Analysis of Button Bit Wear and Performance of Down-The-Hole Hammer Drill*

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Abstract

This work investigates bit button wear and performance of Down-The-Hole Hammer (DTH) drill in Navachab Gold Mine, Namibia. Rock samples obtained were tested in the laboratory for chemical composition, equivalent quartz content and compressive strength. Schmidt hammer was used to determine the rebound hardness values of the selected rocks. The specific energy was determined by using empirical equation. The length of insert buttons on the surface of the drill bits were measured by using digital vernier caliper at regular intervals as drilling operation progressed and wear rates were correlated with the rock properties. Silica content varied from 71.34 – 71.83% and 83.25 – 83.56% for oxidised and non-oxidised schist respectively. The equivalent quartz content was estimated to 72.30% for oxidised schist and 64.20% for non-oxidised schist. The highest wear rate was experienced on the non-oxidised schist having equivalent quartz content of 72.30%. This revealed that wear of rock drill bit is influenced by rock properties. Uniaxial compressive strength varied from 123 to 194 MPa. The strength characteristics of these rocks varied from medium to high strength. Rebound hardness values from the L-Type schmidt hammer ranged from 42 to 58 for oxidised and non-oxidised schist. Rebound hardness values obtained from N-Type schmidt hammer varied from 50 to 58 for oxidised and non-oxidised schist. The specific energy varied from 6.0 MJ/m^3 for oxidised schist to 12.5 MJ/m^3 for non-oxidised schist. Moreso, wear rate varied from 0.0284 - 0.1045 mm/m for oxidised and non oxidised schist respectively. The result of correlation matrix revealed that uniaxial compressive strength, equivalent quartz content and silica content are dominant rock properties affecting wear rate of bit button of DTH drill.

Keywords: Wear, Button, Down-The-Hole, Drill, Performance

1 Introduction

Generally, rock is drilled blasted, loaded, hauled to primary crusher and then transported to be further processed (Karanam and Misra, 1998). The performance of a particular bit in any formation is dependent on the properties of rock material and drill operating parameters. Thus, a bit will perform poorly in formations that are highly abrassive. Ultimately, the major parameter influencing bit wear and performance is the physico-mechanical properties of the rock, which affect the penetration rate of drilling bit (Prillet, 1990). They form the resistance and barrier that the bit must overcome before optimum penetration can be achieved. These include hardness, strength, texture, elasticity, plasticity, abrasiveness, structure and the characteristic of breakage. The chemical and mineral composition of the rocks affect the performance of the drill bit (Prillet, 1990). The performance of a bit could be determined and measured based on its rate of penetration, bit life and bit wear rate (Tatiya, 2005; Hustrulid, 1999). The rate of penetration denotes the depth penetrated per unit time while the wear rate describes rate of material removal from the bit surface and this is used in projecting bit consumption. A detailed study of the empirical relation between the performance variable (rate of penetration, bit life and bit wear rate) and the various rock properties for different drilling parameters is required for economical analysis and determination of drilling efficiency (Brian, 2012). Bit performance analysis requires correlation of the bit variables (bit life, bit wear rate, rate of penetration) with tested rock properties (Ersoy and Waller, 1995; Adebayo and Akande, 2011). It is necessary to establish the relation between the performance variable and rock properties of the formation in order to predict the longevity of the bit and ultimately provide information for better drilling operations in mines. The hammer is situated down the hole and strikes the drill bit directly. The piston of the hammer strikes the drill bit, resulting in an efficient transmission of the impact energy and insignificant power losses with the hole depth. Simulations carried out by Chiang and Stamm (1998) revealed that the piston and the bit can stay in contact and separate alternatively several times before interaction is completely over.

It is obvious that in the presence of high axial force, natural frequencies decrease in compression and increase in tension (Nguyen and Ngyuyen, 2011). When using Down-The-Hole Hammer Drill to drill through hard rocks, there are a number of problems that can lower penetration rate or even cause stoppage of drilling operation. More importantly, drilling operation is an important aspect in surface mines which can influence overall mining cost. The number of blast-holes that can be produced within a particular period can be estimated with precision. The objectives of this

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research are to determine rock characteristics; evaluate wear rate and specific energy on different rock sections in the mine; and develop regression model to predict wear rate for the drill bit, at the Navachab Coal Mine, Namibia.

