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EFFECT OF MINERALOGICAL COMPOSITION ON GRANITE ROCK STRENGTH IN KWARA STATE: A CASE STUDY OF KAMWIREQUARRY AND FEMAS QUARRY

by

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Abstract
This research work presents the effect of mineralogical composition on the strength of granite rock of KAMWIRE Quarry and FEMAS Quarry. Rock samples obtained from different locations were analyzed based on their strength, degree of weathering and mineral percentage composition. Rock density, rebound hardness values and mineral composition were determined. Rebound hardness value and rock density were used to evaluate the Uniaxial Compressive Strength. The result from the investigation shows that granite deposit from Femas Quarry and Kam Quarry has the highest density, rebound hardness values, compressive strength and highest mineral percentage composition of feldspar. The result of the correlation between the mineral percentage composition and the uniaxial compressive strength determined by simple regression analysis shows that mineralogical composition is one of the main properties controlling the rock strength. It was discovered that increase in the mineral percentage composition of quartz and feldspar increases the strength of the rock while increase in the mineral percentage composition of opaque and garnet decreases the strength of the rock.

Key Words: Mineralogical Composition, Regression Analysis, Rock Density Schmidt Hammer, Uniaxial Compressive Strength.

Introduction

Granite rocks show a variety of engineering properties that may affect the use of rock as a construction material. They are widely used in the construction industry for their high strength, abrasion resistance and structural and textural characteristics. The physical and mechanical properties are a function of the mineralogical and textural characteristics of the rock (Irfan, 1996). Granite rocks include a wide range of rock types varying in their mineral, petrographical characteristics and engineering properties.

Granite rocks are intrusive igneous rocks; they are widely used in the construction industries as dimension stones, aggregates etc. The strength and deformation behaviour of such rocks are essentially required for the design and construction of dams tunnels, slope stability and foundations, design of structures. The physical and engineering properties of such rock are known to be affected by many factors. These factors include geological lithological, environmental and mechanical (Ramamurthy, 2010).

The principal characteristics of granite also include high load bearing capacity, crushing strength, abrasive strength, amenability to cutting and shaping with secondary flows, ability to yield thin and large slabs and above all durability. Due to highly dense grains, it is impervious to strain. Polished granite slabs and granite tiles have achieved a special status as building stone globally. Granite is also used for wall cladding, roofing, flooring, and a variety of other interior and exterior application (Korinets and Alehossein, 2002).

It has also been recognized that in case of rock with similar mineral composition, there is a general trend towards higher strength in finer grained rocks than in coarse grained rock. Hendron (2004) demonstrated that the compressive strength of granite increase with increasing specific surface area of individual grains. It is not only the grain size but also the grain size distribution that is important, with the effect that a large size range gives higher strength compared to a more equigranular or homo-oblastic rock (Lindqvist*et al.,* 2007).

Tugrul (2004) opined that petrographic characteristics of rocks have significant effect of macro-mechanical properties. It can be found presently that research on the relationship between petrographic characteristics of rocks and macro-mechanical properties are mainly focused on the influence of rock micro-structure on rock strength.

According to Moon (1993), rock micro-structure includes the text of a rock and the small scale rocks structure. However, texture is still acceptable because it is a useful means of identifying the origin of rocks, how they formed, and their appearance.

Slake durability index test has long been used to identify the durability and water sensitivity of rocks as subject to engineering requirement under-in-situ conditions. It has been found that compressive strength of rocks tends to increase line only with the slake durability index (Turgrul, 2004).

According to Basu*et al.*, (2009), Unaxial compressive strength (UCS) is one of the most appreciated measurements in routine rock engineering environment. It has long been recognized by many researchers (Akesson*et al*., 2004) that the effect of mineralogical composition controls rock mechanical behaviours.

Location of the Study Area

The study area covers Kwara State, which falls within the Precambrian of North Central Nigeria, which is a part of Nigeria Basement Complex. Sixteen groups of rocks could be identified in the basement complex (Rahaman, 1988). The location of the study areas is presented in Table 1 and Figure 1.

