Determination of Drill-Cuttings Size Distribution and Rock Properties for Mechanical Breakage Performance Analysis

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Abstract

Size distribution of blast-hole drill cuttings and rock properties were investigated to estimate mechanical breakage performance. Drill-cuttings were obtained from the blast-holes drilled and size distributions of the cuttings were determined. In addition, top-hole-hammer drill with button bit of 38 mm diameter was employed at two quarries for rock drilling. Rock samples from two operating quarries in Edo state, Nigeria were tested for Uniaxial Compressive Strength and Rebound Hardness using 1100 kN compression machine and Schmidt hammer respectively. The number of blast holes drilled, depth and duration were obtained; these data were used to evaluate average penetrate rate of drilling. Mineral composition was determined by method of modal analysis. The result of size distribution analyses of the blast-hole cuttings of the weight retained on 1700 µm, 212 µm and 75 µm sieve sizes varied from 36 - 96 g, 36 - 65 g and 73 – 98 g respectively for Fanalou Quarry. The size distribution of the blast-hole cuttings of the weight retained on 1700 µm, 212 µm and 75 µm sieve sizes varied from 16 - 80 g, 36 - 65 g and 70 - 96 g respectively for Golden Girl Quarry. Uniaxial Compressive Strength of selected rocks from Fanalou Quarry and Golden Girl Quarry were 44.39 MPa and 46.95 MPa, while the rebound hardness values were 34.7 and 39.7 respectively. The percentage of quartz, calcite and clay were 10 %, 56 %, 20 % and 13 %, 59 %, 15 % for Fanalou and Golden Girls Quarry respectively. The average penetration rates varied from 10.02 – 15.47 m/min and 10.36 - 15.77 m/min for both quarries at drilling length of 3,810 m and 3,429 m respectively. The breakage performance of the drill is likely to be better when drilling on rocks at Fanalou quarry and bit stalling that occurred at the two locations may be due to clay content of 15 % to 20 % present in the rocks.

Keywords: Cuttings, drill, breakage, mechanical, hardness

1 Introduction

Drilling is an important operations carried out in mining, geo-technical engineering and civil construction. It is a means of creating artificial holes for placement of explosives or gaining access to reservoir housing hydrocarbon or aquifer. The processes of drilling are affected by formation characteristics, mechanical behaviour of rocks and operational factors (Bageri *et al*., 2020). Accurate monitoring and prediction of the penetration rate help in planning of the rock excavation projects more efficiently. Ersoy and Waller (1995) observed that grains size, moisture contents may influence drillability. The performance of a particular bit in any formation is dependent on the properties of rock material and drill operating parameters (Adebayo and Akande, 2015). Different methods of excavation utilize different mechanisms to loosen or excavate a rock body, and various rock types exhibit different strength characteristics against fracturing (Mohd *et al.*, 2009). Ersoy and Waller (1995) presented drilling tests using polycrystalline diamond and impregnated diamond core bits in the rock and they concluded that grain size of rock can be used as a predictive factor for assessing wear potential of rocks. Thuro (1997) put forward that drilling bit wear increased when the equivalent quartz content is high. Moreover the equivalent quartz content is a mineral and hardness properties influencing tool wear in drilling operations. Adebayo and Mukoya (2019) observed at the mining sites that majority of drill rig operators do not take into account the effect of adjusting drilling machine parameters in softer and harder rock formations. Also, quarry operators are lamenting unavailability of information on rock properties and their relationships with drill cuttings. Generating database for rock properties and using size distribution of drill cuttings as part of measure of mechanical breakage performance will assist driller in the planning of drilling operations. The objectives of this paper therefore are to analyze size distribution of drill cuttings, determine intact rock properties and use the results obtained to estimate mechanical breakage performance of the drill.

2 Materials, Methods Used

2.1 Determination of Mineral Composition

The slides were prepared for the rock samples and viewed with the aid of polarizing microscope. In addition, the mineral composition of the selected rocks were estimated using method of modal analysis, all these are in accordance with the standard procedure suggested by ISRM (1989).

