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Investigation on the Suitability of Metamorphosed Granite in Ilorin Nigeria for Road Construction and Polished Rock

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Abstract

The suitability of metamorphosed granite for road construction and polished rock were investigated. Samples were taken from zones of Man Hardi Quarry Ilorin using random sampling method. The samples were subjected to different test namely, chemical analysis, polish value, oxidation properties, compressive strength and hardness test. The average chemical analysis shows the silica contents for samples from zones A, B and C are 67.73%, 73.62% and 72.40% respectively, specific gravity obtained are 4.52, 4.80 and 3.60 for zones A, B and C. The oxidation properties test reported, with no peeling was observed, the polish stone value (psv) test for the samples showed result of good abrasiveness and produced attractive colour; the values for zones A, B and C are 90.88, 97.36 and 93.71 while respectively compressive strength test estimation obtained were 142.37, 201.62 and 164.62 MPa for samples from zones A, B and C. The Hardness test values are 85.59, 96.84 and 88.11 respectively. Hence, the value obtained from the investigation on the suitability of metamorphosed granites for road construction and polish rock shows that they are good for road constructional and production of polished stoneworks.

Keywords: metamorphosed granite, road construction, polished rock, compressive strength, oxidation properties, polish value, chemical analysis, hardness test, suitability.

1. Introduction

Granite rocks has several physical and mechanical properties which influence their use as a construction material. They are generally used in structural and civil engineering works. The physical and mechanical properties of granites depend on their texture and mineralogy [1,2].

Granite is formed under great heat and pressure by the molten magma from depth of the earth, it is produced into large slabs and other kinds of shapes and are suppled from different parts of the world [3]. Granite is one of the hardest rocks, made up of feldspar and quartz minerals mainly, their hardness are; 6 and 9 respectively. The scale of hardness ranges from 1 to 10, the higher the number shows the harder the mineral [4].

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Polished value is a parameter which relates to the micro texture properties of an aggregate, and it can be measured in a standard manner. The Polished Stone Value of aggregate is a measure of resistance to the polishing action of vehicle tyres on rocks when they are subjected to conditions similar to those occurring on the surface of a road. The effect of road vehicle tyres on road surfaces produces polishing of the surface of exposed aggregate surface, and its state of polish is one of the principal factors which affect the resistance to skidding. This property has been related to traffic and condition of roads where granite was used for its construction [5].

The compressive strength of a rock can be defined as the maximum load per unit which it can bear without crushing. The higher the compressive strength, the bigger the load it can bear [6].

The main causes of oxidation in stone paving are porosity of the rock, the minerals it contains; some rocks i.e., granite contain some iron ore which can be brought to the surface when moisture reacts with the rock [7]. Granite rock is felsic in nature, this means that it has some relatively low specific gravities, which vary between 2.7 to 2.8, often 2.75 [8].

[9] carried out an extensive study on large number of rock samples with different types of rocks (basalt, diabase, dolomite, gneiss, granite, limestone, marble, quartzite, rock salt, sandstone, schist, siltstone, and tuff) to develop an engineering classification system for the intact rock, they discovered that classification is strongly affected by rock mineralogy, texture, and anisotropy. The consumption of natural resources has increased because of the increasing demand for their uses in recent building decoration. [10] reported that human has consumed more aluminum, copper, iron and steel, phosphate rock, diamonds, sulfur, coal, oil, natural gas, and even sand and gravel over the past century than over all previous centuries combined.

Due to ruggedness and wide distribution of granite, it has been used as a construction stone since antiquity. It was used to build some of the pyramids of ancient Egypt and temples of ancient southern India. Nowadays, granite continues to be used as a dimension stone in buildings and monuments. In addition, given its strength and aesthetic appeal, it is used for kitchen countertops and flooring tiles. Polished granite stones are also used in the team sport known as curling [11].

The study was carried out to determine the suitability of rock from Man Hardi Quarry for construction of roads and polished stone production.