Table 1: Description of the Study Areas

Location Sample	Quarry	Town	State	Co-ordinates of Location
Sample A	Kamwire Quarry	Oke – Oyi	Kwara	08^{o} 33' 18"N 004^{o} 45' 31" E
Sample B	Femas Quarry	Egbejilla	Kwara	08^{o} 24' 45" N 008^{o} 32' 009"E

Geology of the Study Area

There are two distinct geological regions in Kwara State is the region of sedimentary rock in the south, and the region of Precambrian Basement Complex rocks in the north. Some few kilometres north of Oke-Oyi occurs the Basement Complex Sedimentary rocks boundary. The sedimentary rocks are mainly of the post cretaceous sediments and the cretaceous Abeokuta formation. The basement complex is mainly of the medium grained gneisses. These are strongly foliated rocks frequently occurring as out crops. On the surface of those outcrops, severally contorted, alternating bands of dark and light coloured minerals can be seen. The bands of light coloured minerals are essentially feldspar and quartz, while the dark coloured bands contain abundant biotic mica. A small proportion of the state, especially to the north east, overlies the coarse grained granites and gneisses, which are poor in dark ferromagnesian minerals.

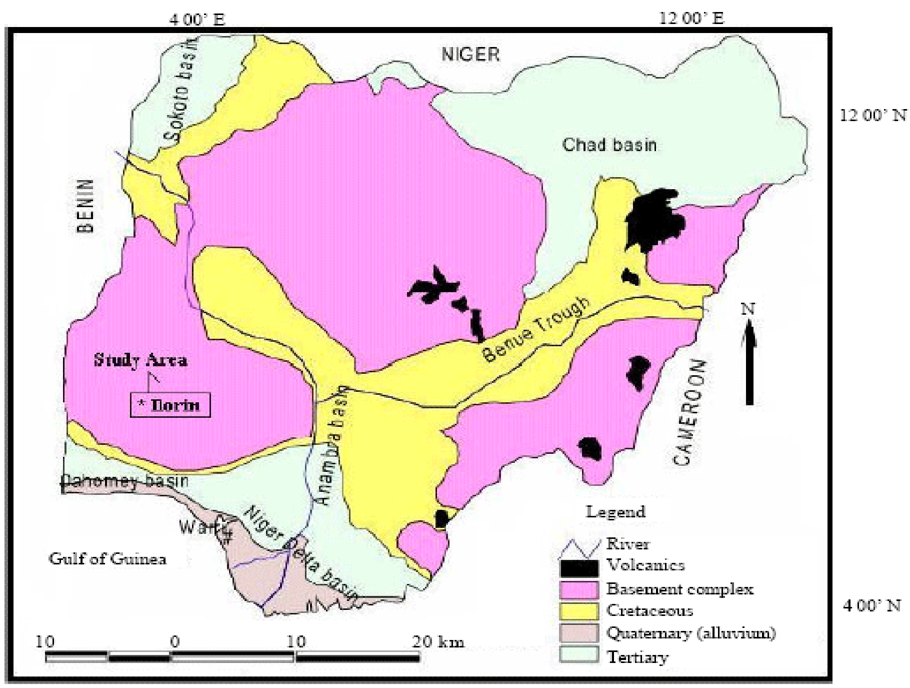

Figure 1: Geological Map of the Nigeria Showing the Study Area
(Source: Nwankwo, *et al.*, 2004)

Sample Collection

Samples were collected from two different deposits. The samples were taken randomly from two different location within each deposit; Kamwire quarry and Femas quarry. A sledge hammer was used to break the samples into different sizes from the boulders and the primary size that was collected was 25mm to 50mm range. Each samples were labelled A and B respectively and placed into different sample bags. A global positioning system was used to measure the Northern, Eastern and elevation of each deposit.