2.2 Determination of Particle Size Distribution

Particle size of distribution of drill cuttings collected from two selected quarries were determined using standard method of (ASTM) D 2487

2.3 Determination of Compressive Strength

The Uniaxial Compressive Strength test (UCS) was carried in accordance with method suggested by ASTM (2001). The samples were cut with length to diameter ratio of 2:1 (ISRM 1989), which is the required ratio to calculate the compressive strength of a given rock core sample. The rock sample was subjected to an axial load (P) without any lateral confinement. The axial load was increased gradually until the sample failed. Uniaxial compressive strength was determined using Equation 1;

$$C_o = P/_A = 4P/_{\pi D^2} \qquad (1)$$

Where C_O is the Uniaxial Compressive Strength, P is the applied load and A is the area of the rock sample.

2.4 Determination of Rock Hardness

The rebound hardness value was determined, using Schmidt hammer, and the procedure conform to the standard procedure suggested by ISRM (1989)

2.5 Determination of Point Load Strength Index

Point load strength index was determined using point load tester. Forty millimeter diameter and one hundred millimeter length of rock samples were used for the experiment. Point load testing equipment utilizes hydraulic pressure to compress rock sample between conical platens. The force on the platens was increased by means of hand operated lever until failure occurs. The pressure of the hydraulic fluid or the reaction force on the platen at failure was recorded. The uncorrected point load strength index, *Is*, is expressed in Equation 2;

$$I_s = P/_{(De)^2} \qquad (2)$$

where;

I_S is uncorrected point load strength, P is the force at failure, *De*² is the square of the “equivalent core diameter”, equal to *D*² for diametral tests.

2.5 Determination of Penetration Rate

Top-hole-hammer drills with 38 mm button bits were employed in this research. The length of holes drilled and time taken were recorded and the average penetration rate was determined using Equation 3.

$$Penetration\ Rate = \frac{drilled\ depth\ (m)}{Time\ taken\ (min)} \qquad (3)$$

3 Results and Discussions

3.1 Mineral Composition of Selected Rocks

Table 1 presents mineral composition of selected rocks. The results reveal the mineral present in the dolomite samples. The percentage of minerals present in the rocks are: Quartz (Q) -13% Calcite (Ca) – 59%, clay mineral (CM) - 15%, Hematite (H) - 10%, Mica (M) - 3% for dolomite selected from HNF/Fanalou while Quartz (Q) - 10%, Calcite (Ca) – 56%, clay mineral (C) - 20%, Hematite (H) - 11.5%, Mica (M) - 2.5% for dolomite selected from Golden Girl Quarry. The photomicrographs are presented in Figures 1 and 2. The dominant mineral in the two samples is calcite having the highest percentage composition in the rock. The stalling of the bit during drilling may be attributed to clay mineral in the rock samples.

Table 1 Mineral Composition of Selected Rocks

Quarry	*Q %	*Cal %	*C %	*H %	*M %
HNF/Fanalou	13	59	15	10	3
Golden Girl	10	56	20	11.5	2.5

