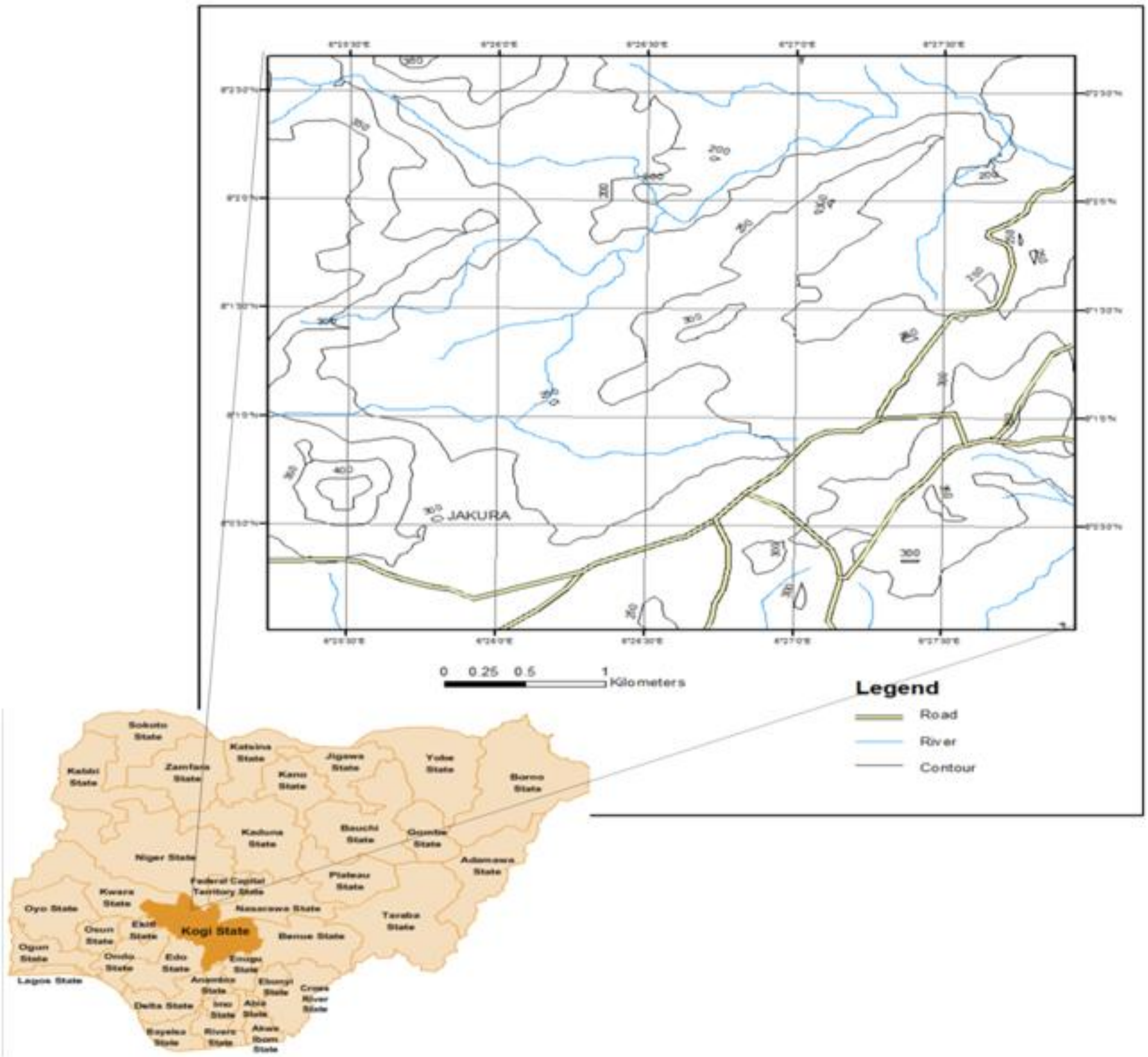

Fig. 1: Map of Nigeria showing the study area.

II. Geology

Marble bodies are widely distributed within the Precambrian Basement Complex of Nigeria and are commonly associated with the Schist Belts which may be regarded as folded belts (perhaps initially protobasins) into the multiple deformed and variable metamorphosed migmatite-gneiss-quartzite complex [10]; [11] and [12]. Associated with these major petrological units are other localised minor rocks units namely: Quartz-biotite gneiss, Quartz-biotite-hornblende-pyroxene gneiss and Quartz-biotite-garnet gneiss. These igneous rocks occur as small, circular to oval outcrops and include members of the older granite suite mainly granites, granodiorites and syenites while associated schists in the area are: quartz-biotite schist, amphibolite schist, muscovite schist and quartzitic schist [13].

