



Interface between Mineralogy and Mechanical Properties of Granitic Rocks in Some Parts of S/W Nigeria for Dimension Stone Production

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Abstract

Keywords:

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Granites are quarried for construction as well as structural support purposes. The materials to serve these purposes must meet the required mechanical properties. Interface between the mineralogy and the mechanical properties of selected granite rock types were analyzed to identify the granite regions that are suitable for dimension stone quarrying. From this work, it can be established that granodiorite, monzogranite and syeno – granite are all suitable for all dimension stone application based on their mechanical properties. K-feldspar granite and tonalite may have limited application due to high percentages of feldspar. Quartzolite and quartz-rich granitoids may not be suitable due to their brittle nature. All granite outside these region are predominantly feldspar (k and plagioclase) which will result in a significant reduction in mechanical properties and this in turn make them unsuitable for dimension stone production

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INTRODUCTION

Mineralogy and mechanical properties of granites have been identified as two main properties that influence suitability of granites for dimension stone production (Saliu, 2008). Few research works have been carried out on these two properties to generate interface between them in order to establish granites region that are suitable for engineering works. Incorrect selection of granite for construction work, most especially in road construction will lead to quick failure of the road (Quick, 2002).

Mineralogy

Petrography is the description and classification of rocks by means of microscopic examination. Where rock materials are to be used for construction purposes, petrographic descriptions must emphasize any deleterious components (Quick, 2002). Other

analytical techniques must also supplement the petrography (e.g. x-ray diffraction, scanning electron microscopy and energy-dispersal x-ray analysis). Accurate description of the mineralogy, texture and other microscopic features of the rock will allow a prediction of its chemical, physical and mechanical performance in service. For example, constituent minerals such as swelling smectite clays, zeolites and sulphides (e.g. pyrite) have affected the long-term durability of some dimension stone products, (Quick, 2002). Petrography must not be used in isolation to predict the durability of rocks; the uses will determine what other tests are required to predict its services performance. Rocks can be classified into various categories based on their mineralogical composition. Using Quartz, Alkaline Feldspar and Plagioclase Feldspar (QAP) diagram as shown Figure 1, rocks are classified based on the

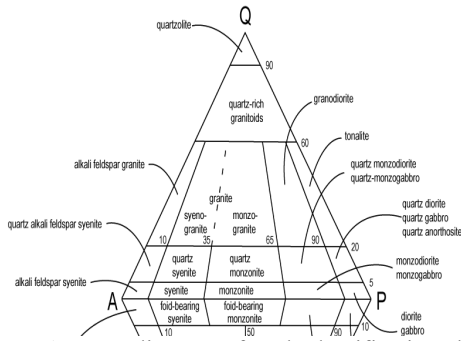


Figure 1: QAP diagram of rock classifications based on mineralogical composition.

percentage of quartz, alkaline feldspar and plagioclase. As it would be established in the later part of the work, an interface between mineralogy and mechanical properties would be generated to determine these categories of rocks that are suitable for engineering application based on their strength properties.

Mechanical properties

Mechanical properties that influence suitability of rock for engineering application include the following: compressive strength, flexural strength, hardness, abrasion resistance, absorption and density (Quick, 2002). The minimum requirements of these properties for dimension stone application are shown in Table 1.

Table 1: ASTM Specification of materials for construction purposes (Quick, 2002)

I	II	III	IV	V	VI	VII
Granite	0.40	2560	131	8.27	25	-
Marble	0.20	-	52	7	10	-
Calcite		2595				
Dolomite		2800				
Serpentine		2690				
Travertine		2305				
Limestone				NS	10	-
(I) low density	12	1760	12			
(II) medium density	7.5	2160	28			
(III) high density	3	2560	55			
Quartz based				NS		-
(I) sandstone	8	2003	27.6		2	
(II) quartzitic	3	2400	68.9		8	

Note: I = Type of Stone; II = Absorption C97 (wt%, Max); III = Density C98 (kg/m², Min); IV = Compressive Strength (MPa, Min); V = Flexural Strength (MPa, Min); VI = Abrasion Resistance (Ha, Min); VII = Acid Resistance (Min)

Water Absorption, Porosity and Density:

Water absorption is the proportion of water absorbed by a rock under specific immersion conditions. The value obtained provides some indication of the rock performance in service, particularly its strength, durability and stain resistance. The water absorption value is also closely related to its inherent apparent porosity i.e. the volume of open pores accessible to moisture within the rock. The rate of water absorption was observed to depend on the bulk density (mass per unit volume) of the granite (the higher the bulk density, the lower the water absorption (Scheffler and Lesak, 2000).