Sample Preparation

The sample was prepared to the required length and diameter for each test carried out and continuously tested in the machine. The reading was taken immediately to avoid error of computational datum, and error due to parallax was strictly guided against for proper accountability and accuracy in reading of the instruments. The methods and procedures adopted in each experimental

finding were highlighted in each section. The statistical analysis was used in determining the actual strength of the rock.
The test involved the use of Schmidt impact hammer of type N for the hardness determination of lump rock samples. The rebound value of the Schmidt Hammer is used as an index value for the intact strength of rock material, but it is also used to give an indication of the compressive strength of rock material (ISRM, 1981). The result of the hardness test is used to evaluate the uniaxial compressive strength (UCS). The standard method for the Schmidt hammer test as described by ISRM (1981) and ASTM (2002) was followed. The measure test value for the samples was ordered in descending order. The lower 50% of the values were discarded and the average obtained of the upper 50% values to obtain the Schmidt Rebound Hardness (ISRM, 1981).

The granite (block) samples and the proponed lumps used were assumed as the representatives of the rock mass. The empirical expressions; P/A F P/D_2 and 2P/ΠtD were used for the calculations to compute each of the dutum, and formulate represent, compressive strength (C_o).

Where; P is the load at failure (kN); A is the cross sectional area of the sample
D is the Diameter of the specimen (mm); and t is the thickness of the rock specimen (mm), likewise, the strength classification of rocks for compressive strength was reference.

Physical Properties

Determination of Mineral Composition

The study of the thin section was carried out on the slides prepared in accordance with procedure suggested by ISRM (1981). The prepared slide was viewed with the aid of polarizing microscope. The mineral composition of the rocks was estimated using modal analysis, the percentage of each mineral form was also determined as presented in Table 2.

Table 2: Estimate Modal

	Mineral	Composition	Rock
Kamwire Quarry	QUARTZ	29	
	FELDSPAR	42	
	GARNET	8	GNEISS
	OPAQUE	5	
	BIOTITE	16	
	TOTAL	100	
Femas Quarry	QUARTZ	28	
	FELDSPAR	44	
	GARNET	9	GNEISS
	OPAQUE	7	
	BIOTITE	12	
	TOTAL	100	

Determination of Density

Density is measure of mass per unit of volume. It is sometimes defined by unit weight and specific gravity. The dry density of rock samples collected was irregular from the locations. The saturation for irregular rock sample was adopted and the procedures follow the standard suggest by ISRM (1981) and conform to ASTM (2001). The saturated volume of the sample was calculated using equation 1;

$$SSSSSSSSSSSSSS\ SSSSSS\ SSSS = S_S - S_S \quad 1$$

Where; V_1 (ml) is the initial water level and V_2 (ml) is the final water level in the cylinder after the immersion of the irregular rock sample.

The dry density of the rock samples was calculated using equation 2;

$$S\ SSSSSSSSSSSSShSSSSSSSS\ SSSS = \frac{S}{S_S S\ S_S} \quad 2$$

Where; M (g) is the oven dried mass at a temperature of 105°C.

Determination of Strength

Strength test was carried out and they include; Compressive test and Schmidt test.

Uniaxial Compressive Strength Test

The uniaxial compressive strength test of the rocks was determined using 1100kN compression machine. The rock specimen to be tested was placed on the machine platen. The machine was jacked manually, the release value was closed, and seating of the exhaust system thereby allows the pump to bull up pressure and activates the ram. As the load was applied, it was shown on the gauge after failure and the failure load was recorded. The test procedure was in accordance with ISRM (1981) and ASTM (2001) D2938. The uniaxial compressive strength was determined using equation 3:

$$SS = \frac{S}{S} = S/S\ .S \quad 3$$

Where;

C_o is the uniaxial compressive strength (MPa); P is the applied peak load (kN); W is the width of the sample (m); D is the height of the sample (m).

Rock hardness is a term used in geology to denote the cohesiveness of a rock and is usually expressed as the compressive strength. Terms such as hard rock and soft rock are used by geologists to distinguish between igneous/metamorphic and sedimentary rocks, respectively. These terms originated from historical mining terms, reflecting the methods needed to economically mine an ore deposit. For examples, they hardly need to be mined with explosive and a soft rock can be mined with hard tools, such as pick and shovel.

