Relationship between Petrography and Uniaxial Compressive Strength of Some Crystalline Basement Complex Rocks of some Areas in Southwestern Nigeria

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Abstract

The petrography and uniaxial compressive strength of six crystalline basement complex rocks of Akure and Igarra areas were studied, analyzed and correlated. The outcrops of porphyritic biotite granite, biotite granite and lamprophyre (in Igarra) as well as gneiss, granite gneiss and charnockitic rocks (in Akure) were examined and sampled. Thin sections were prepared from the samples and investigated for the petrographic characteristics. Photomicrographs were taken and analyzed with the aid of "ImageJ". The UCS of the rock types was determined with aid of Instron Universal tester "3369". The Schmidt rebound hammer was also used to estimate the UCS. The average modal compositions of the major minerals range from 16 to 29% (quartz), 19 to 36% (plagioclase), 5 to 41% (biotite) and 4 to 37% (microcline). The petrography further showed that some of the rocks types particularly charnockitic rocks possessed micro-structures (micro-cracks, bent lamellae, distorted/deformed twinning and undulose extinction). The UCS of the rock types are 171MPa (lamprophyre), 149MPa (granite gneiss), 117MPa (biotite granite), 101MPa (gneiss), 82MPa (charnockitic rocks) and 56MPa (porphyritic biotite granite). The correlation coefficient (r) of the relationship between the mineral content and the UCS evaluated the highest value of 0.6229 for quartz. Textural and micro-structural characteristics of the rock types were discovered to have more influence on the UCS than the mineral content.

Keywords: Petrography, UCS, ImageJ, micro-cracks, Schmidt hammer.

1. Introduction

Uniaxial compressive strength was recommended as the best compressive strength test that could be carried out on rocks (Quick, 2002). The test is tedious, time consuming and expensive to carry-out (Teme, 1983; Aydin & Basu, 2005). This strength characteristic is believed to be affected by some factors which include petrography (mineral content, texture and microstructures) of the rock being tested (Liu *et al*. 2005, Mendes *et al*. 1966, Merriam *et al.* 1970, Onodera & Asoka 1980, Tug rul & Zarif, 1999).

The basement complex of Nigeria has been various classified by workers which include Rahaman (1976, 1988); Odeyemi (1988) and Adekoya *et al*. (2003). Adekoya *et al*. (2003) classified the complex as follows:

(i) Gneiss-migmatite-quartzite complex,
(ii) The schist belts which are low to medium grade supracrustal and meta-igneous rocks;
(iii) The Pan African granitoids (older granites) and other related rocks such as charnockitic rocks and syenites, and
(iv) Minor felsic and mafic intrusives.

The rocks that were tested in this research were from the Igarra and Akure in the southwestern part of Nigeria (Fig. 1) and fall into categories (i) and (iii) of the aforementioned classification.

The following rock types were selected for the research (a) from Akure: (i) gneiss, (ii) granite gneiss and (iii) charnockitic rock and (b) from Igarra: (i) biotite granite, (ii) porphyritic biotite granite and (iii) lamprophyre.

2. Materials and Methods

2.1 Field study: The rock types were selected to reflect varieties. The selected rock types were studied in the field for their relationships, texture, mineralogy and structures. They were sampled for laboratory studies. The samples were labeled Ak001 for gneiss, Ak002 for granite gneiss, Ak003 for charnockitic rock, Ig001 for porphyritic biotite granite, Ig002 for biotite granite and Ig003 for lamprophyre.

The Schmidt rebound hammer was used to acquire rebound values which was converted to UCS with the Deere & Miller graph (Ademeso, 2008).

2.2 Laboratory Study: Thin sections were prepared from the samples and the thin sections were studied under the petrographic microscope with the photomicrographs of significant features taken. The modal composition was carried out with the aid of "ImageJ" (Ademeso, 2010).

The UCS of the rock types was determined with the Instron Universal Tester. Specimens of the rock types were prepared in line with ISRM (1979). The graph plotted by the computer was subjected to post failure characteristics (PFC) test (Hoek & Brown, 1997). The yield strength column of the table of values generated by the computer was also inspected to confirm if the tests got to the yield point without which the results were unacceptable.