Generally, with higher water absorption, porosity and lower density, rocks tend to be less durable and less stain resistant and more susceptible to frost and salt attack. However, the pore space is distributed within the rock: whether there are many fine pores, which increase likelihood of absorption by capillary tension or a smaller number of coarse pores.

Rock units produced by thermal jet processes tend to have extended micro cracking and thus have increased absorption properties. Some rocks, after absorbing water and alkalis from the mortar bed or cementations adhesions, may have their volumetric dimensions permanently changed. As a result, these rocks may display warping and bowing e.g. serpentines.

Compressive Strength

Compressive strength of a stone is the measure of the load that a stone can take before it fails and it is a measure of the rocks ability to support load-bearing structures. As most modern stone installations are non-load bearing, the test has little direct relevance for cladding systems. It can be useful in evaluating different rocks for floor applications if density, abrasion and slip resistance are also considered [Smith(ed), 1999 and Quick, 2002]. Types of compressive strength test includes Uniaxial compressive strength, Point load system and Schmidt hammer methods. Quick (2002) recommended uniaxial compressive strength as the best type of compressive strength of rock.

Flexural Strength

The flexural strength, which is otherwise known as the 'bending strength', is critical in both the design and detailing of building facades, and also for use as a flooring material.

Quick (2002) noticed that flexural strength is useful in determining the maximum load a stone panel can withstand in a curtain-wall system with anchors located at the edges of the panel. It also assists in the evaluation of the stone's resistance to wind

loads. Flexural strength is a measure of the tensile strength induced by bending; it is highly affected by the surface condition of the face of the stone that is in tension.

Spray (1989) noticed that the flexural strength of thermally finished granite is 30% lower than polished granite. The test can be used to determine whether a thin stone unit will crack or fail under externally induced stress condition. Generally speaking, the flexural strength of a rock increases as the water absorption decreases for stone of equal grain size. The methods include central point loading system and three point loading system. He concluded further that the three point loading system is the best as it gives reliable result.

Hardness

Testing for hardness is usually considered when selecting stone for flooring applications. Some rocks are very soft and should not be used in areas of high traffic or in areas close to external entrances, where loose grit or sand can be brought in by shoes or wind and ground into the stone’s surface, unless appropriate measures are taken. Stones with low scratch resistances will require a higher level of maintenance Quick (2002). Hardness test methods include Scratch hardness, Vicker hardness and Schmidt hammer method. He then recommended Scratched hardness and Vicker equivalent as the best method.

The scratch hardness test which involves the use of Moh’s hardness scale for minerals has been in use since 1822. It simply consists of 10 minerals arranged in order from 1 to 10. Diamond is rated as the hardest and is indexed as 10; talc as the softest with index number 1. Each mineral in the scale will scratch all those below it as in Table 2.

Table 2: Comparison between Mohr’s hardness scale and Vickers hardness (After Townhill-Rewston, 1984).

Mineral	M	V
Diamond	10	-
Corundum	9	2428
Topaz	8	1745
Quartz	7	1413
Orthoclase	6	788
Apatite	5	530
Fluorite	4	188
Calcite	3	125
Gypsum	2	40
Talc	1	14

Note: M = Mohr’s Scale; V = Vickers’ micro hardness (mean, kgmm⁻²)

This test is useful as a rapid and portable qualitative test for hardness, where conventional hardness testers are not available or practicable. To make the Mohr’s scale to be more quantitatively acceptable by engineers and designers, Townhill-Rewston (1984) derived a correlation between Vickers’s hardness test and scratch hardness and the values in Table 2 were obtained. With the above table the Mohr’s value can be more accurately determined.