Rock can be tested for their uniaxial compressive strength by using ASTM standard tests. The involve loading a small rock core/cuboids. The compressive strength is given as the maximum stress necessary to induce failure of the rock core/cuboids. This value gives an indication of the cohesiveness and density of a rock. As seen in Table 2, igneous, metamorphic and sedimentary rock can be classified from very weak to very strong with regards to their uniaxial compressive strength (Inyang*et al.*, 1990). Generally, sedimentary rocks can range from weak to medium (10 – 90 MPa), and igneous rocks range from medium to very strong (40-320MPa). The highest uniaxial compressive strength observed in a rock is on the order of 400MPa.

Schmidt Rebound Hardness Test

The uniaxial compressive strength of the rock samples was estimated from the values of the equivalent type L Schmidt Hammer Hardness and the density of the rock. The uniaxial compressive strength was used for the strength classification and characterization of the intact rock for the generalized Hoek-Brown criterion for obtaining the friction angle and the cohesion. Figure 2 displays a typical Schmidt hammer.

Figure 2: Schmidt Hammer

Result and Discussions

Physical Properties Results

Density

The density results obtained from the samples analysis was carried out in the rock mechanics laboratory which show that sample (B) of Femas quarry and product limited has the highest density, while sample (A) of Kam quarry limit has the least.

According to Jones (2012), it implies that sample (B) is tightly crammed together than sample (A). Table 3 shows the summary of density results while Table 4 shows the unit weight.

Table 3: Summary of Density Results

Test No	(A) Kam Quarry	(B) Femas Quarry
1	12.57	2.69
2	2.45	2.55
3	2.43	2.43
4	2.62	2.82
5	2.63	2.68
6	2.52	2.72
7	2.71	2.65
8	2.59	2.81
9	2.53	2.59
10	2.65	2.53
AVERAGE	**2.57g/cm^3**	**2.65g/cm^3**

Table 4: Summary of Unit Weight Results

Test No	(A) Kam Quarry	(B) Femas Quarry
1	25.9	26.9
2	24.5	25.5
3	24.3	24.3
4	26.2	28.2

5	26.3	26.8
6	25.2	27.2
7	27.1	26.5
8	25.9	28.1
9	25.3	25.9
10	26.5	25.3
AVERAGE	**25.7kN/m^3**	**26.5kN/m^3**

Strength Results

Schmidt Rebound Hardness

Table 5 shows the arrangement of the rebound hardness in descending values. The lower 50% of the values were discarded and the average obtained in the upper 50% values for each of the rock samples as suggested by ISRM (1981). The average of the upper half is taken to represent the average rebound values of the hardness test. The result of the Schmidt rebound hardness and equivalent compressive strength is presented in Table 6.

Table 5: Descending Values of Schmidt Rebound Hardness

	Test No	(A) Kam Quarry	(B) Femas Quarry
Upper 50% Value Average	1	54	58
	2	54	56
	3	52	54
	4	52	54
	5	50	52
	6	50	50
	7	46	50
	8	44	48
	9	42	48
	10	40	46
Lower 50% Value Discarded	11	38	43
	12	38	42
	13	36	40
	14	32	40
	15	30	38
	16	30	34
	17	30	30
	18	26	30
	19	26	28
	20	20	24

Table 6: Results of Schmidt Hammer Test and Equivalent Uniaxial Compressive Strength

Sample Location	Average Schmidt Hammer Result, (MPa)	Equivalent Uniaxial Compressive Strength (MPa)
A (KAM Quarry)	48.4	115
B (FEMAS Quarry)	51.6	149

Table 7: Summary of Strength Characterization

S/N	Samples	UCS (MPa)	Rock Classification
1	Kam Quarry (A)	115	Very High Strength
2	Femas Quarry (B)	149	Very High Strength

The rock types tested are of "Very High Strength Class" sample (B) deposit has the highest value which is in agreement with its high density and hardness, while sample (A) having the lowest value.

Thin Section

The results obtained from thin section in Table 8 shows that Quartz, feldspar, garnet, opaque and Biotite were the main minerals present with other mineral accessories. From the result, sample (A) of Kam Quarry Limited has the highest percentage composition of Quartz content of 29% compared to sample (B) of Femas Quarry Limited. It can be concluded that sample (A) of Kamwire Quarry Limited has the highest strength value

.