Marble, a metamorphosed limestone occurs within the migmatite gneiss- schist-quartzite complex as relicts of sedimentary carbonate rocks.The marble have roughly NE-SW trend and thinning out in the South-Western direction (Fig.2). The marble is grey-pure white in colour, medium to coarse grained (mosaic texture with increase in depth) in nature with few mica specks. In some places, mica schist and granulite intrude the marble. The marble is overlain by an average thickness of 6.83 meters of overburden, which appears to be red sandy clay and marl clay. The stratigraphic succession of the area consists of magmatic intrusion of older granite series, folded meta-sediments of Igarra-Kabba-Jakura formation and gneissic complex.

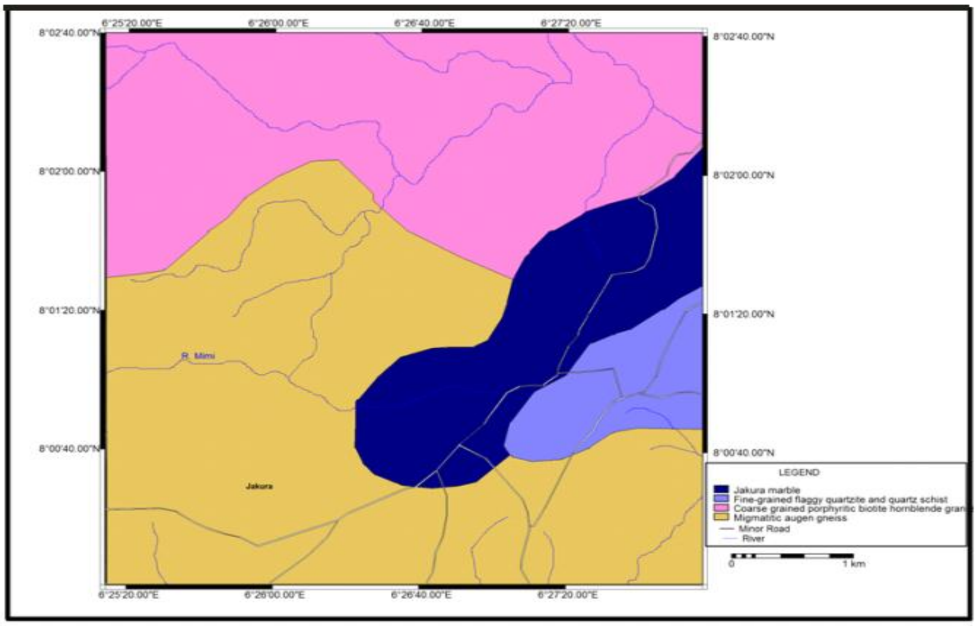

Fig 2: Geological Map of the study area

III. Materials And Methods

Twelve representative marble samples from Jakura and environs as shown in fig. 3 were collected and tested for specific gravity, density, water absorption, uniaxial compressive strength, hardness, soundness, flexural strength and Los Angeles abrasion. The procedures for the determination of these parameters are discussed below:

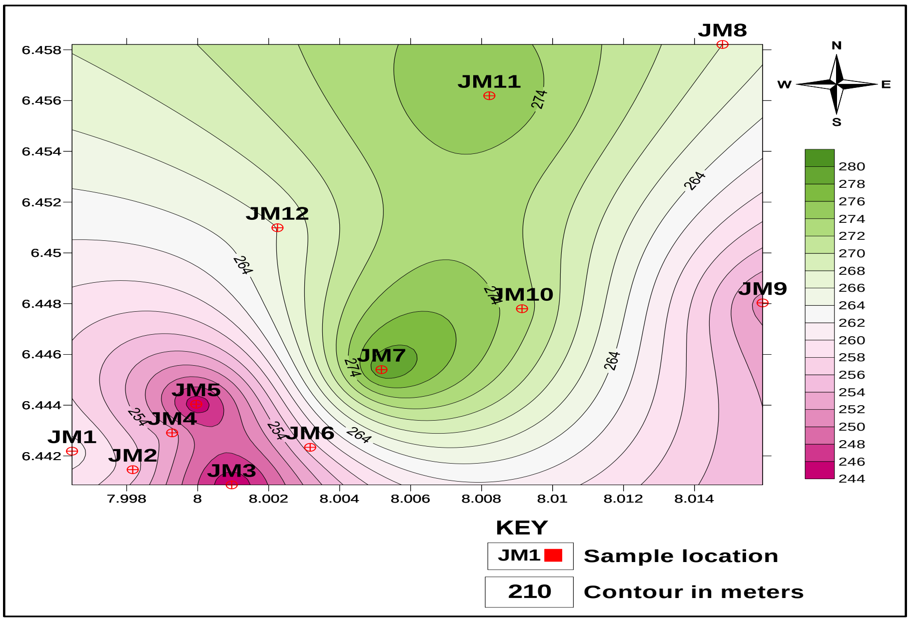

Fig. 3; Map of the study area showing the sample location points

3.1 Specific Gravity

The Bulk or Apparent specific gravity, G_b is the ratio of the dry weight, $\mathbf{W}_d$ of a rock to the weight, W of water equal to the total volume of rock including voids. The rock sample was dried for 24 hours in an oven at a temperature of 105^{0}C to expel all water present in the rock sample. It was allowed to cool and the dry weight, **W**d determined. The rock sample was completely immersed in water to enable it attained saturation for 48 hours and the saturated weight **W**w was measured and recorded. The rock sample still in a soaked condition was weighed (**W**s) while suspended in water. This can be mathematically represented as:

$$G = \frac{Wd}{Ww - Ws}$$

The essence of heating and then saturating is to determine the amount of water in the pore spaces of the sample.

3.2 Density

The density of the rock sample was determined by multiplying the specific gravity, G with the density of water. Therefore, the rock sample density was calculated as follows:

$$\rho = G\rho w = 1000G\ (Kg/m^3)$$

Where ρw is the density of water =1000Kg/m^3

3.3 Porosity

The sample was dried to a constant weight at a temperature of 105°C in an oven and cooled for 30 minutes in a desiccator. The porosity n, was determined by dividing the volume of water filling the pores (Ww-Wd) by the total volume of the rock sample, v. This is expressed in percentage as follows:

$$n = \frac{Ww - Wd}{v} \times 100 \quad \%$$

3.4 Water Absorption Test

The ASTM C97 procedure was adopted where the specimens were soaked in water for 48 hours [14], wiped dry, and weighed again. The difference in weights was divided by the dry weight and multiplied by 100 to give the percentage of water absorption. This is expressed mathematically as:

$$Wsw = \frac{Ww - Wd}{Wd} \times 100$$

3.5 Uniaxial Compressive Strength

To determine the compressive strength, the sample was cut into a cube of 5cm and loaded gradually, one at a time, on the base of a Universal Testing Machine (UTM). The loading was continued till the first crack appears in the test specimen indicating beginning of failure. The load at failure (F) divided by the area of cross-section (A) of the sample gave the unconfined compressive strength of the sample:

$$Co = \frac{F}{A}$$

Where Co is crushing Strength
F = Total load at failure
A = Cross sectional area

3.6 Hardness Test

N-Type Schmidt hammer with rebound measurement was used for this test. The Schmidt hammer was pointed perpendicularly on the surface of the sample. The hammer was released and reading on the hammer was taken. The reading gives directly the Schmidt hammer hardness value. The standard Schmidt hardness number is taken when the hammer was pointing vertically down.

3.7 Soundness Test

Soundness test refers to the testing of rock samples to estimate their soundness when subjected to weathering action. This was done by repeatedly immersing the samples in saturated solution of sodium sulphate (Na_2SO_4), followed by oven drying to completely dehydrate the salt precipitated in permeable pore spaces of the rock sample. This was done for 12 cycles as recommended by ASTM C88 standard. The percentage loss in weight of the sample was calculated by the ratio of the difference in the initial weight of the sample and its weight after 12th cycle to the initial weight expressed in percentage. This is mathematically expressed as follows:

$$\frac{W - W12}{W} \times 100$$

Where W = initial weight of the sample
W_{12} = Weight after 12th cycle

3.8 Flexural or Transverse Strength

The flexural strength or bend strength is referred to as the failure exhibited in a rock due to bending stresses both in structural and decorative rock. This was determined by loading transversely a bar sample of 20 × 8 × 8 cm and supported at ends from below. The load at which the sample breaks is taken as the modulus of rupture.
The flexural strength is given by:

$$R = (3_w l) / (2bd^2)$$

Where R is the flexural strength or modulus of rupture
w is the applied force at failure
l is the length of the support span
b is the sample width
d is the thickness of the sample

3.9 Los Angeles (L.A) Abrasion Test

The standard L.A. abrasion test subjects a coarse aggregate sample (retained on the No. 12 (1.70mm) sieve) to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. ASTM method C131-66 was used for the LA abrasion test.