2 Materials and Methods Used

2.1 Chemical Composition of the Rocks

The samples for X-Ray Florescence analysis for the oxidised and non-oxidised schist were prepared in accordance with ASTM standard procedure (Anon. 2005).

2.2 Determination of Equivalent Quartz Content

Equivalent Quartz Contact (*EQC*) was determined by multiplying percentage of minerals present in rock by Rosiwal abrasiveness value (Thuro, 2003). Equivalent quartz content was determined using Equation 1.

$$EQC = \sum_{i=1}^{n} A_i R_i \% \qquad (1)$$

where: A is mineral amount (%), R is Rosiwal abrasiveness (%); and n is Number of minerals

2.3 Determination of Compressive Strength of the Rocks

Rock samples were collected from 5 different locations in the mine. These constituted two different rock types namely the oxidised schist and non-oxidised schist (footwall material). The samples were prepared in accordance with ISRM, 1981. The specimens were tested using uniaxial compression machine. The uniaxial compressive strength was determined using Equation 2.

$$C_O = P / W.L \qquad (2)$$

where: C_0 is Uniaxial compressive strength (MPa); P = the applied peak load, (kN); W is Width of the sample (m); and L is Length of the sample (m)

2.4 Determination of Rebounds Hardness Value

The rebound hardness value was determined, using schmidt hammer, and procedure was in accordance with standard procedure suggested by ISRM (1981). It was suggested that twenty rebound values from single impacts separated by at least a plunger diameter should be recorded and the upper ten values averaged. All the tests were carried out with the hammer held vertically downwards and at right angles to horizontal faces of large rock blocks.

2.5 Determination of Specific Energy

The specific energy required by the bit to break a unit volume of rock for both oxidised and non-oxidised schist was determined from field data using empirical Equation 3 (Teale, 1965)

$$S.E = {Wob}/{A} + {2\Pi NT}/{A * ROP} \qquad (3)$$

where: S.E. is Specific Energy, WOB is the Weight on Bit, A is Circular Area of the bit (m^2); N is Bit revolutions per minute (r/min), T is Torque and ROP is Rate of Penetration.

2.6 Determination of Wear Rate of the Bits

The diameter of the gauge buttons of the bits were measured at regular intervals at the beginning of drilling each hole and at the end. This process continued until the bit was changed.

2.7 Development of Bit Wear Rate Model

Regression model for bit wear rate was developed using SPSS for Down-The Hole hammer (DTH) drill.

3 Results and Discussions

3.1 Analysis of Chemical Composition

Table 1 presents the result obtained from chemical composition of the selected rocks in the mine. Oxidised schist contained silicon dioxide of 40.69%, aluminum oxide of 21.42%, titanium oxide of 0.97%, chromium oxide, iron oxide, magnesium oxide, calcium oxide, sodium oxide, potassium oxide, lead oxide and sulphide ranging between 0.02 to 13.53%. Silicon dioxide was the highest composition in oxidised schist. Also, in non-oxidised schist, silicon dioxide was again the highest constituent of 55.31%. This is followed by aluminum oxide with a value of 21.42%. The other minerals such as titanium oxide, chromium oxide, magnesium oxide, calcium oxide are contained in trace amounts ranging from 0.02% to 5.6%.

Table 1 Chemical Composition of the Rocks in Navachab Gold Mine

Composition	Oxidised Schist (%)	Non-Oxidised Schist (%)
SiO_2	40.69	55.31
Al_2O_3	17.17	21.42
TiO_2	0.97	0.86
Cr_2O_3	0.02	0.02
Fe_2O_3	13.53	7.23
MgO	7.05	4.62
MnO	3.23	0.33
CaO	2.99	5.61
Na_2O	0.12	0.92
K_2O	4.81	5.44
P_2O_5	0.48	0.54
SO_3	1.87	0.54
LOl	3.25	1.48

3.2 Silica Content of Selected Rocks in Navachab Gold Mine

Table 2 shows the silica content that present in the selected rock types. The silica content on block L41 EZ1 2 was estimated to be 71.34% which is the least in oxidised schist rock type and value of 71.81% the highest on block L54 NP 10Y. In non-oxidised schist rock type the silica content ranged from 83.25% to 83.56% which is high when compared to oxidised schist.