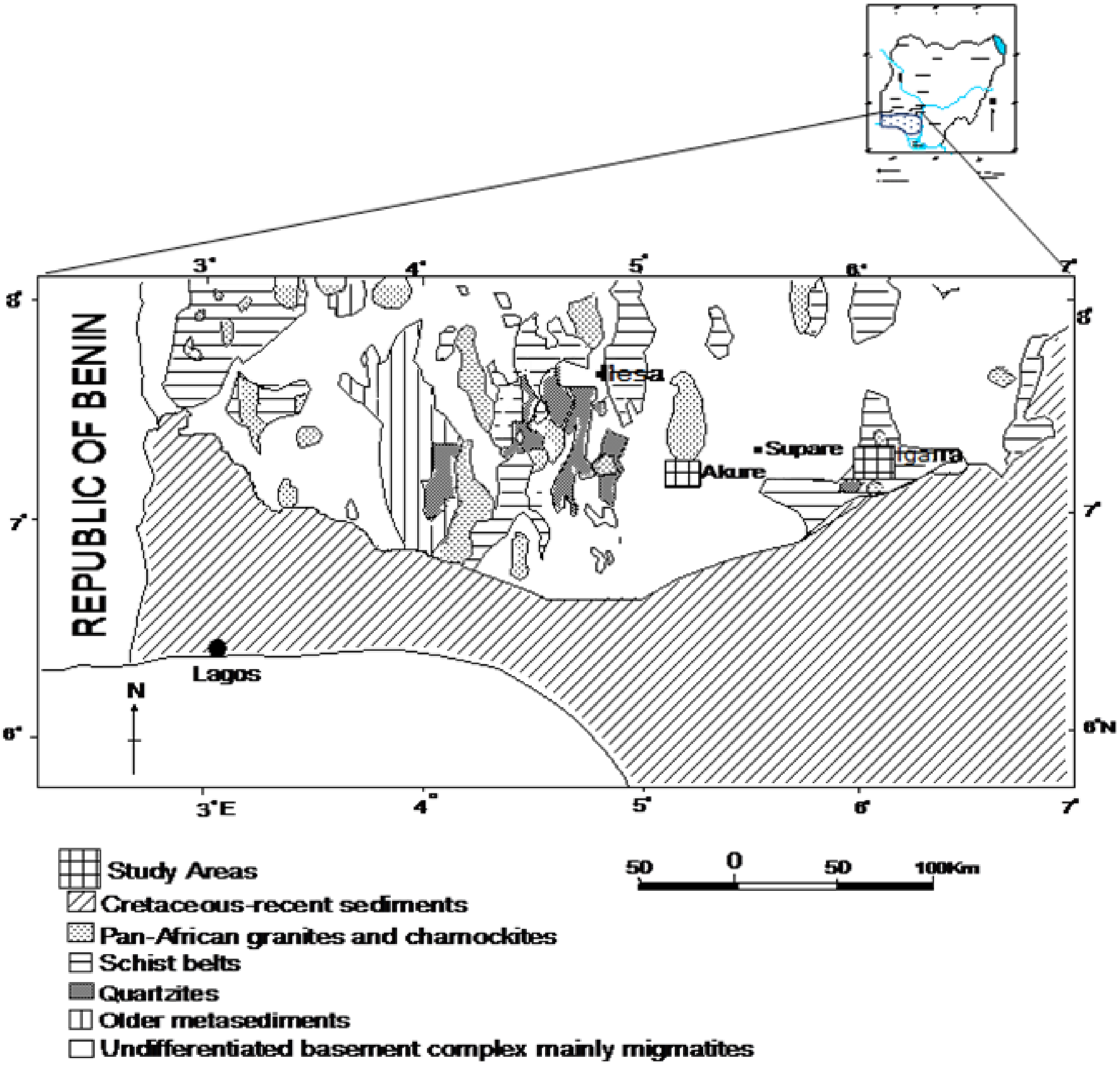


Fig. 1: Geoogical Map of Southwestern Nigeria Showing Study Areas.

2.3 In converting rebound values to UCS, the mean of at least 10 single impact readings were calculated and the values that deviated from the mean by more than seven units were discarded and the remaining values considered for further treatment in accordance with ASTM (2001).

The data collected from different tests were treated statictically with Microsoft Office Excel 2007.

3. Results

3.1 Field Characteristics and Petrography

The field characteristics and petrography of the rock types are presented as follow:

(a) Gneiss occurs as inselberg and hills. The gneissic component is essentially dark-coloured while the pegmatitic part is generally light-coloured. Petrographically, the rock is medium to coarse grained and it contains plagioclase, quartz, biotite, hornblende, and orthoclase as major minerals while hypersthene, muscovite, pyroxene and mymerkite form the accessory. The modal content of the minerals is 36%, 25%, 21%, 7%, 6%, 3%, 1%, 1%, and 0.3% respectively.

(b) The granite gneiss occurs as domes, hills and pavement outcrops and is in contact with other rock types of the gneiss-migmatite-quartzite complex. Macroscopically, the weakly foliated rock is medium grained with biotite flakes forming alignment that imparts a gneissose structure to the rock. Microscopically, quartz, biotite, plagioclase, microcline and hornblende constitute the major minerals in thin section of the rock while mymerkite occurs sporadically. The modal analysis of the rock gives 29%, 23%, 21%, 18%, 8% and 1%.