The samples were oven-dried at 105–110°C for 24hrs and then cooled to room temperature before they were tested. After drying, the samples were sieved into individual size fractions, and recombine to one of two specified grading that most nearly represents the aggregate gradation. The total sample mass was about 5000g. Six steel spheres were placed in a steel drum along with the 5000g of aggregate sample. The drum was rotated for 500 revolutions at a rate of 30–33 rev/min. After the revolution was completed, the sample was sieved through the 1.7 mm sieve (Sieve No 12). The amount of material passing the sieve is expressed as a percentage of the original weight.

The LA abrasion loss or percentage loss was calculated as follows:

$$W = \frac{P1 - P2}{P1} \times 100$$

Where W is the abrasion loss (%)
P1 is the initial weight (g)
P2 is the weight passing through sieve no 12 (g)

IV. Results And Discussion

The results are discussed with reference to the recommended standard in the use of materials for Tiles production. The summary of the result is as shown in the table 1. Also, fig. 4 to 12 shows the variation of each test among the samples.

Table 1: Summary of the laboratory test result

Properties	JM1	JM2	JM3	JM4	JM5	JM6	JM7	JM8	JM9	JM10	JM11	JM12
App Specific Gravity	2.52	2.58	2.5	2.65	2.63	2.51	2.54	2.63	2.51	2.51	2.52	2.5
Density (Kg/m^3)	2520	2580	2500	2650	2630	2510	2540	2630	2510	2510	2520	2500
Water Absoption (%)	0.29	0..33	0.27	0.28	0.35	0.28	0.25	0.22	0.38	0.32	0.36	0.35
Void Ratio	0.0051	0.0054	0.0052	0.0054	0.0052	0.0051	0.0054	0.0053	0.0053	0.0052	0.0054	0.0054
Porosity (%)	0.51	0.54	0.52	0.54	0.52	0.51	0.54	0.53	0.53	0.52	0.54	0.54
Abrasion Value (%)	33.5	39.0	38.75	35.9	29.4	37.5	28.0	31.0	37.2	38.0	37.0	40.0
Soundness (chemical Resistance (%)	10.75	10.00	10.80	10.30	10.25	10.90	10.95	9.34	10.50	10.55	10.65	10.40
Crushing Strength (N/mm^2)	52.39	57.63	55.89	65.49	73.78	62.87	61.12	78.58	58.94	48.02	51.52	52.39
Crushing Load(kN)	120	132	128	150	190	144	140	210	135	110	118	120
Hardness Test	2.72	2.60	2.29	2.74	2.06	1.89	2.68	2.86	2.29	2.58	2.17	1.93
Flexural Strength (N/mm^2)	10.8	13.39	11.15	18.84	20.0	14.90	12.8	22.34	12.73	08.38	9.52	9.55
Colour	White											
Texture	Coarse Grained											