3.3 Analysis of Equivalent Quartz Content of the Rock Samples

Table 3 presents Equivalent Quartz Content (EQC) of the selected rock types. The results show that EQC is high in non-oxidised schist and low in oxidised schist rock type as shown in Table 3. EQC of 72.3% was obtained in non-oxidised schist and 64.2% in oxidised schist.

3.4 Uniaxial Compressive Strength

Table 4 presents uniaxial compressive strength of the selected rocks in Navachab Gold Mine. The compressive strength turned out to be high in non-oxidised schist with a maximum strength of 194 MPa. Compressive strength on the other hand was low in oxidised schist with values ranging from 123 to 125 MPa.

3.5 Rebounds Hardness Values

Table 5 shows rebound hardness for non-oxidised and oxidised schist. The rebounds hardness values obtained with L-Type Schmidt Hammer varied from 42 - 49, while the rebounds hardness values of N-Type Schmidt hammer varied between 50 and 59. The rebound hardness values for oxidised schist from L-Type Schmidt Hammer varied from 42 and 58. The rebounds hardness values obtained from N-Type Schmidt Hammer varied from 53 and 58.

3.6 Specific Energy for the Selected Rocks

Table 6 shows the specific energy required by the drill bits to break a unit volume of rock. In addition, with rotational speed and torque of the drill rig kept constant and the variations are in cross sectional areas of the bits, weight on bit (pull down force), and rate of penetration. Specific energy was high in non-oxidised schist ranging between 10.5 - 12.5 MJ/m^3. The specific energy tends to be low in oxidised schist with values varying from 6.0 to 7.2 MJ/m^3. This means that non-oxidised schist required higher energy by drill to break the unit volume; this may be due to higher hardness values and compressive strength of the non-oxidised schist.

Table 2 Silica Content of Selected Rocks in Navachab Gold Mine

Rock name	Silica content (%) [L41 EZ1 2]	Silica content (%) L39 E1 18X	Silica content (%) [L53 NP 1X]	Silica content (%) [L54 NP 10Y]	Silica content (%) [L40 P 80]
Oxidised Schist	71.34	71.76	71.47	71.81	71.75
Non-Oxidised Schist	83.25	83.56	83.29	83.36	83.41

Table 3 Equivalent Quartz Content of the Rock Samples

Rock type	Minerals	Amount (%)	Rosiwal (%)	EQC (%)
Oxidised Schist	Lamprophyre	25.3	20	5.10
	Calcrete	32.2	24	7.70
	Lower Schist	51.4	100	51.40
	∑			72.3
Non-Oxidised Schist	Bracciated Marble	28.4	21	6.00
	Grey banded Marble	43.8	32	14.00
	Upper Schist	52.3	100	52.30
	∑			64.2

Table 4 Uniaxial Compressive Strength

Location	Rock type	UCS (MPa)
EZ1 Pit	Oxidised Schist	124
E1 Pit	Oxidised Schist	125
NP3	Non-Oxidised Schist	194
NP3	Non-Oxidised Schist	193
E1 Pit	Oxidised Schist	123

Table 5 Rebounds Hardness Values

Non-Oxidised Schist		Oxidised Schist	
L-Type	N-Type	L-Type	N-Type
45	50	42	54
42	55	48	56
47	56	52	58
46	59	58	56
49	58	54	53

Table 6 Specific Energy for the Selected Rocks

Bit type	Rock type	WOB (kg) 10^2	A (m^2) 10^{-3}	N (r/min)	Torque (Nm)	ROP (m/min) 10^{-2}	S.E (MJ/m^3)
Bit 01	Non-Oxidised schist	112	49	45	55	38.86	10.5
Bit 02	Oxidised Schist	112.5	53	45	55	58.25	7.2
Bit 03	Oxidised Schist	112.2	51	45	55	79.63	6.0
Bit 04	Non-Oxidised Schist	112	49	45	55	36.96	10.9
Bit 05	Non-Oxidised Schist	112.3	50	45	55	30.19	12.5
Bit 06	Non-Oxidised Schist	112	49	45	55	78.27	6.3