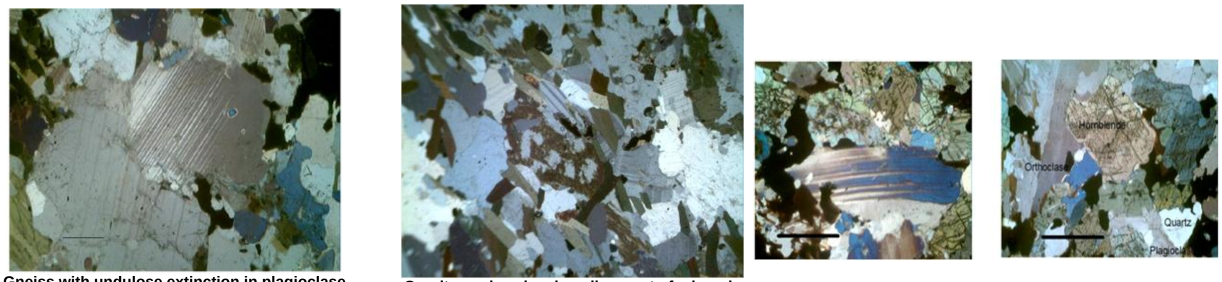
(c) The charnockitic rocks occur as small hills and pavement outcrops within the gneiss-migmatite-quartzite complex. Plagioclase, biotite, quartz, hypersthene, hornblende, muscovite and orthoclase are the major minerals while opaque minerals (probably iron oxide) and zircon are the accessories identified in the thin section of the rock. The modal analysis of the rock gives 32%, 16%, 16%, 16%, 11%, 4%, 3%, 1% and 1% respectively. The petrography further revealed (i) undulose extinction in quartz and plagioclase; (ii) distorted twinning in plagioclase; (iii) bent lamellae in plagioclase; (iv) compressed plane of carlsbad twin of orthoclase; and (iv) micro-cracks in virtually all minerals of the rock (Ademeso, 2009).

(d) The porphyritic biotite granite occurs as pavement outcrops, small hills and inselbergs in the area. The rock is essentially light coloured with large greyish feldspar phenocrysts. The groundmass of quartz, biotite and feldspar, although medium to coarse grained, is generally finer than the phenocrysts giving the rock a porphyritic texture. Xenoliths of phyllite and metaconglomerate occur in the outcrops. Biotite, plagioclase, quartz, microcline and hornblende are the major minerals in the thin section of the rock while mymerkite and zircon constitute accessories. The result of the modal analysis of the rock is 31%, 30%, 23%, 10%, 4%, 3% and 1%, respectively.

(e) Granite occurs as small hills and boulders (some of which rest precariously on the top of the hills). The rock which was well exposed at a road cut along Ibillo-Igarra road is characterized by pavement and craggy outcrops. It is generally light coloured (leucocratic) with medium to coarse grained texture. The occurrence of microcline, plagioclase and quartz as major minerals with biotite and hornblende as accessory is revealed from the microscopic examination of the thin sections of the rock. The result of the modal analysis of the rock is 37%, 30%, 27%, 5% and 1%, respectively.

(f) The Lamprophyre intrusives occur as dykes within the quartz-biotite-schist and gneiss complex. The road-cut along Igarra-Auchi road reveals the rock as a dyke with an E-W trend, having a width of about 60m. Some outcrops of the rock occur as N-S trending dykes of about 50 to 75cm width. Generally the contacts with the host rocks are sharp. Biotite, quartz, plagioclase, hornblende, microcline and opaque minerals are the major minerals identified in the thin section of the rock while zircon is the accessory. The result of the modal analysis is 41%, 23%, 21%, 6%, 5%, 5% and 0.5% respectively.

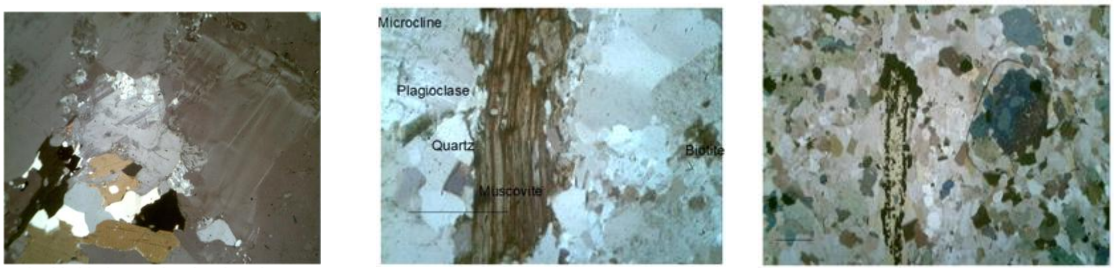
The photomicrographs and the modal composition of the rock types are presented in Fig. 2 and Table 1 respectively.