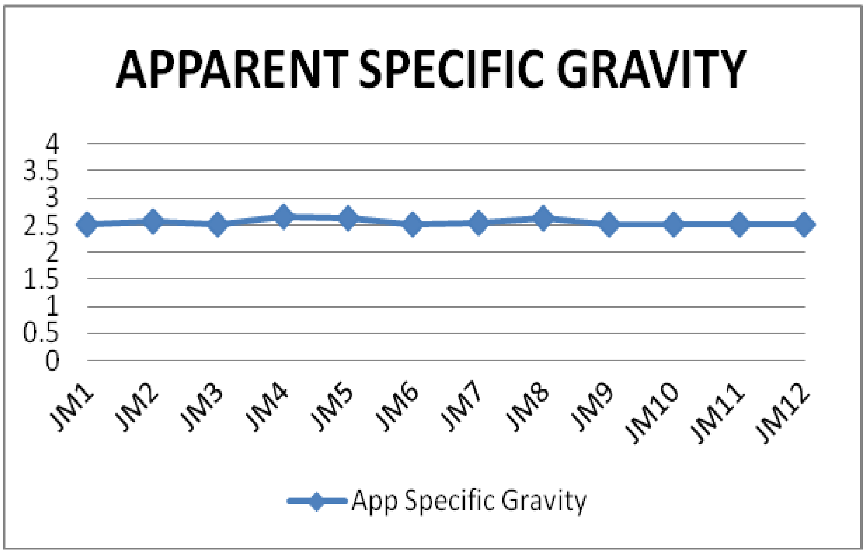

Fig. 4: A variation of Apparent Specific Gravity among the rock samples

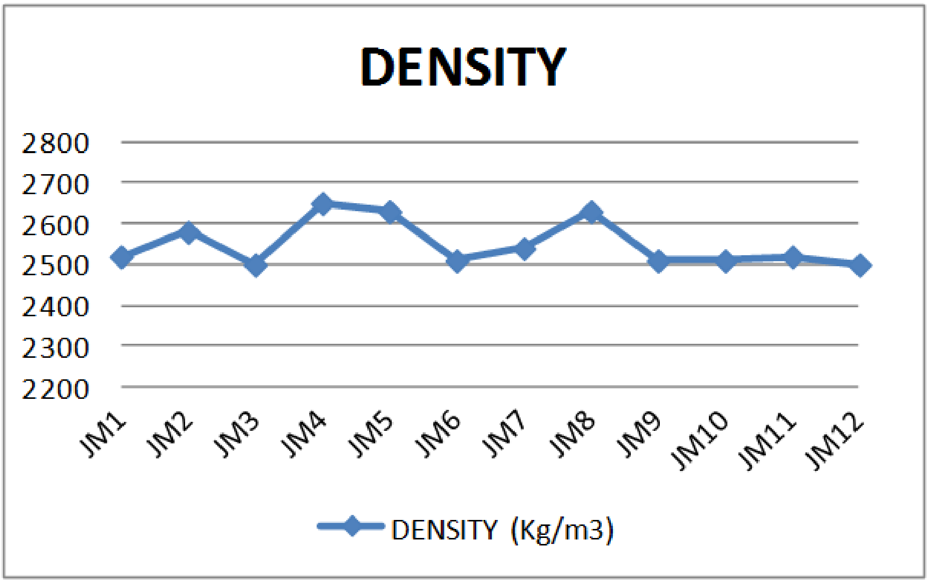

Fig 5: A variation of Density among the rock samples

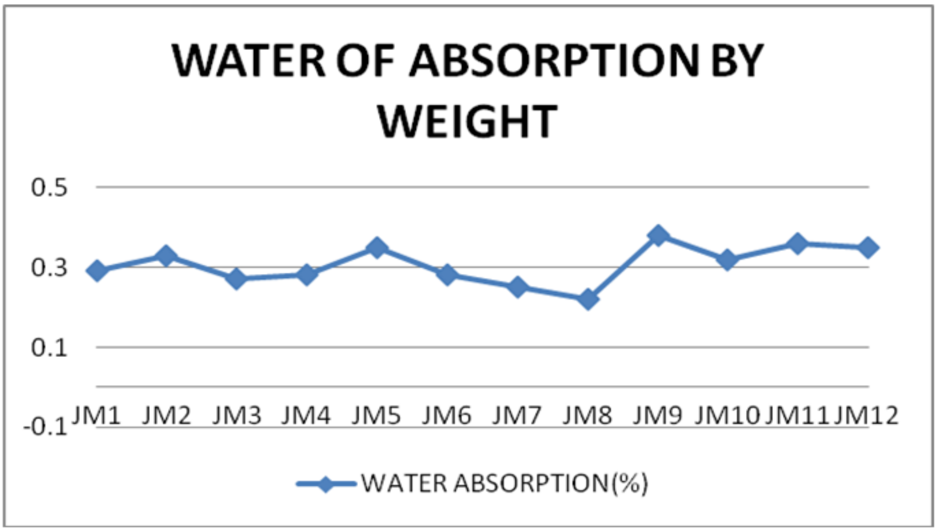

Fig. 6: A variation of Water of Absorption by weight among the rock samples

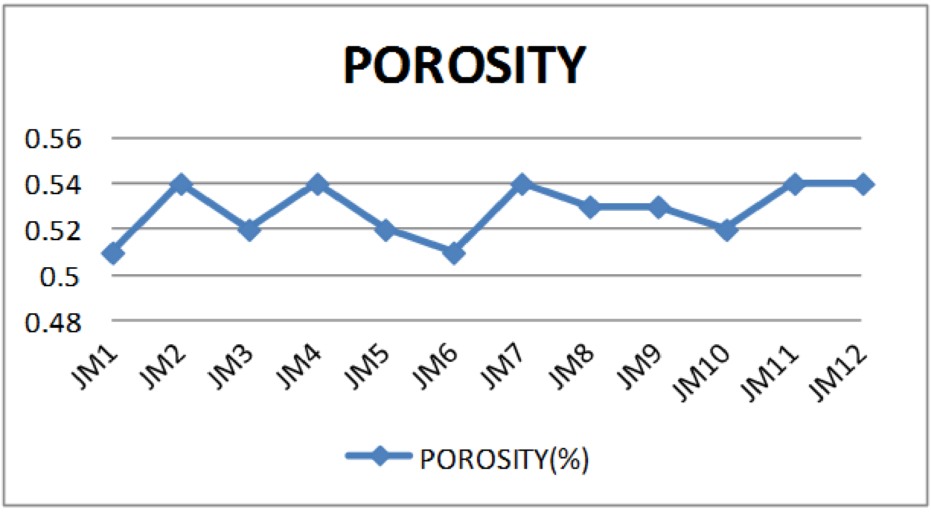

Fig. 7: A variation of Porosity among the rock samples

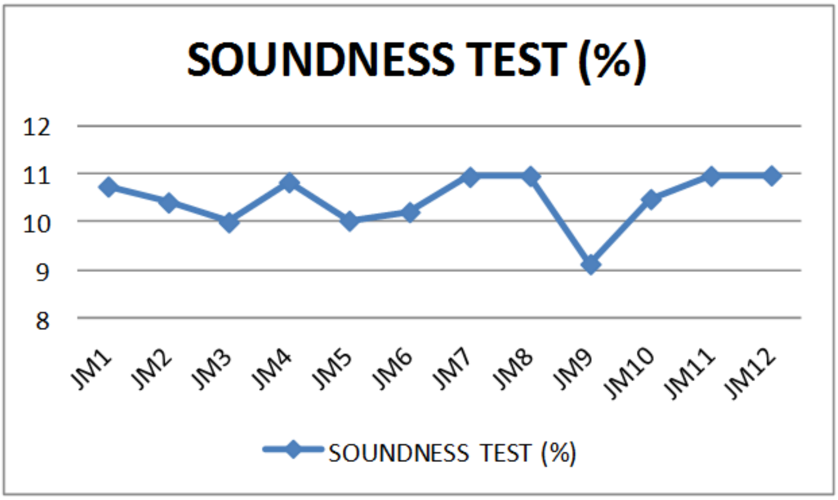

Fig. 8: A variation of Soundness Test among the rock samples

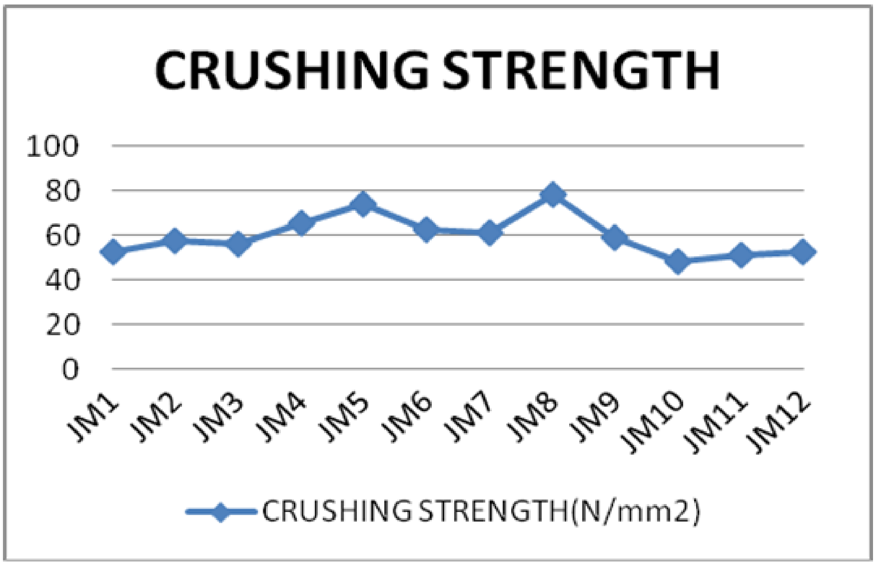

Fig. 9: A variation of Crushing Strength among the rock samples

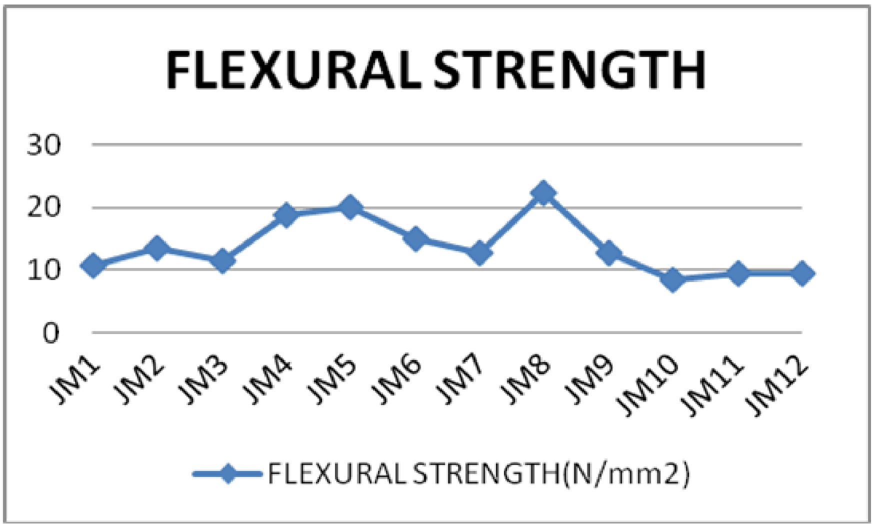

Fig. 10: A variation of Flexural Strength among the rock samples