2. Materials and Methods

2.1 Description of the study Area

MAN HARDI Nig. Ltd. Quarry is situated on Latitude N 008034.291′, Longitude E 0040 34.771′ in Ilorin South Local Government Area of Kwara State. The Quarry has a land area of about 4000m2 and is at about a distance of 2.4km from Kangile, the nearest village. The site overview comprises of granite deposit, and it is surrounded by thick bushes, trees and stream. A fine boundary clearance separates the mining area from the surrounding vegetation. Fig. 1 shows the map of Kwara State, Nigeria indicating the studied site.

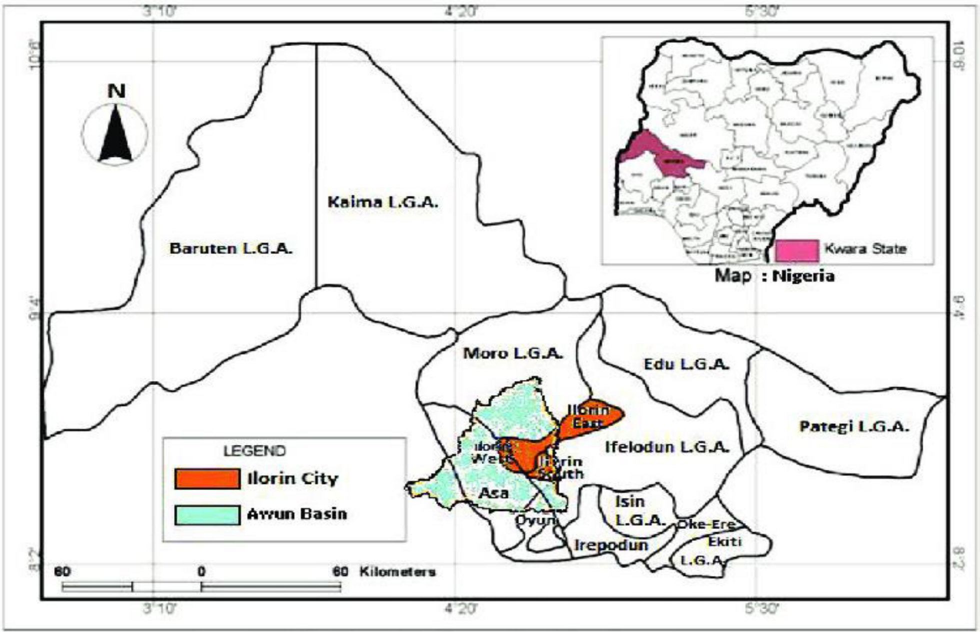

Figure 1. Map of Kwara State, Nigeria showing the Study Area.

2.2. Sample Preparation

Granite samples obtained from the MAN HARDI Quarry were taken to laboratory for further analysis. The granite samples were carefully selected for the following analysis: XRF, Hardness, Polish value, compressive strength, oxidation properties, specific gravity of granites.

2.3 X-Ray Fluorescence (XRF)

X-Ray Fluorescence is used to analyze the elemental composition of samples which is based on surface analysis. It is the emission of characteristic 'secondary' (or fluorescence) X-rays from a material that has been exited while bombarding with high energy X-rays or gamma rays. The method employed in this analysis is the Energy-Dispersive analysis (ED-XRF) and the machine model is the Shimadzu EDXRF-702HS., it was used to determine the basic chemical composition of the samples.

The samples were prepared with the following procedure; The sample was ground to a fine powder (to obtain a homogenous sample) using a vibration grinding mill with a steel milling. It was sieved through a 200-mesh sieve and dried to constant weight in a furnace at 110 °C.

XRF was performed on sample prepared in the form of glass disks with a sample/melt ratio of 0.5/5; $Li_2B_4O_7$ was used as the melt. The reference materials GSS8 and BCS-CRM 354 were used to produce standards; mixtures of these with an oxide content including that of the samples to be analyzed were used to produce a calibration curve. The reference materials were mixed with a 5% Au/Pt ZGS glass rod and melted in a furnace at a temperature of 1100 °C for 15 min. The melt was taken from the furnace and stirred after 10 min and then replaced to eliminate bubbles. It was then poured into a Pt/Rh 30-mm diameter mold to form a glass disk, of 30 mm diameter and 9 mm thickness were used for the analyses.