Gneiss with undulose extinction in plagioclase. Bar scale is 2um.

Granite gneiss showing alignment of minerals particularly mica. Bar scale is 2um.

Charnockitic rock showing undulose extinction, bent lamellae, micro-cracks and distorted as well as incomplete twinnings. Bar scale is 3um.



Porphyritic biotite granite showing phenecryst of plagioclase. Bar scale is 2um

Biotite granite with bent lamellae of mica. Bar scale is 4um

Lamprophyre showing biotite phenocrysts in fine groundmass. Bar scale is 1um.

Fig. 2: Photomicrographs of some of the rock types

Table 1: Modal Content of the minerals in the rock types

S/No	Sample No	Modal (%) Content of Minerals												
		Qtz	Pla	Mic	Ort	Bio	Hyp	Mus	Hnb	Pyx	Zir	Mym	Opa	Total
1.	Gn(Ak001)	25	36	-	6	21	3	1	7	1	-	0.3	0.1	100.4
2.	Ggn(Ak002)	29	21	18	-	23	-	-	8	-	-	1	-	100
3.	Chk (Ak003)	16	32	-	3	16	16	4	11	-	1	-	1	100
4.	Pgr(Ig001)	23	30	10	-	31	-	-	4	-	1	4	-	100
5.	Gr(Ig002)	27	30	37	-	5	-	-	-	-	1	-	-	-
6.	Lam(Ig003)	23	21	4	-	41	-	-	6	-	-	-	5	100

Generally, the photomicrographs of the rocks show varying degrees of microstructures ranging from mineral alignment to undulose extinction to microcracks to bent lamellae and kinked or bent twin planes. The microstructures are more conspicuous in the charnockitic rocks. Most of the thin sections have grains with sutured margins.

3.2 Schmidt Rebound Hammer

The rebound values were acquired, their mean evaluated, the adjusted mean (the evaluated mean after the values that deviated from the original mean by more than seven units have been discarded) calculated and the UCS estimated with the aid of the Deere and Miller (1966) graph. This was done for all the rock types as exemplified by the table for granite gneiss (Ak002) (Table 2). The UCS of each rock types was estimated as explained and the result is presented in Table 3.

Table 2: Conversion of rebound values of granite gneiss (Ak002) to UCS using Deere and Miller (1966) Graph

S/No	G.P.S. Reading	Rebound Values	Mean	Adjusted Mean	Density (g/cc)	UCS (MPa)
1	005°13'46"E 07° 14' 03"N	48, 48, 54, 53, 45, 54, 46, 46, 52, 54.	50	50	2.67	150
2		53, 48, 50, 52, 55, 52, 56, 55, 50, 52.	52	52	2.67	163
3		48, 50, 53, 49, 51, 52, 54, 46, 53, 50.	51	51	2.67	156
4		51, 48, 49, 52, 55, 50, 48, 54, 53, 45.	51	51	2.67	156
5		46, 54, 49, 45, 53, 54, 55, 45, 53, 48	50	50	2.67	150
6		50, 47, 55, 53, 45, 53, 48, 51, 49, 41.	45	47	2.67	131
7		42, 45, 53, 55, 50, 46, 48, 53, 51, 50.	49	49	2.67	146
8		55, 44, 50, 51, 49, 53, 45, 51, 46, 46.	49	49	2.67	146
9		53, 46, 52, 46, 55, 45, 50, 49, 49, 50	50	50	2.67	150
10		45, 46, 45, 54, 48, 51, 47, 49, 53, 50.	49	49	2.67	146

3.3 UCS Determination with "Instron Universal Tester 3369"

Fig. 3 is the plot of compressive load versus compressive extension of the test for the determination of the UCS of the rock types with "Instron Universal Tester 3369" while Table 4 was generated for the compression test.

3.4 Comparison of the UCS estimated with the Schmidt Rebound hammer and that determined with "Instron Universal Tester".

Table 5 compares the UCS from the Schmidt Rebound hammer and the "Instron Universal Tester". As a result of the very small sizes of the specimens that were used for the test on the Instron, the results were only used for comparative. The UCS estimated from the Schmidt Rebound hammer was used for further analysis.

Table 3: Summary of the UCS of the rock types derived from the conversion of rebound values.

