ANALYSIS OF VARIABILITY OF ROCK PROPERTIES INFLUENCING WEAR OF BIT

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Abstract: *This paper examines the analysis of variability of the rock properties influencing tool wear in quarries. Rock samples were collected from six different locations within the South Western Nigeria. These samples were tested in the laboratory for hardness, uniaxial compressive strength, point load strength index, silica content, and mineral composition using Schmidt hammer, 1100kN compression machine, X-Ray fluorescence spectrometer and petrological microscope respectively. The equivalent quartz content for all the samples were determined as well. The results obtained show that the value of Schmidt rebound value, uniaxial compressive strength, point load strength index and equivalent quartz content varies from 47.10 - 52.60, 90.6 -124.71MPa, 7.59 - 13.54 MPa and 45.60 - 63.53%. The average coefficient of variation for all the samples ranges 0.16- 3.01%. All wear parameters have relationship with silica content.*

Keywords: *Drill Bit, Wear, Variability, Silica Content, Rock, Strength, Rebounds, Quarries*

1. Introduction

Rock properties and types varied widely therefore, the capability of rocks to cause erosion or deterioration of drill bits/cutting tools will vary as well. Goktan and Ayday [1] confirmed that rock hardness is a function of the mineral composition, strength and bonding capability of the matrix material, hence, variations in these factors is expected to affect the performance of excavating or drilling machine. All these points to the fact that results of wear indices from one type of rock would be difficult and misleading to be transferred to another. Wear parameters of rocks play important role in mining operations such as drilling, extraction – loading and crushing of run-of-mine. However, there is possibility that the operation cost will be higher when exploiting rocks with higher wear parameters than rocks with lower wear parameters. In this study, rocks were tested in the field and in the laboratory. Larsen-Basse [2] identified the type of wear that could be initiated by hard and abrasive rocks are surface impact-spalling and surface fatigue–spalling. Montogomery [3] was of the view that micro-spall formation rate strongly depend on rock hardness and other wear parameters. Higher impact energy and rock hardness increases surface spalling [4]. Gatelier et al [5] expressed that mineral composition and fabric have key effect on damage mechanism and the two main mechanisms are compaction and micro cracking. Beste [6] observed from his study of cemented carbides that reptile skin formation is an important deterioration mechanism obtained when drilling in some soft rock types. He described the typical reptile skin as a pattern of plateaux and valley. The plateau encompasses several WC grains and has a polished surface. In the valleys, the WC grains are detached and fractured. The reptile skin often leads to catastrophic fracture, which can destroy a whole drill. Furthermore, Stjernberg et al [7] stated that the reptile skin that is not formed by a fatigue process is developed when drilling in low abrasive rock types and that it is formed after a pile up of tensile stressed in the surface layer. Rock is a heterogeneous material that likely to fracture through development, growth and coalescence of micro cracks [8].

Ersoy and Waller [9] stated in their work that external characteristics are major factors in determining the mechanical behaviour of rocks and measure of resistance to cutting/drilling tools. Rock texture has been defined as “the degree of crystallinity, grain size or granularity and fabric or geometrical relationship between the constituents of a rock [10]. Some of the compositional features include mineral content, cement type and degree of cementation or crystallization and bonding structure. Iphar and Goktan [11] observed that all studies about rock abrasiveness are grain size and cementation degree of quality, the geometry of abrasive mineral and mechanical strength. Microscopic rock properties such as equivalent quartz content and the degree of mineral interlocking are wear parameter that predominantly tool wear [12, 13].

The investigation of geotechnical wear indices show that Vickers Hardness Number of Rock (VHNR) and equivalent quartz content can be used for drill lifetime calculation [14, 15]. The assessment of about hundred (100) used bits showed that highly abrasive rock with a high compressive strength can lead to breaking of hard metal bit or even breakout of the bit's steel body [16]. Therefore, wear indices data were generated and their extents of variability were obtained by using coefficient of variation. Ultimately, investigation of variation of wear potential of rock formations of different settings will serve as a reliable data for accurate estimation of drilling, excavation and crushing tool consumption as well as cost.

2. Materials and methods

2.1 Location of the study area

The location map of the study area is shown in Figure 1.