The samples were irradiated with X-rays within the instrument. When an X-ray photon was absorbed by the sample of sufficient energy then an electron was emitted via the photoelectric effect producing in an electron hole in the atom. An inner shell electron will then fall back to fill this hole resulting in the release of electromagnetic energy with a frequency characteristic of the element present.

A metallic filter, which was 100-m-thick titanium or 50-m-thick zirconium, was attached to the Rh x-ray tube. The aluminum collimators of inner diameters of 6 mm and 3 mm were attached to the x-ray tube and the detector, respectively. The x-ray tube and the detector were tilted to 45 degrees. The detector and the sample holder were placed on a Z-stage and to adjust the distance from the point of the detector to the sample surface. The external diameter of the sample holder was 44.5 mm (inside diameter: 40.5 mm) and height was 25.5 mm. The thickness of sample could be changed depending on the volume put in the sample holder

The energy dispersive X-ray fluorescence spectrometer Shimadzu EDXRF-702HS was operated at 40 kV and 18 mA. The current was automatically adjusted (maximum of 1 mA). A 10 mm collimator was chosen. The counting time was 100 seconds for all measurements. The intensity of element Kα counts per second (cps/µA) was obtained from the sample X-ray spectrum using the Shimadzu EDX software package.

2.4 Specific Gravity Determination of Samples

20 g of each of the samples was weighed (W) using Ohaus Digital Weighing Balance (Model: Ohaus AX2202/E-USA) and was later inserted into 100 ml measuring cylinder of known volume of water, refers to as initial volume (Volume (V2) of water was measured and the difference in the initial volume and final volume of water was recorded as the displacement. Specific gravity was calculated using the following equation [12].

$$\text{Specific Gravity} = \frac{\text{Mass of sample (g)}}{\text{Displacement value}} \times \text{Density of water}$$

$$\text{Specific Gravity} = \frac{W}{V2 - V1} \times \text{Density of water}$$

These were repeated for other samples

The Ohaus Digital weighing balance (model Ohaus AX22021 E-US) is a standard laboratory equipment to ensure solid weighing performance and accurate repeatable results. It has a capacity of 2,200grams and a readability of 0.01gram (10miligrams).

2.5 Rock well hardness Testing

The Rock well hardness testing machine (Model: GMBH3806) is a device that indicates the hardness of a material usually by measuring the effects on its surface of a localized penetration by a standardized rounded or pointed indenter of diamond carbide or hard steel. It was used to determine the hardness of the rock samples.

The hardness test was carried out on the sample of dimension 20mm x 20mm x 20mm using a Rockwell Hardness Testing Machine (Model: GMBH3806) with steel ball as the indenter. The indentation was carried out on five randomly selected points on the surface of each sample, average of the hardness value was taken and reported.

Figure 2 shows Rock well hardness testing machine *(Model: GMBH3806)*

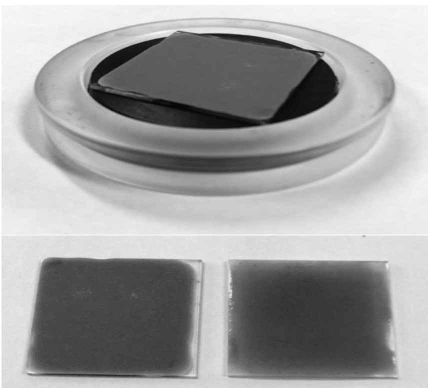

Fig. 2. Rock well hardness testing machine

2.6 Rock Polish

The Polished Stone value of the samples were determined in accordance with procedure of BS 812 [13]. The following laboratory equipment were used.

The Road Wheel polishing machine is a great machine for grinding, smoothing and polishing process, it produces a high quality, repeatable finishing solution to achieve a highly polished results.