S/No	Rock Type	Sample No	UCS (MPa)	
			Range	Average
1.	Gneiss	Ak001	90-150	101
2.	Granite gneiss	Ak002	131-163	117
3.	Charnockitic rock	Ak003	68-95	82
4.	Porphyritic biotite granite	Ig001	44-68	56
5.	Biotite granite	Ig002	87-163	117
6.	Lamprophyre	Ig003	135-188	171

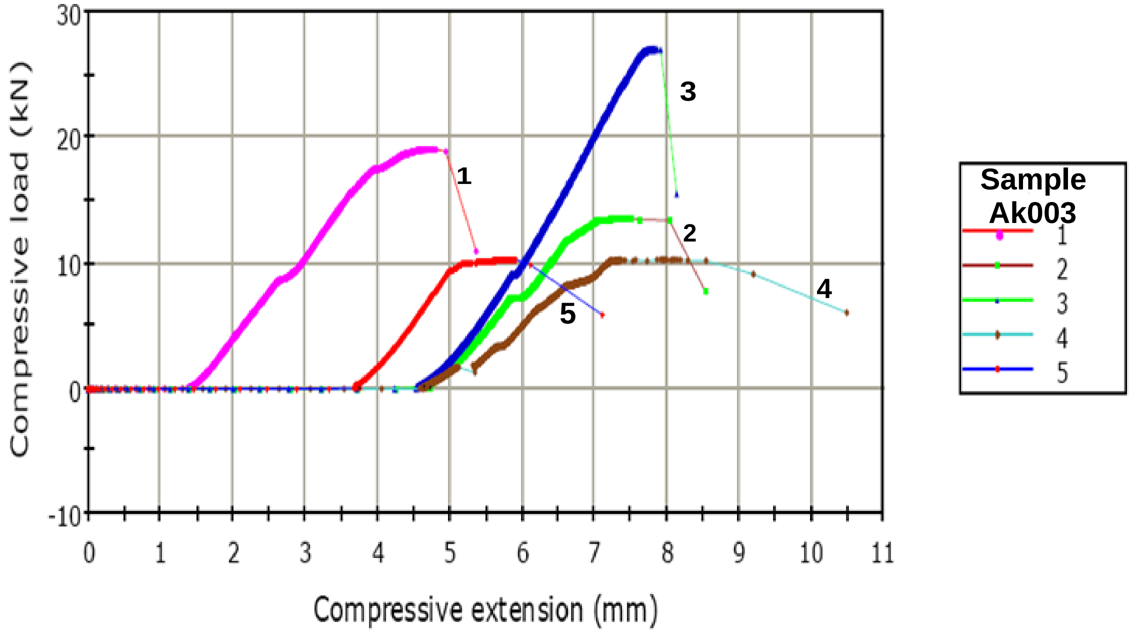
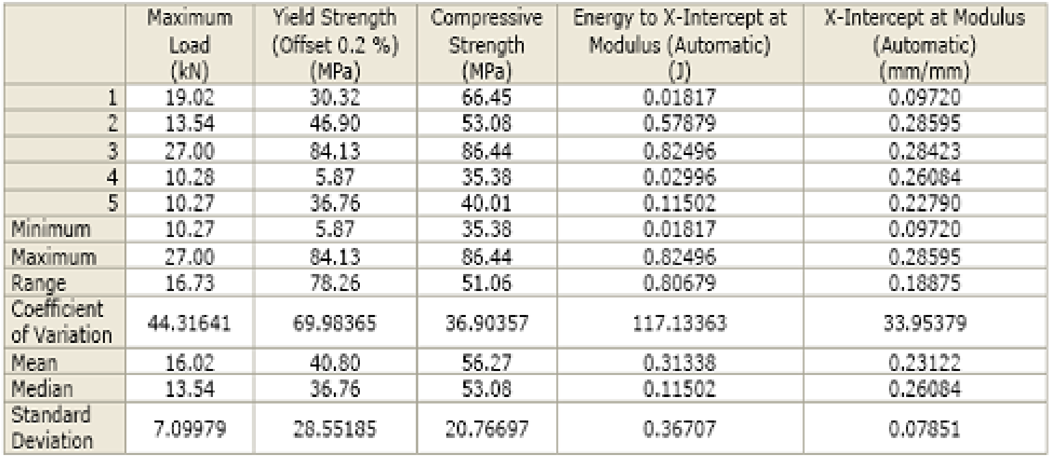


Fig. 3: Instron 3369 generated graph during the determination of UCS of charnockitic rock (Ak003).

Table 4: Instron 3369 generated compression results for charnockitic rock (Ak003)



	Maximum Load (kN)	Yield Strength (Offset 0.2 %) (MPa)	Compressive Strength (MPa)	Energy to X-Intercept at Modulus (Automatic) (J)	X-Intercept at Modulus (Automatic) (mm/mm)
1	19.02	30.32	66.45	0.01817	0.09720
2	13.54	46.90	53.08	0.57879	0.28595
3	27.00	84.13	86.44	0.82496	0.28423
4	10.28	5.87	35.38	0.02996	0.26084
5	10.27	36.76	40.01	0.11502	0.22790
Minimum	10.27	5.87	35.38	0.01817	0.09720
Maximum	27.00	84.13	86.44	0.82496	0.28595
Range	16.73	78.26	51.06	0.80679	0.18875
Coefficient of Variation	44.31641	69.98365	36.90357	117.13363	33.95379
Mean	16.02	40.80	56.27	0.31338	0.23122
Median	13.54	36.76	53.08	0.11502	0.26084
Standard Deviation	7.09979	28.55185	20.76697	0.36707	0.07851

Table 5: Comparison of UCS of the rock types determined/estimated with different methods.