Table 8: Summary of Mineral Composition of the Two Quarries as Determined By Thin Section

Sample Name	MINERALS					
	Qtz (%)	Fspar (%)	Gar (%)	OP (%)	Bio (%)	Total
Femas(A)	29.00	42.00	8.00	5.00	16.00	100.00
Kamwire(B)	28.00	44.00	9.00	7.00	12.00	100.00

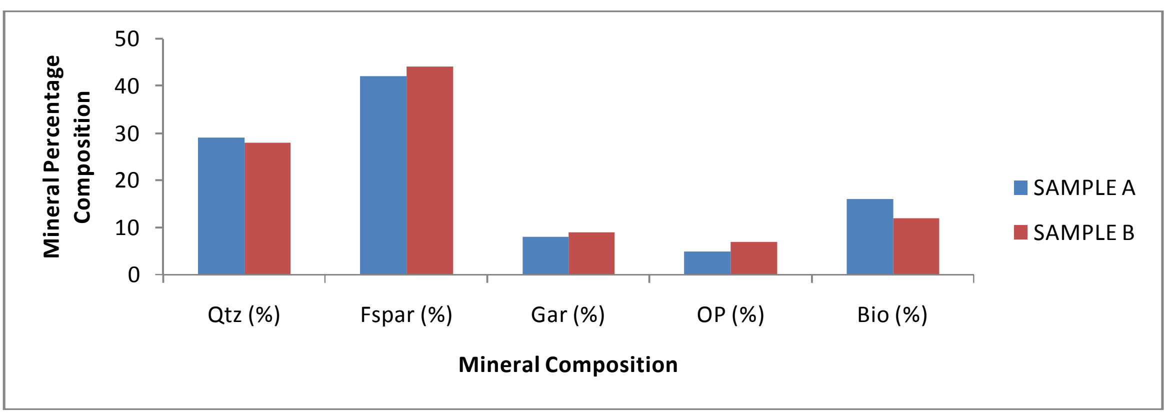

Figure 3: Mineral Composition of Rock Studied as Determined by Thin Section

As can be seen in Figure 3, the main minerals present in the two quarries are shown in the multiple bar charts. It can be seen that feldspar is the major mineral found in the sample rock, followed by quartz, biotite, garnet, and opaque.

Table 9: The Relationship between the Mineral Percentage Composition of Quartz and Uniaxial Compressive Strength of all the Quarries

Sample Names	Quartz (%)	Uniaxial Compressive Strength
Femas	29.00	115
Kamwire	28.00	149

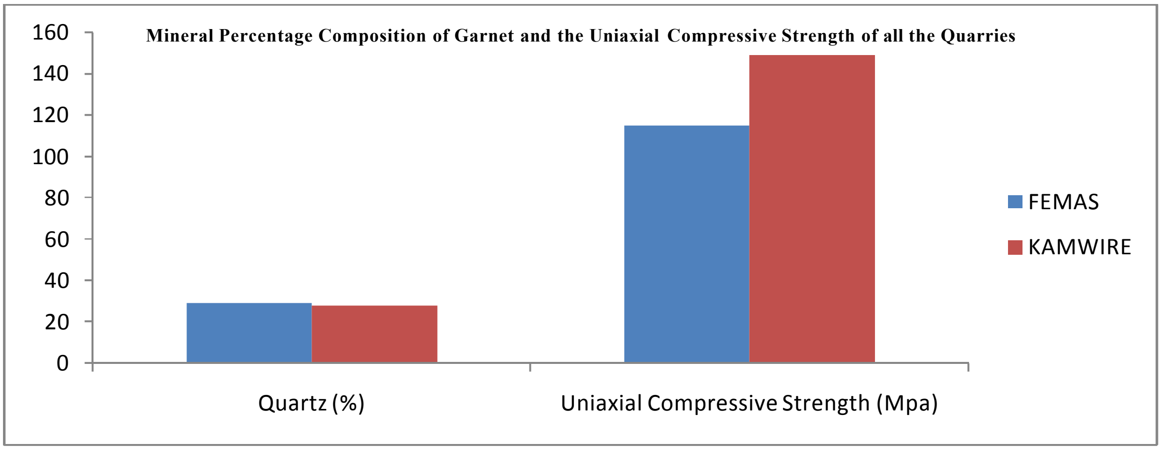

Figure 4: Relationship between the Mineral Percentage Composition of Quartz and the Uniaxial Compressive Strength.