The Syno-electro –magnetic produced by machine corporation (FMC) is a machine used to re-polish the samples with oxidized surface employing variable speed of 250 rpm (maximum) after the samples have been removed from the machine, cleaned with oxygen damp paper of grade one and dried with pressurized air. The polish Value test was carried out on the samples to determine the display of good abrasiveness and yielding attractive color tints.

Figure 3 shows Syno-electro –magnetic machine

Fig. 3. Syno-electromagnetic machine

2.7 Determination of Percentage Loss on Ignition

Approximately 1.0g of sample was weighed in a platinum crucible at a temperature of 25°C, this material was heated at a temperature between 900-1,000°C, cooled and weighed, W1. The loss in weight was checked by a second heating at same temperature for 5 minutes and the content reweighed. This process was repeated until a constant weight was attained, and recorded as W2. The loss in weight was recorded as the loss in ignition. Percentage loss on ignition was calculated as follows:

W3= W1 – W2,

% loss of ignition = (W3 x 100)/W,

Where:

W = weight of sample taken.

W3 = Loss in weight.

plastics or stainless steel.

2.8 Compression Test

This test was used to measure the Uniaxial Compressive Strength of rock samples. The procedure employed was that of [14], American Society for Testing and Materials (ASTM)170. Standard Test Method for Compressive Strength of Dimension Stone (2008).

Compression stress was measured using form test seidner, model GMBH D7940 compression machine, made in Riedlingen - West Germany. Compressive stress was applied uniaxially to each sample of dimension 20mm x 20mm x 20mm with a crosshead speed of 20 mm per minute to determine the behavior of the composites under a compressive load.

Figure 4 shows Form Test Seidner (Model GMBHD7940)

Fig. 4. Form Test Seidner

2.9 Oxidation Test

The oxidation test was carried out to determine the rate of decomposition or break down of the rock samples surfaces when exposed to air, heat, and acidic solvent before and after they have been polished. The procedure used for the test is described as follows; cutting of samples of dimensions 20mm X 20mm X 20mm, they were polished before being exposed to prepared solution of tap water, dilute hydrochloric acid (HCL) and oil. These samples were then left exposed to atmospheric condition for four days. After, these the samples were then re-introduced into a Synon-Electro Magnetic machine under variable speed of 250rpm (Maximum) to allow re polishing of the oxidized surface. Finally, the samples were removed from the machine, cleaned with Oxygen damp paper of grade one and dried with pressurized air. The dried samples were then observed under a Nikkonophiphot polarized microscope to observe any damage done to the already polished surface i.e., peeling due to the corrosive nature of the solution of acid, oil and air.

3.0 Results and Discussion

Rock characterization is a source of important input parameters required for the design of structure founded on rocks. Granitic rocks, typical intrusive igneous rocks are widely used in the construction industries i.e., dimension stone, aggregates etc. because of their high strength, abrasion resistance and durability. The knowledge of strength and mechanical behaviour of such rocks are essentially required for the design and construction of structures. The physical and engineering properties of such rocks are known to be influenced by many factors including geological, lithological, environmental and mechanical [15].

3.1 Chemical composition of samples

Tables 1, 2 and 3 show the chemical composition of selected samples

Table 1 shows the average chemical composition of Selected Samples from zone A

S/N	Basic Oxides	Formulae	% Composition
1	Silicon Oxide	SiO_2	67.73
2	Aluminum Oxide	Al_2O_3	13.39
3	Ferric Oxide	Fe_2O_3	4.16
4	Calcium Oxide	CaO	0.37
5	Magnesium Oxide	MgO	0.12
6	Sodium Oxide	Na_2O	4.81
7	Potassium Oxide	K_2O	6.00
8	Sulphide	SO_3	0.02
9	Manganese Oxide	MnO	0.09
10	Lead Oxide	Pb_2O_5	0.02
11	Titanium Oxide	TiO_2	0.33
12	Loss of Ignition	LOI	2.95