S/No.	Rock Type	Sample No.	UCS (MPa)	
			Direct (Instron)	Schmidt Hammer
1.	Gneiss	Ak001	57	101
2.	Granite gneiss	Ak002	113	149
3.	Charnockitic rock	Ak003	86	82
4.	Porphyritic biotite granite	Ig001	88	56
5.	Biotite granite	Ig002	89	117
6.	Lamprophyre	Ig003	115	171

3.5 Correlation of UCS with the contents of quartz+feldspar, mica, quartz, feldspar, and minerals that are harder than 5 on the Mohs' scale of hardness.

The UCS of the rock types was correlated with the percentages of quartz+feldspar (Q+F), mica (M), quartz (Q), feldspar (F) and minerals that are harder than 5 on the Mohs' scale of hardness (X). The correlation coefficients were determined. Q has the highest correlation of 0.6228 with UCS while Q+F has the least of -0.0415 (Table 6). The spider diagram further portrays the correlation (Fig. 4). The scatter diagrams with lines of regression were also plotted to further show the correlation (Fig. 5).

Table 6: The correlation of UCS with percentages of Q+F, M, Q, F and X for the rock types.

(A)

S/No	Rock Type	Sample No	UCS(MPa)	(Q+F) %	M(%)	Q%	F%	X(%)
1	Gn	Ak001	101	67	22	25	42	78
2	Ggn	Ak002	149	69	23	29	40	76
3	Chk	Ak003	82	51	21	16	35	78
4	Pgr	Ig001	56	63	31	23	40	67
5	Gr	Ig002	117	94	5	27	67	95
6	Lam	Ig003	171	49	41	26	23	55

(B)

UCS	R^2	r
(Q+F)%	0.0017	-0.0415
M(%)	0.0544	0.2332
Q(%)	0.3880	0.6228
F(%)	0.0591	-0.2431
X(%)	0.0646	-0.2541

Note: (1) Gn = gneiss, Ggn = granite gneiss, Ch = charnockitic rock, Gr = biotite granite, Pgr = porphyritic biotite granite and Lam = lamprophyre.

(2) UCS {Y(MPa)} = the uniaxial compressive strength of the rock types, Q+F = quartz plus feldspar, M = mica, Q = quartz, F = feldspar and X = minerals harder than 5 on the Mohs' scale of hardness.

(3) (i) R^2 = the square of Pearson product moment correlation coefficient. (ii) r returns the correlation coefficients between two sets of data.

(4) (A) is the table of values and (B) is the table of correlation (R^2 and r).