2.2 Schmidt Rebounds Hardness Values

The rebounds hardness of the was done in accordance with ISRM (17) and the results are presented in Table 1

2.3 Uniaxial Compressive Strength

The test procedure was in accordance with ISRM [17] and ASTM [18] D 2938. The uniaxial compressive strength was determined using equation 1 as shown in Table 2

$$Co = \frac{P}{A} = \frac{P}{W.D} \quad (1)$$

where Co = Uniaxal compressive strength. MPa

P = the applied peak load, kN, W = Width of the sample, mm, D = Height of the sample, mm

2.4. Point load strength index

Five rock samples were prepared for each location to the standard suggested by International Society of Rock Mechanics ISRM [17] and American Society for Testing and Materials ASTM [19] D5731. The point load index was determined using equations 2-3 for blocks as presented in Table 3

$$Is = \frac{F}{W.D} \quad (2)$$

I_S = Point load Strength Index, W = Width of the sample, F = Applied load at Failure.

equation 2 was proposed by [20] to obtain I_S value for a standard diameter of 50 mm $I_{S(50)}$

$$Is_{50} = \frac{f_x F}{4\,W.D} \quad (3)$$

2.5 X- ray Fluorescence Test for Determination of Silica Content

The palletized samples were inserted into the sample holder were prepared in accordance with (ASTM C-118), so that the beams of x-ray light can fall on flat surface of the palletized sample the result as presented in Table 4

3. Results and Discussion

The coefficient of variation of wear parameters of rock samples from South Western Nigeria were determined to ascertain the variability of the various test parameters on each rock samples from this zone as presented in Tables (1-5). Therefore, the coefficient measures the variability of rock properties influencing wear of machine cutting elements such as drill bit, rock cutting blade and cutter picks. The Schmidt Hammer Rebounds number ranges from 47.10 for granite from Piccolo Buneli Quarry, Ore (OR02) to 52.60 for granite from Associated Granite Quarry, Igbo-Ora while coefficient of variation ranges from 2.67% to 3.66%. The Uniaxial Compressive Strength value varies from 90.65 Mpa for granite from Sonel Boneh Quarry, Ile-Ife (IF03) to 124.71 MPa for granite from Obasanjo Holding Quarry, Odeda (DE05). The coefficient of variation ranges 0.06% for granite from Obasanjo Holding Quarry, Odeda (DE05) to 3.82% for granite from Piccolo Buneli Quarry, Ore (OR02).

The point load strength index value varies from 7.59 MPa for granite from Sonel Boneh Quarry, Ile-Ife (IF03) to 13.54 MPa for granite from Obasanjo Holding Quarry, Odeda (DE05). The coefficient of variation ranges from 0.30% for granite from Associated Granite Quarry, Igbo-Ora (IG04) to 6.33% for granite from Johnson Industry Quarry, Akure (AK06).

The equivalent quartz content (EQC) value varies from 45.60% for granite from Sonel Boneh Quarry, Ile-Ife (IF03) to 63.53% for granite from Piccolo Buneli Quarry, Ore (OR02). The coefficient of variation ranges from 1.11% for granite from Associated Granite Quarry, Igbo-Ora (IG04) to for granite from Johnson Industry Quarry, Akure (AK06). The Silica content value varies from 67.71% for hornblende granite from Geovertrag Ado-Ekiti (AD01) to 78.02% for granite from Piccolo Buneli Quarry, Ore (OR02). The coefficient of variation ranges from 0.86% for granite from Sonel Boneh Quarry, Ile-Ife (IF03) to 1.06% for granite from Piccolo Buneli Quarry, Ore (OR02).

Silica content of the rock samples were correlated with the rock properties using method of least squares regressions. The equations of best-fit line correlation coefficient R^2 were determined for each regression. Fig. 1 establishes the relationship between the silica content and Schmidt rebounds value. The polynomial relationship between silica content and Schmidt hardness rebound value is expressed by equation 6 which is an equation of order 4 and

$$SC=0.658Rh^4-131.2Rh^3+9814Rh^2-32591Rh+4E+06, \quad R^2 = 0.961 \qquad (6)$$

where SC is the silica content and Rh is the Schmidt hardness rebound value

$$SC = -0.019\sigma_c^{\ 2} + 4.334\sigma_c - 166.6, \quad R^2 = 0.882 \qquad (7)$$

where SC is the silica content and σ_c is the uniaxial compressive strength. The plot of silica content as a function of the point load strength index, this is presented in Figure 3, a polynomial function of order 3 exist between silica content and point load index. The equation of the curve is given as

$$SC = -0.650I_{s50}^{3} + 20.04\ I_{s50}^{2} + 198.9\ I_{s50} + 710.6, \quad R^2 = 0.933 \qquad (8)$$

where SC is the silica content and I_{s50} is the Point load strength index. The plot of silica content as a function of equivalent quartz content is presented in Figure 4, a polynomial relationship of an equation of order 3 exist between them. The equation of the curve is given as

$$SC = 0.019EQC^{\ 3} - 3.098EQC^{\ 2} + 165.3EQC - 2846, \quad R^2 = 0.738 \qquad (9)$$

Where SC is the silica content and EQC is the equivalent quartz content.