*Q-Quartz, Ca – Calcite, C- Clay mineral, H-Hematite, M- Mica

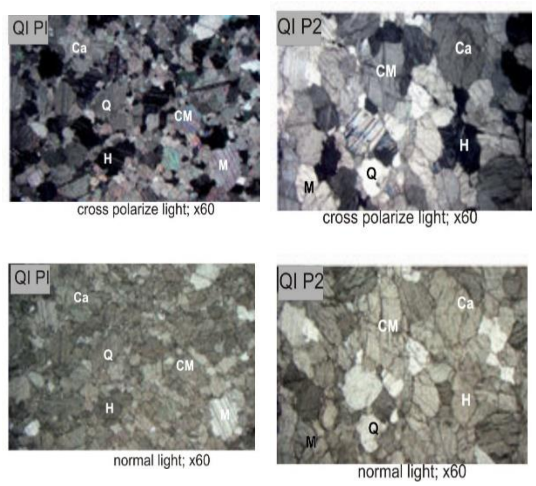

Fig. 1: Thin Section of HNF/Fanalou Rock Samples

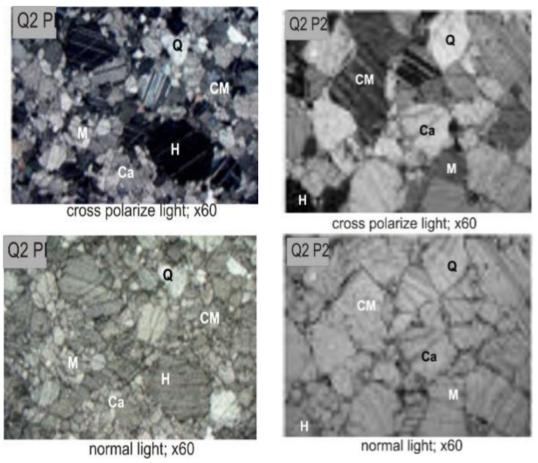

Fig. 2: Thin Section of Golden Girl Rock Samples

3.2 Intact rock properties of the Selected Rock

Table 2 presents the summary of the intact rock properties which were investigated for the two quarries. The average values of the rock strength and hardness reported for HNF/fanalou and Golden Girl are: 44.33 MPa-46.95 MPa for Uniaxial Compressive Strength, 5.77 MPa - 7.46 MPa for Point load Index, and 34.7-39.7 for the rebound hardness values respectively. The results indicated that the Golden Girl Quarry has a higher strength value as compared to HNF/Fanalou. Despite the fact that the two rocks are dolomite, there are variations in intact rock properties. It may be due to formation characteristics.

Table 2 Intact Rock properties of Selected Rocks

Location	UCS (MPa)	Point Load Index (MPa)	Rock Hardness
HNF/Fanalou Quarry	44.39	5.77	34.7
Golden Girl Quarry	46.95	7.46	39.7

3.3 Penetration Rate and Sieve Analysis

The average penetration rate and particle size distribution retained on sieve sizes of 1700 µm, 212 µm and 75 µm are presented in Tables 3 and 4 for HNF/Fanalou and Golden Girl Quarries. Drill cuttings from section (1) have the highest weight retained of 79 g on 1700 µm at the penetration rate of 15.47 (m/min); the highest weight of 69 g was retained on 212 µm at the penetration rate of 11.16 m/min in section 4 and highest weight retained of 98 g was recorded on 75 µm sieve size at the penetration rate of 11.76 and 10.56 m/min for HNF/Fanalou Quarry. Also, drill cuttings from section (1) have the highest weight retained of 80 g on 1700 µm at the penetration rate of 15.77 (m/min); the highest weight of 65 g was retained on 212 µm at the penetration rate of 13.18 m/min in section 4 and highest weight retained of 96 g was recorded on 75 µm sieve size at the penetration rate of 10.36 m/min for Golden Girl Quarry. It could be inferred that drilling with new button bit is likely to generate cuttings of larger sizes.

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Table 3 Summary of Penetration Rate and Cuttings Size Distribution - (HNF/Fanalou Quarry

Drill Cuttings from Section	PR (m/min)	Weight retained (g) (1700µm)	Weight retained (g) (212 µm)	Weight retained (g) (75 µm)
1	15.47	79	65	73
2	14.70	29	61	74
3	13.13	41	59	74
4	13.21	28	68	97
5	12.49	15	55	97
6	11.76	30	41	98
7	11.16	28	69	92
8	10.56	20	36	98
9	10.02	27	53	76

Table 4 Summary of Penetration Rate and Cuttings Size Distribution – Golden Girl Quarry

Drill Cuttings from Section	PR (m/min)	Weight retained (g) (1700µm)	Weight retained (g) (212 µm)	Weight retained (g) (75 µm)
1	15.77	80	38	70
2	15.42	35	56	63
3	13.73	44	62	80
4	13.18	28	65	95
5	11.86	16	57	93
6	11.37	32	41	95
7	12.00	29	51	90
8	11.09	25	64	92
9	10.36	18	36	96