Table 1: Average chemical composition of selected sample from zone A

Table 2 shows the Average Chemical Composition of Selected Sample B

S/N	Basic Oxides	Formulae	% Composition
1	Silicon Oxide	SiO_2	73.62
2	Aluminum Oxide	Al_2O_3	14.23
3	Ferric Oxide	Fe_2O_3	0.26
4	Calcium Oxide	CaO	0.62
5	Magnesium Oxide	MgO	0.02
6	Sodium Oxide	Na_2O	5.04
7	Potassium Oxide	K_2O	3.92
8	Sulphide	SO_3	0.04
9	Manganese Oxide	MnO	0.08
10	Lead Oxide	Pb_2O_5	0.04
11	Titanium Oxide	TiO_2	0.46
12	Loss of Ignition	LOI	1.63

Table 2: Average Chemical composition of selected samples from zone B

Table 3 shows the Chemical Composition of selected Sample C

S/N	Basic Oxides	Formulae	% Composition
1	Silicon Oxide	SiO_2	72.40
2	Aluminum Oxide	Al_2O_3	16.10
3	Ferric Oxide	Fe_2O_3	1.42
4	Calcium Oxide	CaO	0.18
5	Magnesium Oxide	MgO	0.06
6	Sodium Oxide	Na_2O	3.67

7	Potassium Oxide	K_2O	4.28
8	Sulphide	SO_3	0.03
9	Manganese Oxide	MnO	0.08
10	Lead Oxide	Pb_2O_5	0.04
11	Titanium Oxide	TiO_2	0.30
12	Loss of Ignition	LOI	1.40

Table 3: Average Chemical composition of selected samples from zone C

Silica content are 67.73, 73.62 and 72.40. These values are closer to the value of 70-77% silica contents state by [16]. It can then be concluded that the granite is acidic since its silica content is greater than 65 % and it was also revealed that the critical mineral of granite is quartz [17].

3.2 Hardness value of the samples

Table 4 shows the Hardness Value

Samples from zones	Hardness Value (%)		
	1	2	Average hardness
A	86.00	85.17	85.59
B	97.16	96.51	96.84
C	88.06	88.15	88.11

Table 4: Hardness Value

Table 4 is the result of the hardness test, which shows that samples from zones A, B, and C have high hardness value of 85.59, 96.84 and 88.11, but sample B has the highest maximum hardness value of 96.84. The highest value was 96.84, [18] described the value of 93.23 hardness as good enough for road construction. Hence, this, shows that the sample is hard enough for a road constructional work. The silica content contributes to the hardness value of this granite since the oxide quartz and a large group of silicates are the most important rock forming minerals. Silica (Si02) one of the oxides of silicon occurs as quartz, chalcendony, agate and flint etc. Silica is a hard mineral having a "Moh's scale Hardness of 7" [17].

The hardest and most durable granites has a greater proportion of quartz and a smaller proportion of feldspar and mica. Feldspar makes granite to decompose easily by the solution potash contained in it, potash feldspar is less durable than lime [19].

3.3 Polish value of the sample

Table 5 shows the Polish Value

Table 5: Polish Value

Sample from zones	Polish Value (%)		
	1	2	Average polish value
A	90.00	91.75	90.88
B	97.40	97.32	97.36
C	93.41	94.00	93.71

Table 5 shows the result of the polish value of samples from zones A, B and C to possess good abrasiveness properties, and yielding PSV values of 90.88, 97.36, 93.71, but sample B has the maximum abrasiveness and yielding value of 97.36 and thus shows that the samples are good enough for construction of roads, as stated by [20]. The values of 91-97 were considered excellent for lapidary [21], and these tested samples' values fall within this range.

The beauty of granite, a natural product comes from porosity, crystalline quartz structure, fissures, and movement of the conglomerate, mineral composition, veining and grain. These are formed by the molten magma deep within the earth under immense heat and pressure when solidified in the earth crust [22].