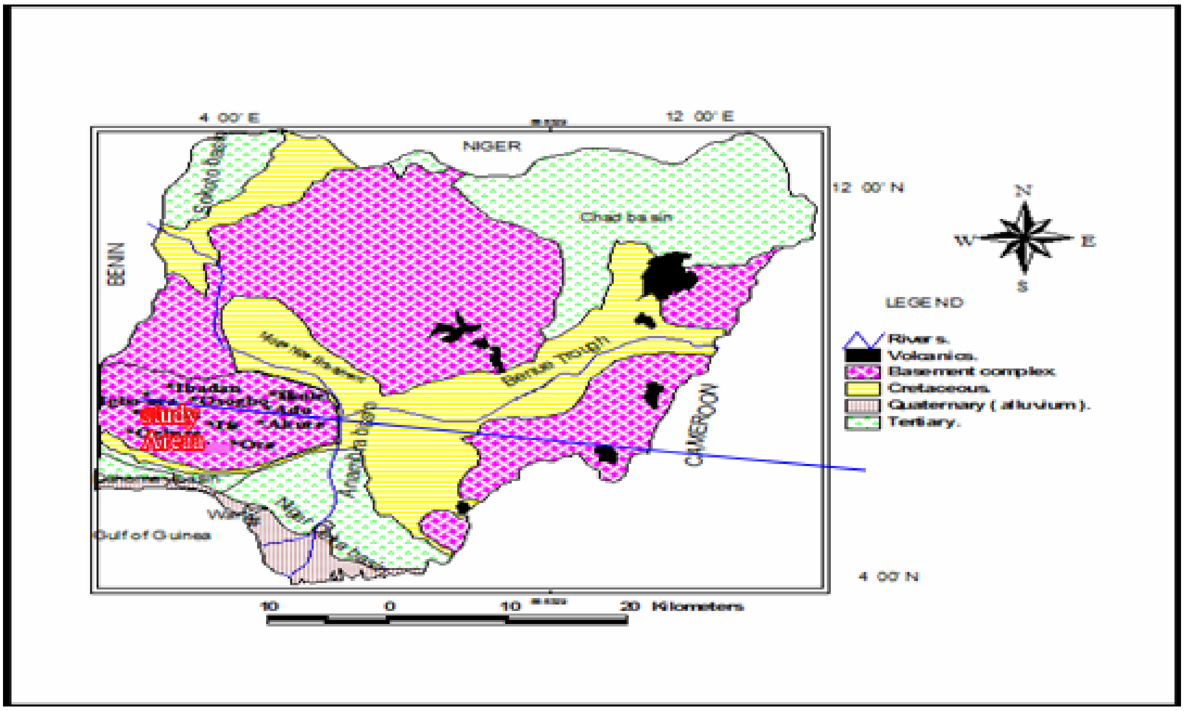

Fig. 1: Map of Nigeria showing the study area

Table 1: Results of L-Type Schmidt hammer Rebounds Hardness Values for S/W Nigeria Rocks

Rock Code Number	Rock Type	Rebounds Hardness Values	Standard Deviation	Coeff. of Variation (%	Average Coeff. of Variation (%)
AD01	Hornblende Granite	52.00	1.41	2.71	3.01
0R02	Granite	47.10	1.26	2.67	
IF03	Granite	48.00	1.48	3.08	
IG04	Granite	52.60	1.93	3.66	
DE05	Granite	51.00	1.65	3.23	
AK06	Granite	50.90	1.40	2.75	

Table 2: Results of uniaxial compression test of selected rocks from S/W Nigeria

Rock Code Number	Rock Type	Compressive Strength MPa	Standard Deviation	Coefficient of Variation (%)	Average Coefficient of Variation (%)
AD01	Hornblende Granite	91.48	0.09	0.10	1.65
0R02	Granite	121.54	4.65	3.82	
IF03	Granite	90.65	0.25	0.27	
IG04	Granite	96.65	1.84	1.90	
DE05	Granite	124.71	0.07	0.06	
AK06	Granite	98.70	3.71	3.75	

Table 3: Results of point load strength index I s50 of selected rocks from S/W Nigeria