Abrasion Resistance

Abrasion resistance represents the resistance of the stone’s surface to wear, usually caused by pedestrian traffic or objects such as the wheels on the legs of furniture. In selecting stone for pavement materials, one must determine the abrasion resistance. Granite and bluestone (Basalt) are highly desirable as flooring material due to their hardness and uniform wearing qualities (Quick, 2002).

The use of softer stone for demanding applications may be difficult to justify in terms of the amount of repair and maintenance required over the expected lifetime of the surface. Mixing stones of different abrasion resistance characteristics causes maintenance problems, and uneven wear and potential trip hazards (Lewis, 1995). Tests include the Cerchar Abrasivity index, modified Tabor Abrasion test and ASTM C241-90 methods respectively

MATERIALS AND METHODS

The samples for this work were collected from Ikole, Ikere and Ewu (Ekiti State); Supare and Ore (Ondo State); Awo (Osun State) in order to have samples from wide areas. The strength properties as discussed above were determined in Rock Mechanics Laboratory of University of Exeter, United Kingdom while the mineralogical analysis was done in the Mineralogical Laboratory of the same institution. The Carnsew’s and Holman’s granites, both from Cornwall, United Kingdom were used as controlled laboratory work to ensure that the values obtained for Nigeria granite are accurate

Compressive Strength Test

The uniaxial compressive strength test is the most widely used measure of the strength, deformation and fracture characteristics of the rock because of its accuracy. The uniaxial compressive strength test (UCS), is relatively costly, time consuming and uses standard equipment, but the results are more reliable than other test methods and it is required for much detailed design (ISRM, 1979).

The procedure for the test is as stated in ISRM (1979). Uniaxial compressive strength test is typically characterized by loading a cylindrical sample with a diameter of approximately 50mm and length to diameter (L/D) ratio of 2.5:1 axially until

the specimen fails. The strength of the rock is derived as follows (ISRM, 1979):

$$\sigma_c = \frac{P_{max}}{A} \text{ -----(1)}$$

where σ_c is the uniaxial compressive strength (UCS) of the rock (MPa), P_{max} is the peak load (kN) and A is the initial cross sectional area of specimen (m²).

Where the core length constrains results with L/D values less than 2, it is recommended that the test results be recorded as both uncorrected measurements and values corrected to a normal value using following formula (ISRM, 1979).

$$\sigma_{c2} = \frac{8\sigma_c}{(7 + 2D/L)} \text{ -----(2)}$$

where σ_c is the uncorrected measured uniaxial compressive strength (MPa), D is the specimen diameter (m), L is the specimen length (m) and σ_{c2} is the corrected uniaxial compressive strength (MPa) of the specimen under test.

Flexural Strength Test (Three Point Loading Method)

This method used the arrangement of beam as specified by ASTM. It involves placing a sample between two pairs of rollers at the ends and the third points and loading until failure occurs. The procedure is as specified in ASTM C880-98.

The flexural strength is calculated as follow (ASTM, 2001a):

$$\sigma_b = \frac{3WL}{4bd^2} \text{ -----(3)}$$

where σ_b is the flexural strength of the rock sample (MPa), W is the maximum load at failure (kN), L is the span (mm), b is the width of specimen (mm), d is the depth of the specimen (mm)

The preferred ratio of L to d is specified by ASTM (2001a) as follows:

$$L = 10d \text{ -----(4)}$$

Hardness Test (Scratch Hardness Method)

This method is used in this work as it makes it easier to determine the hardness of the rock directly. The procedure is as stated in ISRM (1979). This involved scratching the rocks with the minerals in the Moh's scale of hardness. This is done until two values were obtained; the minerals that scratched the rock and the one that the mineral scratched. The hardness values of these two minerals were obtained and added together with the average of the values as the hardness of the rock under consideration.

Abrasion Resistance (ASTM C241-90)

This method is useful in indicating the differences in abrasion resistance between the various building stones. The procedure is as stated in ASTM C241-90 The sample is placed in an abrasion testing apparatus and abraded for 225 revolutions. The specimen is removed from the machine, brushed free of dust and weighed to the same precision as for the original weight (ASTM, 2001b).