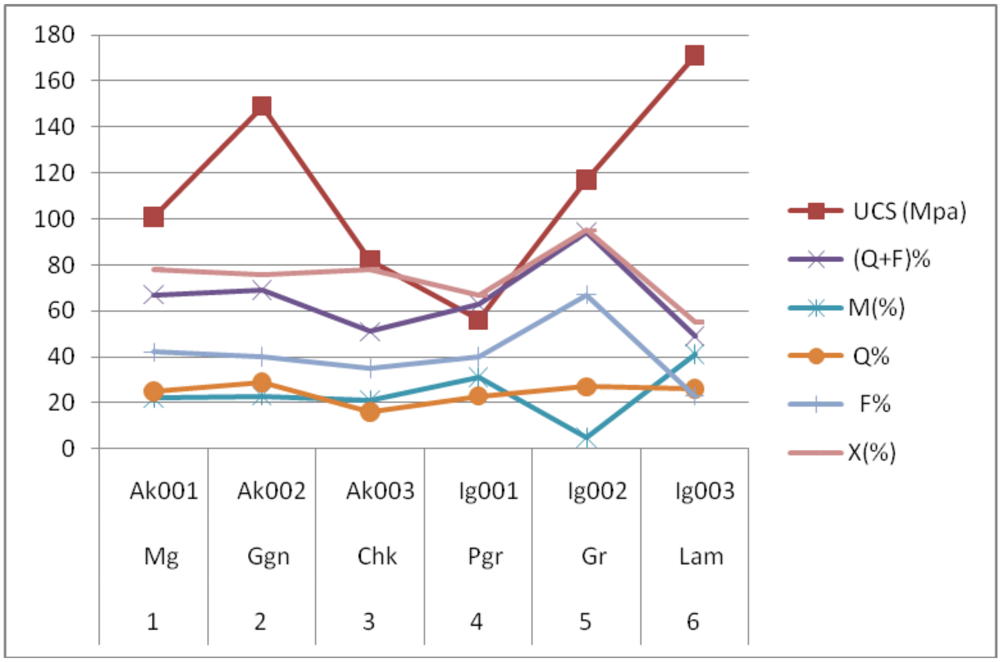
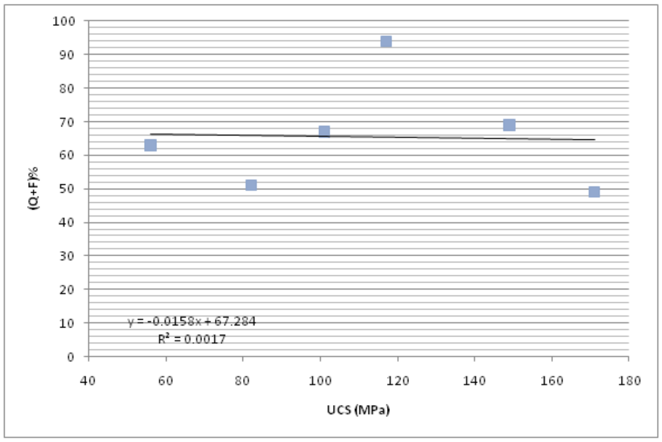
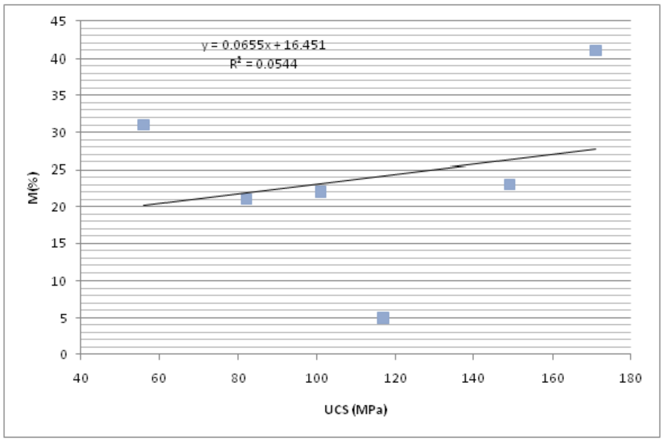


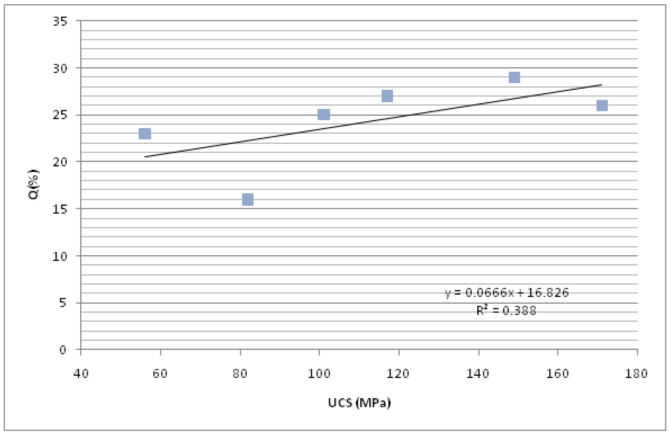
Fig. 4: Spider diagram relating percentages of quartz plus feldspar, mica, quartz, feldspar and minerals harder than 5 on the Mohs' scale with UCS for the rock types