Rock Code Number	Rock Type	Point Load strength Index I s50 MPa	Standard Deviation	Coefficient of Variation (%)	Average Coefficient of Variation (%)
AD01	Hornblende Granite	8.85	0.26	2.91	2.78
0R02	Granite	10.50	0.09	0.87	
IF03	Granite	7.59	0.14	1.89	
IG04	Granite	9.56	0.03	0.30	
DE05	Granite	13.54	0.59	4.35	
AK06	Granite	10.10	0.64	6.33	

Table 4: Results of equivalent quartz content of selected rocks from S/W Nigeria

Rock Code Number	Rock Type	Equivalent Quartz Content (%)	Standard Deviation	Coefficient of Variation (%)	Average Coefficient of Variation (%)
AD01	Hornblende Granite	57.22	0.96	1.67	1.73
0R02	Granite	63.53	1.23	1.93	
IF03	Granite	45.60	0.75	1.64	
IG04	Granite	53.96	0.60	1.11	
DE05	Granite	61.79	0.98	1.58	
AK06	Granite	45.95	1.13	2.45	

Table 5: Results of silica content of selected rocks from S/W Nigeria

Rock Code Number	Rock Type	Silica Content %	Standard Deviation	Coeff. of Variation (%)	Average Coef. of Variation (%)
AD01	Hornblende Granite	67.71	0.93	1.43	1.30
0R02	Granite	78.02	1.06	1.35	
IF03	Granite	70.95	0.86	1.21	
IG04	Granite	73.72	0.97	1.31	
DE05	Granite	76.09	1.04	1.36	
AK06	Granite	74.78	0.88	1.17	

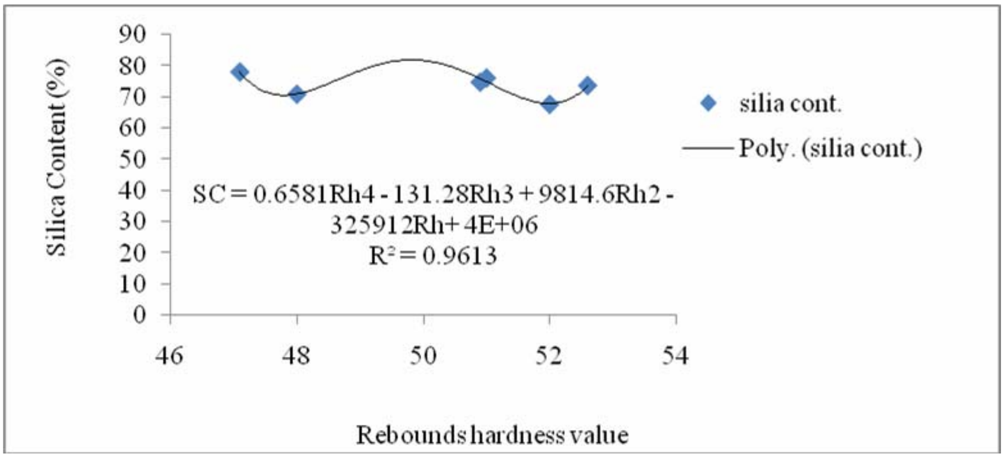

Fig. 2: Plot of silica content against rebound hardness of rocks from S/W Nigeria