The abrasion resistance is calculated using the formula (ASTM, 2001b):

$$Ha = \frac{10G(2000 + W_s)}{2000W_a} \text{ --(5)}$$

where Ha is the abrasion resistance, G is the bulk specific gravity of the sample, W_s is the average weight of the specimen (g) and W_a is the loss in weight during the grinding operation (g).

Absorption Test (ASTM: C97-02)

This method is a standard method for determining the absorption of stone. The procedure is as stated in ASTM (2001c).

This involves cutting the sample into cube of size 60 x 50 x 30mm. All surfaces are reasonably smooth and at least 4 different samples were tested. The samples were dried for 48hrs in oven at a temperature of 60 +/- 2^o. At the 46th, 47th and 48th hours, the specimens were weighed to ensure that the weights are constant. If the weight continues to drop, continued drying for another three hours is recommended until the weight remain the same.

After drying, the samples were cooled for 30 minutes and the weight determined to nearest 0.001g. The samples were completely immersed in distilled water at 22 +/- 2^o for 48 hours. At the end of this period, the samples were removed from the water and surface dry and weight to nearest 0.001g.

The average absorption is obtained from the formula below, ASTM (2001c):

$$\text{Absorption weight (\%)} = \frac{(B-A)}{A} * 100 \text{ -----(6)}$$

where A is the weight of the dried specimen (g) and B is the weight of the specimen after immersion (g).

RESULTS AND DISCUSSIONS

The results of the mechanical properties of the selected granites and the mineralogical analyses (Table 3) show that there is a clear relationship between the mineralogy and mechanical properties of the granites. From the results as shown in Table 3, it can be observed that granites with high percentage of feldspar experience crack initiation earlier than those with low percentage of feldspar. This implies that the percentage of feldspar significantly affect the crack

initiation level of the granites. Similarly, those granites that are equigranular experience high crack damage level than those that are porphyritic with exemption of Ikere granite.

Evaluation of the mineralogy of granites and mechanical data generated from this study shows that Awo and Ikole granites fall in the group of granodiorite, Supare and Ikere fall in a group of monzogranite while Carnsew, Ewu, Ore and Holman's granites fall in syeno-granite (Figure 2).

The granites that fall within these regions are considered suitable for dimension stone production. K-feldspar rich granite and tonalite may have limited application due to high percentages of feldspar.

Quartzolite and quartz-rich granitoids may not be suitable due to their brittle nature. All granite outside these regions are predominantly feldspar (k and plagioclase) will result in a significant reduction in mechanical properties and this in turn make them unsuitable for all dimension stone application. The alteration of Ikere granite significantly reduced the crack initiation and crack damage and invariably other mechanical properties compared to other granites with the same mineralogical composition. This implies that there is a significant negative effect of alteration on mechanical properties of granites.

Table 3: Summary of mineralogy and mechanical properties of selected granites from some parts of SW Nigeria with Carnsew's and Holman's granites (Cornwall, United Kingdom) as control laboratory work.

Properties	Granite locations							
	Ewu	Ore	Awo	Ikere	Supare	Ikole	Carnsew	Holman
Physical								
Texture	Porphyritic	Porphyritic	Equi	Equi	Porphyritic	Equi	Porphyritic	Porphyritic
Average grain size (mm)	3.00	1.25	0.55	1.13	1.39	0.85	1.2	1.0
Mineralogy								
Quartz (%)	<20	30	35	25	32	48	43	40
Feldspar (%)	65	45	30	67	65	40	45	52
Biotite (%)	5	14	15	8	2	10	5	3
Hornblende (%)	10	8	15	-	-	-	-	-
Mechanical								
Crack initiation (σ_{ci}) (MPa)	90	110	160	70	90	140	66	66
Crack damage (σ_{cd}) (MPa)	142	140	168	90	110	160	86	84
UCS (MPa)	154	144	175	123	130	165	131	130
Modulus of elasticity (GPa)	57	43	50	32	43	45	38	48
Poisson's ratio	0.25	0.22	0.15	0.13	0.30	0.26	0.26	0.29
Flexural strength (MPa)	14.3	-	20.5	16.8	7.9	10.2	19.8	19.9
Absorption (%)	0.03	0.09	0.05	0.19	0.16	0.11	0.14	0.15
Vickers hardness (GPa)	15.5	10.8	15.5	10.8	10.8	10.8	10.8	10.8
Abrasion resistance	33.5	-	34.4	24.4	26.8	26.5	27.9	26.2