Figs. 3 – 5 present the relation between penetration rate and the weight retained on 1700 µm 212 µm and 75 µm; for HNF/Fanalou quarry, Edo State. The relations are expressed in Equations 4 - 6. The coefficient of determination varied from 0.2145 – 0.4268. The relations are expressed in Equations 4 – 6. It could be inferred that weak correlation exists between penetration rate and size distribution of weight retained. This suggest that size distribution of weight retained on different sieve size ranges could be used as means of estimating performance of drilling tool employed for rock drilling. At higher penetration rate the weight retained was also very high on sieve aperture size of 1700 µm, this indicated the use of new bit and at lower penetration rate more fines will be generated this may be due to worn buttons on the bit surface hence, the weight retained on aperture size of 75 µm will increase.

$$PR = 0.0641\,Wt + 10.384 \quad (4)$$

$$PR = 0.0829Wt + 7.8284 \quad (5)$$

$$PR = -0.0717Wt + 18.702 \quad (6)$$

where *PR* is the penetration Rate and *Wt* is the weight retained.

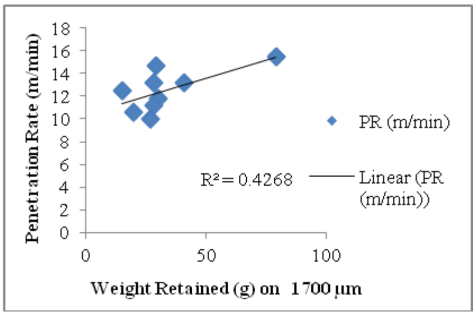

Fig. 3: Penetration Rate against Weight Retained –Aperture 1700 µm

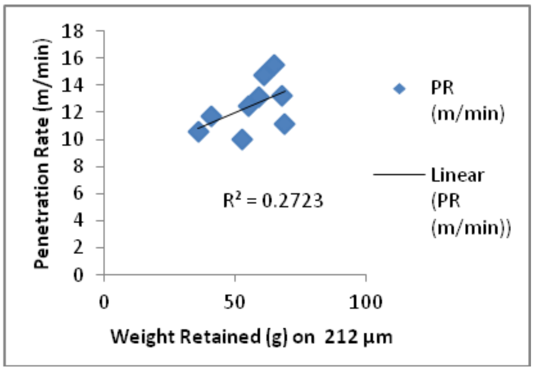

Fig. 4: Penetration Rate against Weight Retained (g) for Aperture 212 µm

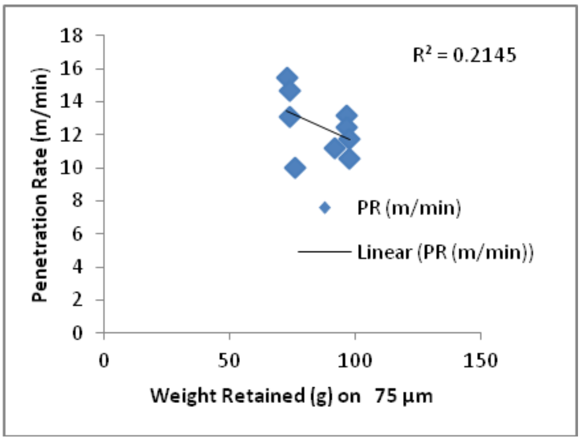

Fig. 5: Penetration Rate against Weight Retained (g) for Aperture ≤75 µm

Figures 6–8 present the relation between penetration rate and the weight retained on 1700 µm 212 µm and 75 µm sieve sizes respectively for Golden Girl Quarry, Edo State. The relations are expressed in Equations 7 - 9. The coefficient of determination varied from 0.0172 – 0.767. It appears that strong correlations exist between penetration rate and weight retained at the sieve aperture of 1700 µm. The relations are expressed in Equations 7 – 9.