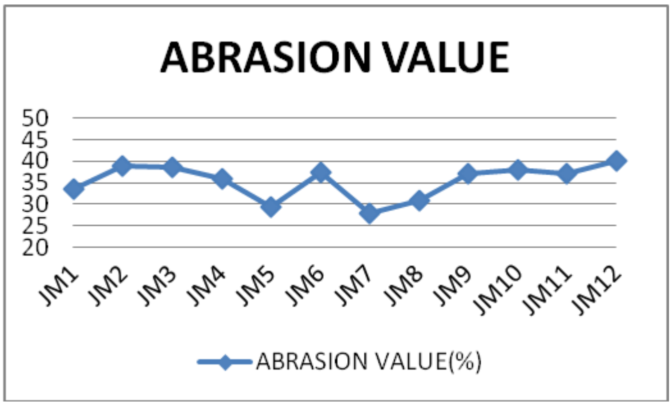

Fig. 11: A variation of Abrasion value among the rock samples

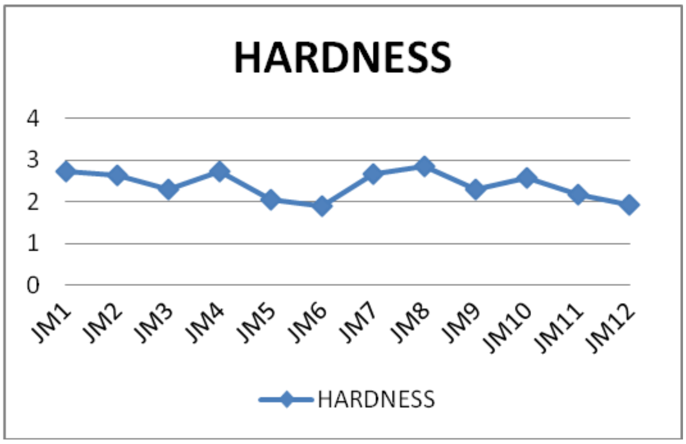

Fig. 12: A variation of Hardness Test among the rock samples

V. Discussion Of Results

5.1 Specific Gravity and Density

The bulk density is important in calculating the weight of the rock in a wall constructional element. The standard specification of ASTM 503C on the use of marble for dimension stone is put at minimum of 2600Kg/m^3. Generally, a higher density rock is probably harder, less porous and stronger. Considering the laboratory test results, the rock samples have a range of values between 2500Kg/m^3 and 2630Kg/m^3 with samples JM4, JM5 and JM8 having values above the minimum standard. All others are slightly below the minimum requirement.

5.2 **Porosity**

Porosity has a direct and indirect effect on most of the physical properties of rocks, and is often considered an important rock parameter. An increasing porosity has an unfavourable influence on the weathering characteristics.

Von Moos and Quervain (1948) developed a classification scheme for porosity of rocks as follows:

<1%	compact
1–2.5%	a few pores
2.5–5%	slightly porous
5–10%	significantly porous
10–20%	many pores
<20%	a lot of pore space

From the test results as shown on table 1 and fig. 7, the porosity values ranges between 0.51% and 0.54%. This according to [15] classification, the marbles are compact and the effect of weathering will be of little implication.