The displayed in Figure 4 shows that there is relationship between the mineral percentage composition of quartz and the uniaxial compressive strength with a strong value. It can be concluded that the uniaxial compressive strength is directly proportional to the mineral percentage composition of quartz.

Table 10: The Relationship between the Mineral Percentage Composition of Feldspar and the Uniaxial Compressive Strength of all the Quarries

Sample Names	Feldspar (%)	Uniaxial Compressive Strength
Femas	42.00	115
Kamwire	44.00	149

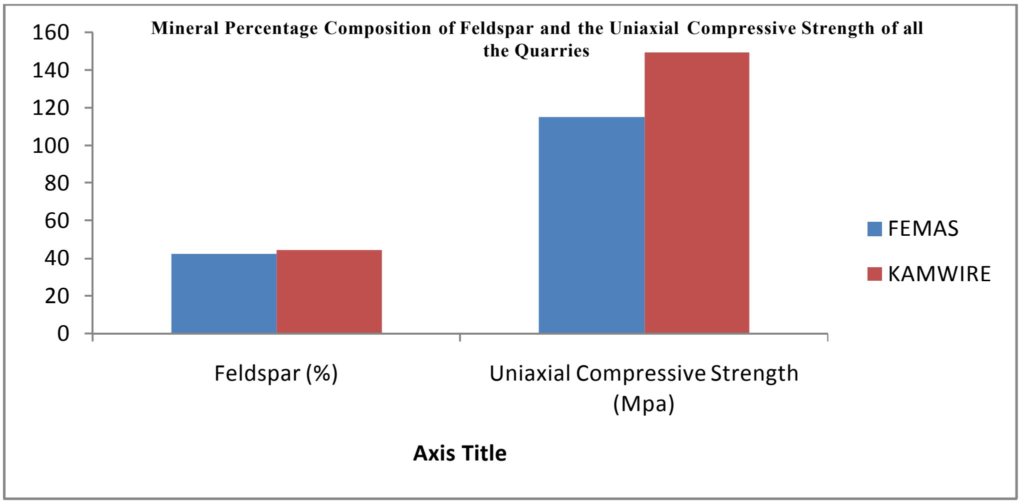

Figure 5: Relationship between the Mineral Percentage Composition of Feldspar and the Uniaxial Compressive Strength

Figure 5 shows that there is relationship between the mineral percentage composition of feldspar and the uniaxial compressive strength with a strong value. It can be concluded that the uniaxial compressive strength is inversely proportional to the mineral percentage composition of feldspar.

Table 11: The Relationship between the Mineral Percentage Composition of Garnet and the Uniaxial Compressive Strength of all the Quarries

Sample Names	Garnet (%)	Uniaxial Compressive Strength
Femas	8.00	115
Kamwire	9.00	149