$$PR = 0.0739Wt + 9.706 \quad (7)$$

$$PR = 9.103Wt^{0.0833} \quad (8)$$

$$PR = -6.208\ln(Wt) + 40.138 \quad (9)$$

where PR is penetration Rate and Wt is Weight Retained

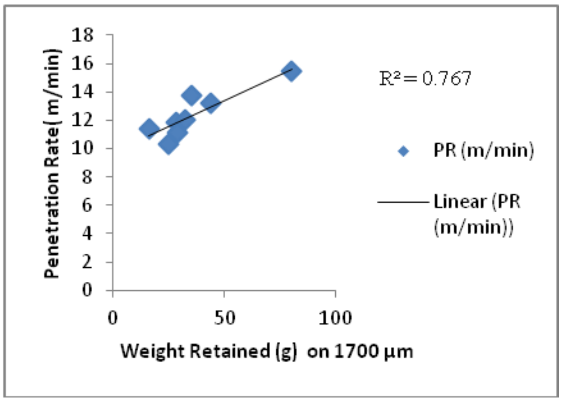

Fig. 6: Penetration Rate against Weight Retained for Aperture 1700 µm

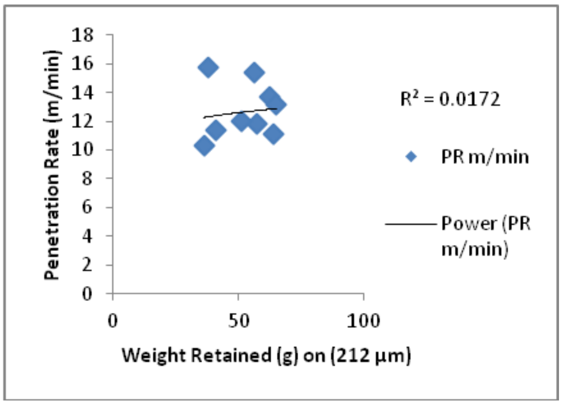

Fig. 7: Penetration Rate against Weight Retained for Aperture 212 µm

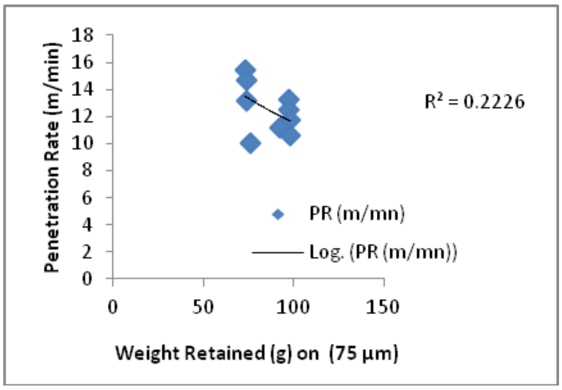

Fig. 8: Penetration Rate against Weight Retained for Aperture ≤75 µm

4 Conclusions and Recommendations

Rock properties, particle size distribution and evaluation of penetration rate from drill monitoring were conducted. From the analyses, the following conclusions can be drawn:

1) The analyses of the drill-hole cuttings using the weight retained on aperture sizes had demonstrated some reasonable correlation with penetration rate and weight retained on sieve aperture of 1700 µm HNF/Fanalou and Golden girl quarries.

2) Quartz and clay are present in samples from both locations.
3) The intact rock properties analyses revealed that there are variations in the strength of the rocks. This confirmed that rock properties varied widely.

4) Regression equations were established for prediction of penetration rate based the weight of the drill-cuttings retained on selected three sieve sizes.
5) Ultimately, drill breakage performance is better in Golden Girl Quarry having weight retained of 80 g on 1700 µm aperture size at the penetration rate of 15.77 (m/min).

Recommendations

It is therefore recommended that:

1) Areas of higher clay content in the rock may experience bit stalling; therefore more bits should be provided in this section of the quarry.

2) Drill operator should monitor drill-cuttings to determine when more fines are produced. This may be use as indicator for detection of worn bits.

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