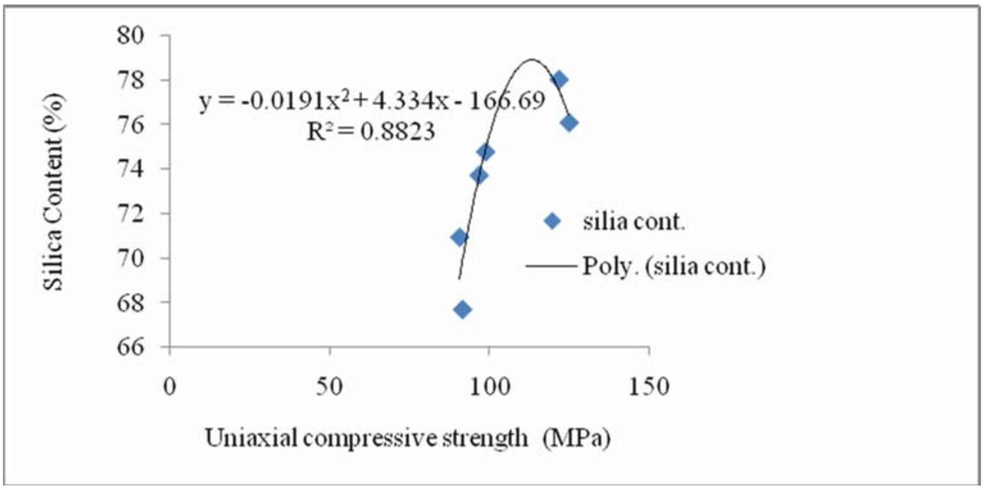

Fig. 3: Plot of silica content against uniaxial compressive strength S/W Nigeria

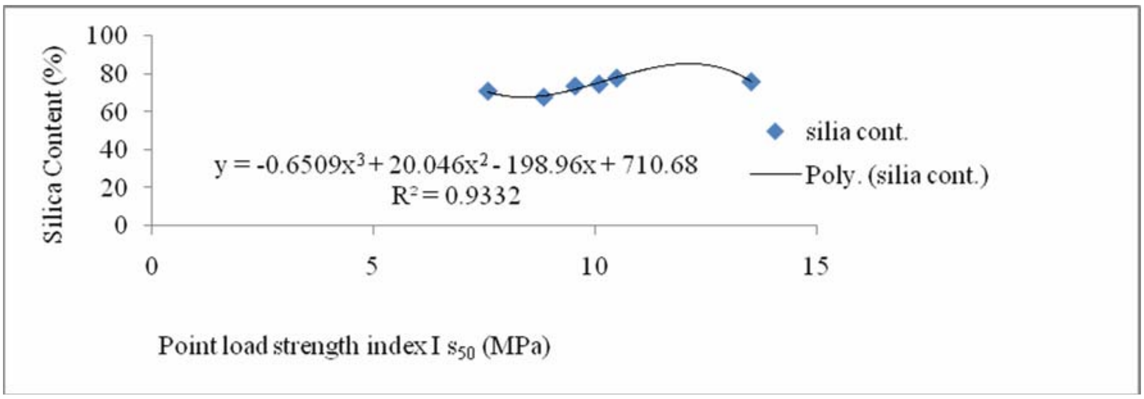

Fig. 4: Plot of silica content against point load strength index I s_{50} of rocks from S/W Nigeria

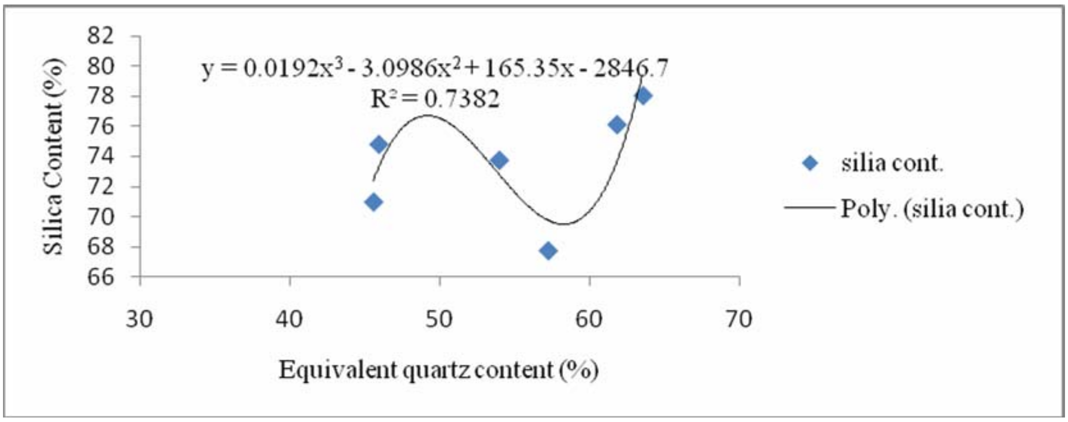

Fig. 5: Plot of silica content against equivalent quartz content of rocks from S/W Nigeria

4. Conclusion

It is observed from this work that silica content as well as equivalent quartz content are consistent, since the coefficient of variation are close. Also, all the wear parameter test values are still within limit. Studies have revealed by different authors that rocks having, higher proportion of silica content, equivalent quartz and angular grain shape would be abrasive and ultimately cause rapid wear of drill bit or cutting tools. Among the rock properties that are influencing wear investigated, there is strong correlation between Schmidt rebounds hardness value, uniaxial compressive strength, point load index and good correlation with equivalent quartz content. The understanding of wear parameters variability in rocks would aid operators of mines in proper selection of drilling tools as well as excavating equipment. It can be inferred from all rock properties influencing wear potential of rocks tested that they are related silica content by a particular proportion. There is need to correlate these properties with wear rate of drill bit or cutter picks in future.

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