Note: Equi = Equigranular

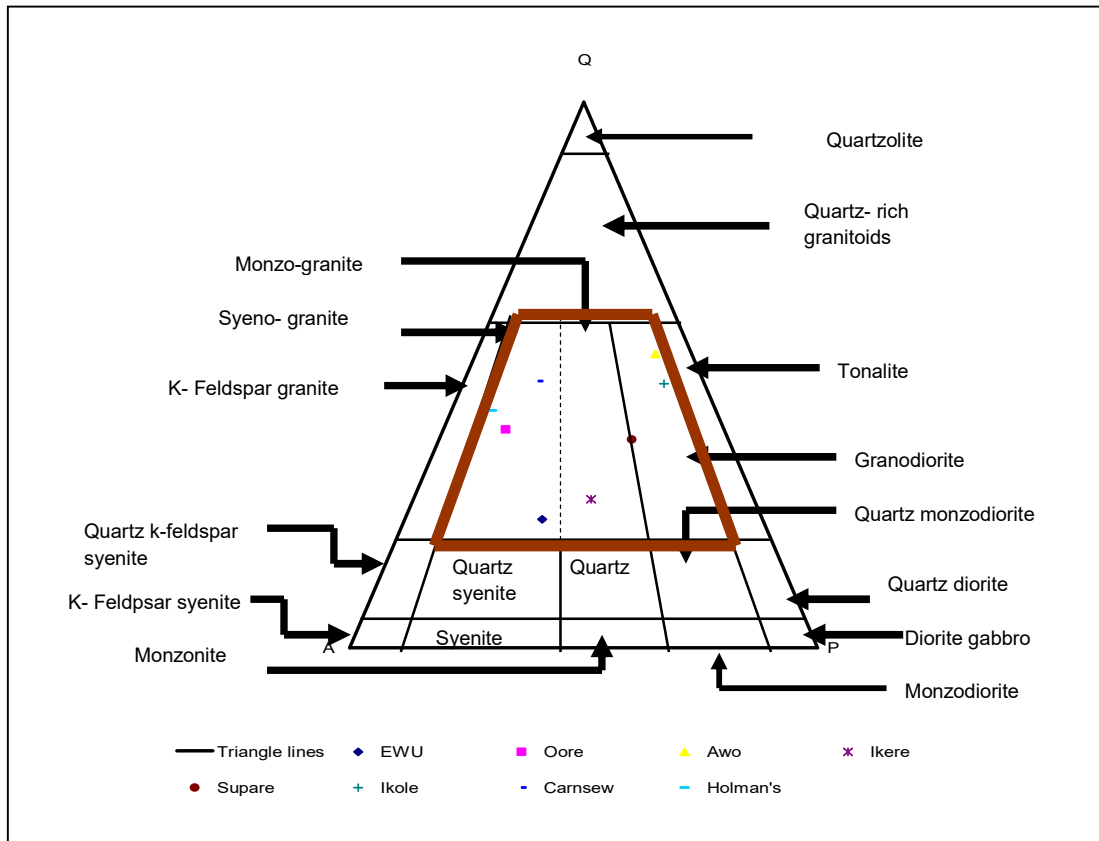


Figure 2: QAP plots of granites under study

CONCLUSION

By comparing mineralogy of the selected granites and the geotechnical data obtained as shown in Table 3 and Figure 2 above, it was observed that granodiorite, monzogranite, monzogranite and synogranite are suitable for dimension stone production as they meet the required mechanical properties for their suitability for dimension stone production. K- feldspar and tonalite granites may have limited application as a result of high percentage of feldspar which will significantly reduce their mechanical properties thus their applicability for dimension stone production. Quartzolite and quartz-rich granitoidals are considered not suitable for dimension stone production due to their brittle nature. Other granites outside these regions are considered unsuitable for dimension stone production due to their predominantly feldspar.

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