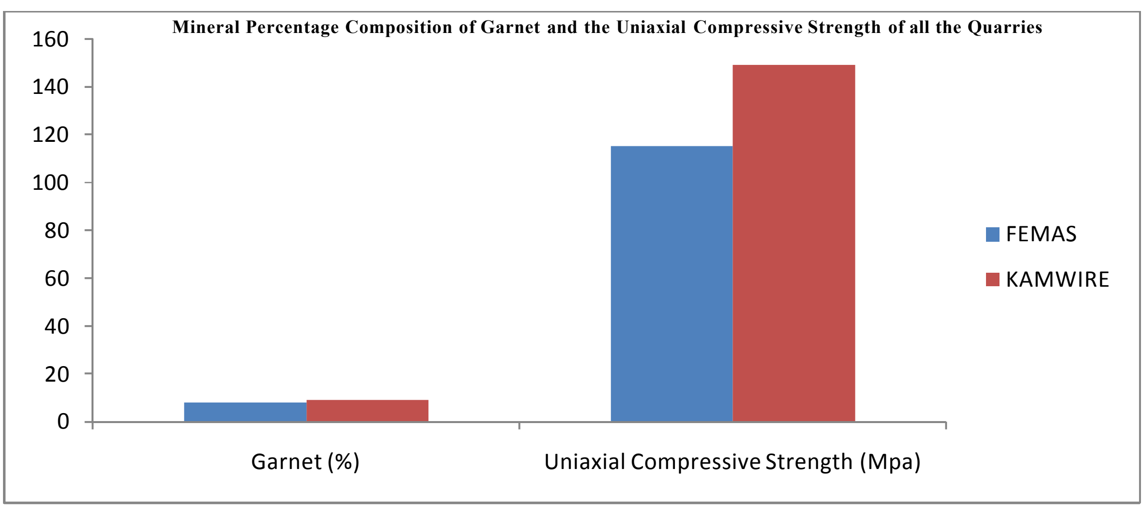

Figure 6: Relationship between Mineral Percentage Composition of Garnet and Uniaxial Compressive Strength

Figure 6 shows that there is relationship between the mineral percentage composition of garnet and the uniaxial compressive strength with a very strong value. It can be concluded that the uniaxial compressive strength is inversely proportional to the mineral percentage composition of garnet.

Table 12: The Relationship between the Mineral Percentage Composition of Opaque and the Uniaxial Compressive Strength of all the Quarries

Sample Names	Opaque (%)	Uniaxial Compressive Strength
Femas	5.00	115
Kamwire	7.00	149

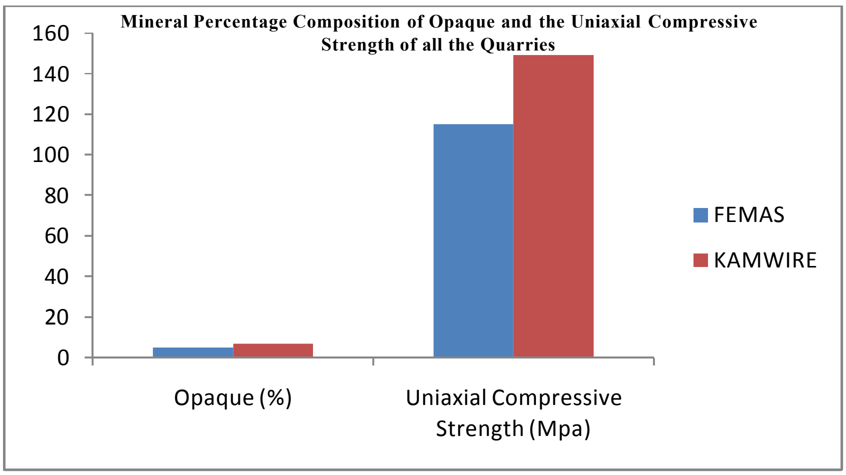

Figure 7: Relationship between the Mineral Percentage Composition of Opaque and the Uniaxial Compressive Strength

Figure 7 shows that there is relationship between the mineral percentage composition of opaque and the uniaxial compressive strength with a very strong value. It can be concluded that the uniaxial compressive strength is directly proportional to the mineral percentage composition of opaque.

Table 13: The Relationship between the Mineral Percentage Composition of Biote and the Uniaxial Compressive Strength of all the Quarries

Sample Names	Biotite (%)	Uniaxial Compressive Strength
Femas	16.00	115
Kamwire	12.00	149