5.3 Water Absorption

From the laboratory result the absorption by weight has a range of value between 0.22 and 0.38%. The ASTM 503C standard on the use of marble for dimension stone recommends a maximum of 0.2%, therefore the laboratory results shows that only the rock sample JM8 can only be acceptable while others are of higher values. However other test result may override this effect.

5.4 Soundness Test

Soundness test is aim at measuring rocks resistance to weathering, surface abrasion, spalling freeze-thaw, durability and moisture penetration. The Los Angeles sodium sulphate test prescribes that a sample is good if the average loss in weight does not exceed 12% after 12 cycles of alternate wetting and drying. The results of the soundness test have a range of values of 9.34% and 10.95%. This indicates that the samples are good as far as soundness is concerned. The rock can therefore be used as facing stone, ornamental rocks embankment and any other use which may expose them to the atmosphere. However, where such rocks are to be used as facing stones over a long period of time in environments that are humid and laden with acids, caution must be exercised to avoid pitting of the rock surface.

5.5 Compressive Strength

[16] The International Society of Rock Mechanics (ISRM, 1978) classify rocks in the range of extremely strong to extremely weak depending on the compressive strength as shown in the table 2 below:

Table 2

Classification	Unconfined Compressive Strength (Mpa or Nmm^2)
Extremely Strong	>250
Very Strong	100 – 250
Strong	50 – 100
Medium Strong	25 – 50
Weak	5 – 25
Very Weak	1 – 5
Extremely Weak	< 1

The required value for marble according to ASTM 503C is 52MPa ($52N/mm^2$). From the laboratory result the crushing strength have a range of values between $48.02N/mm^2$ and $78.58N/mm^2$ with only rock sample JM10 having a value of $48.02N/mm^2$ which is lower than the minimum required as specified by ASTM 503C as can be seen in Table 2 and fig. 9 Therefore all other rock samples are good in the production of tiles if only the compressive strength is to be considered.

5.6 Flexural Strength

Flexural strength is a measure of the tensile strength induced by bending; it is highly affected by the stone's surface condition on the face that is in tension. The flexural strength of stone generally increases as the water absorption decreases for stones of equal grain size. From the laboratory result as shown in table 2, the flexural strength has a range of values between $8.38N/mm^2$ and $22.34N/mm^2$. These values are higher than the minimum required value in line with ASTM 503C on the use of marble for dimension stone. Therefore on the basis of flexural strength all the samples are good and acceptable.

5.7 Hardness

The hardness of a rock is its resistance to abrasion. Every rock has a hardness or range of hardness that ultimately depends on the strength of chemical bonds. Sometimes hardness is used as a strength criterion in rocks. The hardness of a mineral contained in a composite rock reflects to a certain extent the mechanical properties of a rock. The rock samples JM1, JM2, JM4, JM7, JM8 and JM11 has a Mohs' scale of approximately equal to 3.while others are approximately equal to 2.

5.8 Los Angeles Abrasion Test

Floor tiles undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities ranging from human traffic to the movement of equipment. The ASTM C1353 method utilises the Taber abraser and standardized abrading wheels; it establishes a value of abrasion resistance by determining the loss of weight resulting from abrasion on flat specimens under controlled conditions.

However, the L.A. abrasion test measures the degradation of a rock sample that is placed in a rotating drum with steel spheres .As the drum rotates the rock samples aggregate degrades by abrasion and impact with other aggregate particles and the steel. Abrasion resistance represents the resistance of the stone's surface to wear, usually caused by pedestrian traffic, the wheels of trolleys and the legs of furniture.

Therefore, a lower L.A. abrasion loss values indicate rock samples that are tougher and more resistant to abrasion. From the laboratory results as shown in table 2 and figure the abrasion test range of values is between 28% and 40% which is acceptable based on the ASTM C1353 standard.

VI. Conclusion

With the increase in demand for tiles in various building construction projects ranging from outdoor sculpture, interior and exterior cladding, floor covering, e.tc. The exploitation of Jakura marble for tiles production will be a huge developmental growth for the Nigerian economy, considering their good engineering properties as enumerated and discussed in this paper. Jakura marble is presently being worked by Jakura Marble Industry limited, Lokoja for the production of chips which are either used for terrazzo flooring or milled into powder for sale to the glass, oil, paint and steel industries. It is also being worked by Dangote Cement Company, Obajana for the production of cement. Although these uses may be profitable to the national economy, however it is suggested that processing the marble into polished tiles or slabs will be of more economical value both to the investors and the national economy especially at this time of economic recession.

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