3.7 Summary of Wear Rate

Table 7 shows the summary of the average wear rate of the drill bits in Navachab Gold Mine on the different rock types investigated. The results of wear rate show that the bits wore out fast in non-oxidised schist. Also, the diameter of the drill bits decreased significantly as drilling progressed. Deterioration of buttons of the bits in oxidised schist was slower; this shows that the rock is less abrasive than non-oxidised schist. The higher rate of wear experienced in non oxidised schist can be attributed to higher silica content and equivalent quartz content.

Table 7 Summary of Bit Wear Rate of Selected Rocks in Navachab Gold Mine

Bit Type	Rock Name	Location (Block ID)	Depth Drilled /Bit (m)	Wear rate (mm/m
Bit 01	Non-Oxidised schist	EZ1, L41 EZ1 2	108.8	0.0984
Bit 02	Oxidised Schist	EZ1, L41 EZ1 2	113	0.0461
Bit 03	Oxidised Schist	E1, L39 E1 18X	107.5	0.0284
Bit 04	Non-Oxidised Schist	NP3, L53 NP1X	79.1	0.1040
Bit 05	Non-Oxidised Schist	NP3,L54 NP10Y	78.5	0.1045
Bit 06	Non-Oxidised Schist	E1, L40 P80	108.8	0.0341

The relation between wear rate and quartz content is shown in Fig. 1. It was observed that an exponential relation exist between the wear rate of the bits and quartz content for both rock types. This relation is expressed in Equation 4. It could be inferred that as quartz proportion increases the wear rate as well.

$$WR = 0.00000004e^{4.2669QZ} \quad (4)$$

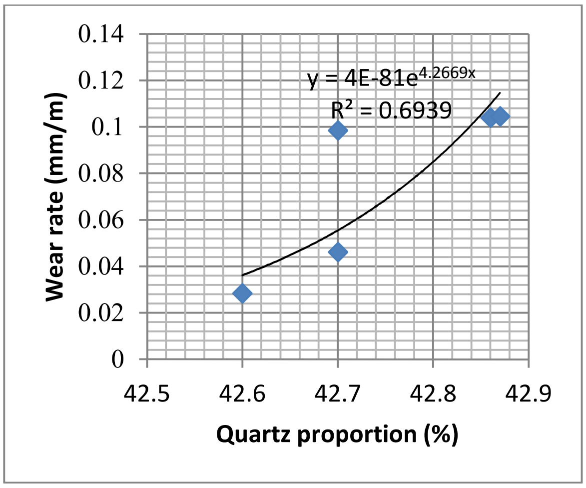

Fig. 1 Bit Wear Rate against Quartz Proportion

Fig. 2 shows the relation between the uniaxial compressive strength of the rocks and bit wear rate. This is also an exponential relation between bit wear rate and uniaxial compressive strength of the rock. The relation is expressed in Equation 5.

$$WR = 102.4e^{4.8426UCS} \quad (5)$$

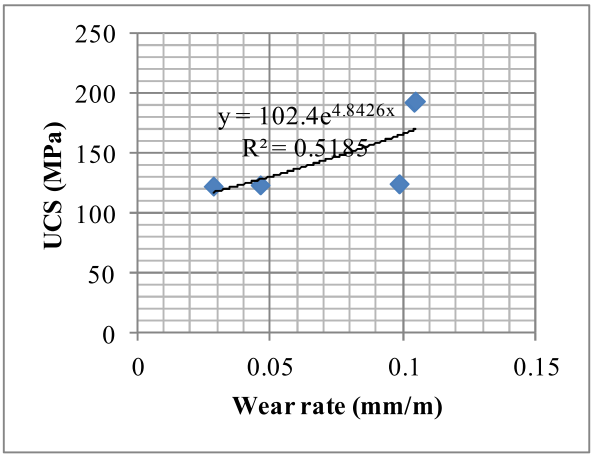

Fig. 2 Uniaxial Compressive Strength against Bit Wear Rate

Fig. 3 shows the results of the relation between wear rate of the bits and silica content of oxidised schist. It was observed that a linear relation exists between wear rate of the drill bits and silica content of oxidised schist. Equation 6 expresses this relation .