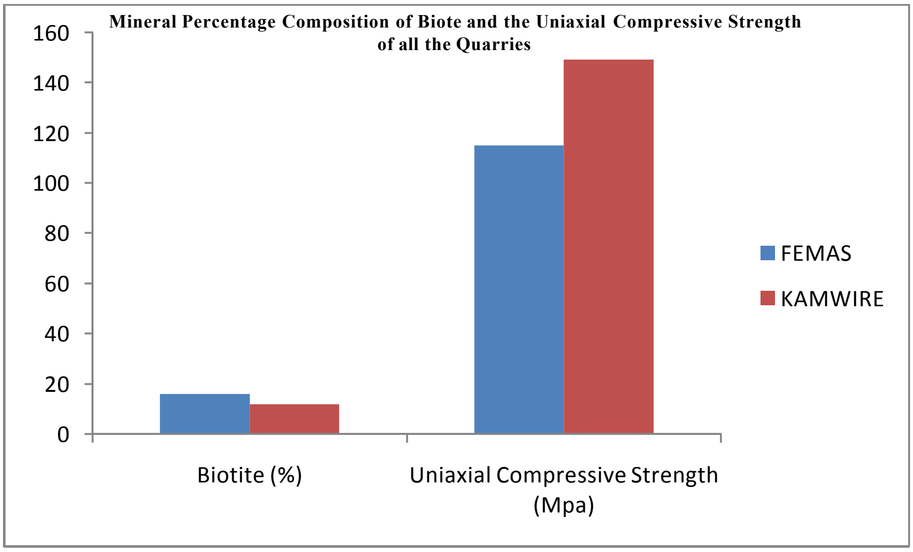

Figure 8: Relationship between the Mineral Percentage Composition of Biotite and the Uniaxial Compressive Strength

Figure 8 shows that there is relationship between the mineral percentage composition of biotite and the uniaxial compressive strength with a very strong value. It can be concluded that the uniaxial compressive strength is directly proportional to the mineral percentage composition of biotite.

Plate 1: Photomicrograph of Gneiss Sample A under Crossed Polar

Plate 2: Photomicrograph of Gneiss Sample A under Plane Polarized Light

Plate 3: Photomicrograph of Gneiss Sample B under Crossed Polar

Plate 4: Photomicrograph of Gneiss Sample B under Plane Polarized

Discussion

From the result obtained on density, Schmidt hammer rebound value, uniaxial compressive strength and thin section. Rock sample (B) FEMAS Quarry Limited has the highest strength value and highest resistance to weathering.

The result from Table 8 shows that quartz, feldspar, garnet, opaque and biotiteare the minerals present in the tested samples. It can be seen from the table that sample (B) has the highest percentage composition of feldspar as compared to other samples.

The correlation between the mineral percentage composition and the uniaxial compressive strength determined by simple regression analysis had shown that mineralogical composition is one of the main properties controlling the rock strength and that the percentage of strength minerals (quartz and feldspar) and weak minerals (opaque and garnet) can have opposite effect on the strength parameters of the rock.

Plates 1 - 4 and Figure 2 (mineral composition) show the variation of the various mineral constituents. The slides were studied using the polarizing microscope and the exact percentages of each mineral composition were calculated.

Conclusion and Recommendations

The field data and laboratory result carried out on the two samples from the two locations shows that the strength characterization of the selected granite rock samples has uniaxial compressive strength ranging from 115 – 149MPa, classified to have high uniaxial compressive strength. The synthesis of these analysis leads to the following conclusions.

1. The rock sample (B) of Femas quarry had the highest density, Schmidt hammer rebound value, uniaxial compressive strength, and highest percentage composition of feldspar of 2.65g/cm^3, 51.6 %, 149 MPa, 44% respectively. This means that rock samples A had the highest strength value and offer greatest resistance to weathering.
2. Mineralogical composition is one of the main properties controlling the rock strength.
3. The percentage of strength minerals (quartz and feldspar) and the percentage of weak minerals (opaque and garnet) can have opposite effect on the strength parameter of the rock.

There is significant correlation between the mineral percentage composition and the uniaxial compressive strength.

Recommendations

1. Since all the rocks tested fall within high strength class, they are very useful for most engineering construction
2. More tests should be done to ascertain the suitability of the rocks for other purposes.
3. Test should be conducted on the effect of cohesion on the strength of granite rock.
4. Test should be conducted to determine the mineralogy and chemical composition of the same size fraction.

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