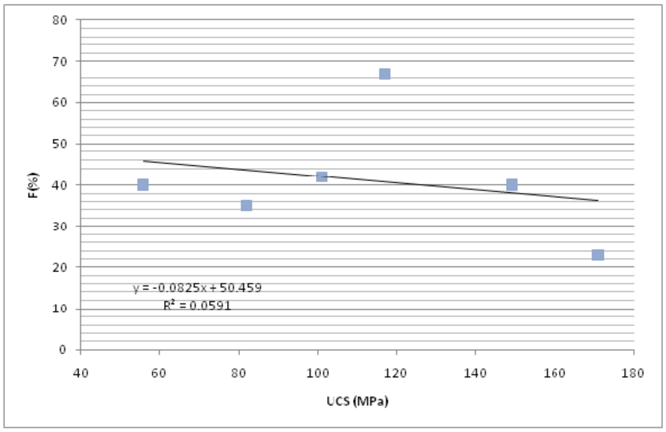
Q+F/UCS



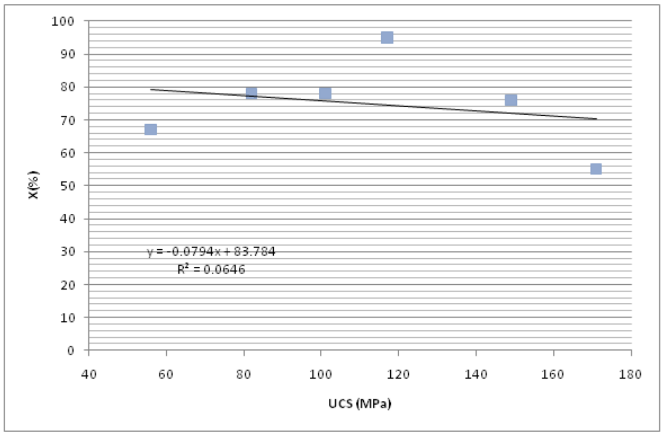
M/UCS



Q/UCS



F/UCS



X/UCS

Fig. 5: Scatter diagrams with lines of regression of the relationships between quartz+feldspar/UCS (Q+F/UCS), mica/UCS (M/UCS), quartz/UCS (Q/UCS, feldspar/UCS (F/UCS) and minerals harder than 5 on Mohs' scale/UCS (X/UCS).

4. Discussion

The correlation coefficient (r) of the relationship between UCS and the mineral content shows a somewhat intermediate value (0.6229) for quartz content (Q%). This implies that the UCS increases with quartz content of the investigated rocks and vice-versa. Such a deduction is consistent with the finding of Bell & Lindsay (1999) that established an increase in UCS with increase in the quartz content of sandstone. A careful look at the table comparing UCS with the minerals (Table 6) shows that although the charnockitic rock and porphyritic granite have the lowest percentages of quartz, the former which had the lower value exhibited a higher UCS value. This gives an indication that the percentage of quartz (or mineral) may not play significant part in determining the uniaxial compressive strength characteristics of the rocks. Using Brown (1981) classification, all the rock types except the charnockitic rock and porphyritic granite fall into the class of very strong rocks (which has a lowest UCS limit of 100MPa). These two rock types are expected to exhibit strength characteristics of granitic rocks (very strong rocks) since they are some types of granitic rock. This is an indication that their strength values might have been lowered. The UCS values of charnockitic rocks and porphyritic biotite granite which are lower than 100MPa most likely caused the r value to fall into the class of moderate linear relationship instead of the strong linear relationship (Ratner, 2003). The correlation coefficient would probably have been higher if the UCS of these two rock types were not diminished probably by the effects of texture and microstructures as observed in the thin sections. The medium to coarse grained texture and the petrographic characteristics [undulose extinction in both plagioclase and quartz, distorted and deformed twin lamellae, bending and kinking of the lamellae in plagioclase, micro-cracks in most of the hard mineral grains (Fig. 4.11)] of the charnockitic rocks are not in support of high strength in rocks (Mendes *et al*. 1966, Onodera & Asoka 1980, Akesson *et al*. 2004, and Liu *et al*. 2005). The characteristics of porphyritic biotite granite believed to be responsible for the relatively low UCS value include (i) the coarse grained texture of the rock, (ii) the wide variations in the sizes of the grains resulting from the porphyritic texture and (iii) about 71% of the mineral content being feldspar and mica which have been found to have high chances of developing microcracks on loading (Liu *et al*. 2005). According to Onodera & Asoka (1980), Tug rul & Zarif (1999), and Liu *et al.* (2005) these factors cause a reduction in mechanical strength of rocks. It can therefore be deduced that the weak correlation between quartz content and UCS is caused by the diminished values of UCS of the charnockitic rock and porphyritic biotite granite in particular. Furthermore, the texture and micro-structures that characterized the two rock types are believed to be responsible for their relatively low UCS values. Therefore the texture and micro-structures are believed to have more influence on the UCS than the mineral content.

5. Conclusion

The deductions imply that even if the percentage of hard minerals that are supposed to impart high UCS to a rock is high, the texture and preponderance of micro-structures may cause a lowering of the UCS even to a critical level. Conclusively, the textural and micro-structural characteristics of rocks generally seem to have more influence on the UCS of rocks than the mineral content.

6. Recommendation

It has been discovered that rock materials that are expected to exhibit very high UCS characteristics have yielded at very low points. This indicates that rock material components of engineering constructions might have been contributing to structural defects and failures. In order to avoid such catastrophe, petrographic analysis of rocks to be used for engineering works should be carried out alongside other engineering tests before application.

Acknowledgement

We sincerely appreciate the staff of Engineering Materials Development Institute, Akure, Nigeria for the use of "Instron Universal Tester". Dr M.A. Saliu is also highly appreciated for making the Schmidt Rebound hammer available for the work.

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