$$WR = 0.1734SiO_2 - 12.343 \quad (6)$$

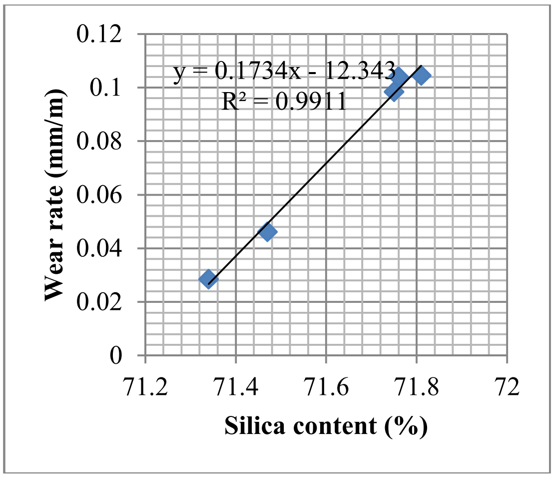

Fig. 3 Wear Rate against Silica Content

3.8 Analysis of Variance for the Regression Model

Table 8 shows the coefficients for wear rate model The Regression Model Equation to predict wear rate of the bits is expressed in Equation 7.

$$WR = -10.354 - 0.64EQC + 0.184SiO_2 \quad (7)$$

Figure 5 presents the plot of wear rate against regression standardised predicted value. The plot has coefficient of determination of R^2 = 0.994 this confirms the validity of the model.

Table 8 Coefficients of Wear Rate Model

Model	Unstandardised Coefficients		Standardise Coefficients	T	Sig.
	B	Std. Error	Beta		
(Const)	-10.354	3.391		-3.053	.201
EQC	-.064	.108	-.205	-.593	.659
UCS	.000	.000	.161	.605	.654
SiO2	.184	.029	1.054	6.350	.099

a. Dependent Variable: WR

Fig. 5 presents the plot of wear rate against regression standardized predicted value. The plot multiple coefficient of determination R^2 = 0.994, confirming the validity of the model.

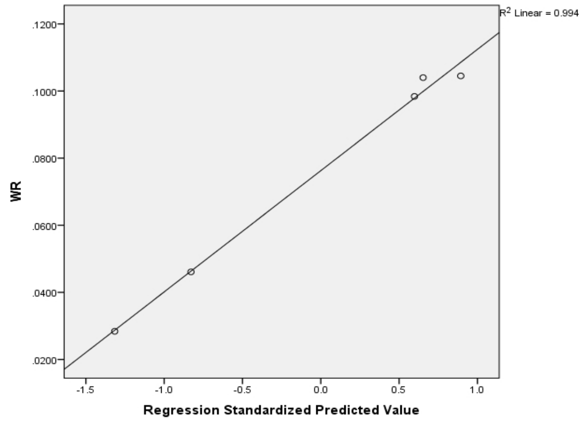

Fig. 5 Wear Rate versus Regression Standardized Predicted Value

4 Conclusions

This work had analysed bit wear and performance of Down-The-Hole Hammer (DTH) drill in Navachab Gold Mine. Rock characteristics determined were used to develop model for bit wear rate. Uniaxial compressive strength revealed that both for oxidised and non-oxidised schist have high uniaxial compressive strength. Chemical compositions revealed that both oxidised and non-oxidised schist contain silicon dioxide content in large amounts and aluminum oxide as a second major element in the sample. Specific energy required by the bits to break a unit volume of rock was observed to be higher in non-oxidised schist than oxidised schist; this may be due to high rebound hardness and compressive strength of 59 and 194 MPa respectively. Wear rate of 0.1040 mm/m was recorded in non-oxidised schist while wear rate of 0.0284 mm/m was recorded in oxidised . The higher wear rate may be attributed to higher silica content of 83.56%. The developed wear rate model could be used to predict bit button wear rate for DTH drill working on similar rock characteristics.

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