3.4 Compressive strength of the samples

Table 6 shows the Compressive Strength

Table 6: Compressive Strength

Samples from zones	Maximum compressive Load (MPa)		Uniaxial Compressive Strength (MPa)		Mean Uniaxial Compressive Strength (MPa)
	1	2	1	2	
A	5.35	5.40	142.74	142.00	142.37
B	8.62	8.50	202.71	200.53	201.62
C	6.34	6.91	151.88	177.35	164.62

Table 6 shows the compressive strength test result of the three zone samples under study. Where samples from zones A, B and C show good compressive strength of 142.37, 201.62 and 164.62 MPA respectively, this is comparable to [23] which state the range of compressive strength of granite to be 146.63MPa to 197.00MPa. However, samples from zone B has the maximum compressive strength. These values are similar to those obtained from Utan granite in Plateau state Nigeria [21].

The average Uniaxial Compressive Strength values obtained in Table 3 lie within the range of the compressive strength (100 – 250 MPa) specified for building stone [24].

3.5 Oxidation properties of the Sample

Figure 5 shows a sample from zone A after the oxidation was carried out

Fig 5. Photograph of Sample from zone A after oxidation test was carried out.

Figure 6 shows the sample from zone B after oxidation test was carried out

Fig 6. Photograph of Sample from zone B after oxidation test was carried out

Figure 7 shows the sample from zone C after oxidation test was carried out

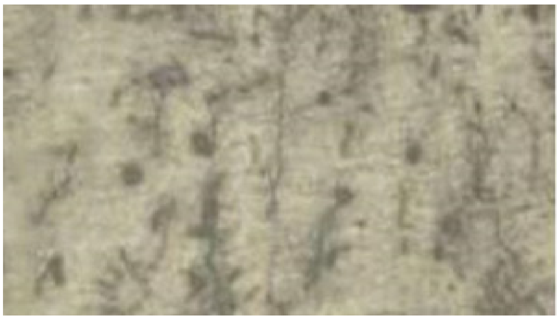

Fig. 7. Photograph of Sample from zone C after oxidation test was carried out

The samples show no peeling, showing that they are good for road construction. When granites are exposed to the environment where ionic solution, multiple mineral ingredients will react with chemical solution such as decomposition reaction, oxidation-reduction reaction, and single displacement reaction. The chemical reactions deteriorate the mechanical property of granites [25].

3.6 Specific gravity of selected samples

Table 7 shows the Specific Gravity

Table 7: Specific Gravity

Sample from zones	Mass (g)		Initial volume V_1 (ml)		Initial volume V_2 (ml)		Displacement V_2 -V_1 (ml)		Specific gravity		Average specific gravity
	1	2	1	2	1	2	1	2	1	2	
A	20.00	20.00	45.00	45.00	49.50	49.35	4.50	4.35	4.44	4.60	4.52
B	20.00	20.00	45.00	45.00	49.35	49.00	4.35	4.00	4.60	5.00	4.80
C	20.00	20.00	45.00	45.00	50.50	50.62	5.50	5.62	3.64	3.56	3.60

Table 7 gives the results of the specific gravity of the metamorphosed granite samples, from this it can be deduced that samples from zones A, B and C have almost uniform specific gravity 4.52, 4.80, and 3.60 respectively. These are heavier than specification of Will, (2006) for granite which is 2.2. Rocks which are denser are stronger while light weight ones are weak. Rocks with specific gravity less than 2.4 are not suitable for building constructions [21]. Granite has high density, making it useful as a massive countertop, which is available in large slab sizes and having varieties available from all over the world [26].

4. Conclusion and Recommendation

The result of the study shows that the tested granite rocks samples possessed a very high engineering properties as well as chemical properties to be used for engineering application such as structural, building and road constructions and polished rocks.

It is recommended that the metamorphosed granite deposit be developed to be used for economic utility i.e. road construction and polished rocks. Further detailed studies are however recommended to be carried out to check for the possible variability within the rock body.

Conflict of Interest

The authors declare no conflict of interest.

Availability of Data and Materials

The dataset used and/or analysed during this study available from the corresponding author on reasonable request.

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