Effect of Powder Factor Variability on Granite Productivity at Tutu Quarry, Kujama, Kaduna State, Nigeria

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Abstract

This research seeks to examine the effect of powder factor variability on granite productivity at Tutu Quarry in Kujama, Kaduna State, North-central Nigeria. Schmidt hammer was used for the in-situ determination of rock hardness. Uniaxial compressive strength (UCS) of in situ rock was estimated from the values obtained from Schmidt hammer rebound hardness test and its density determined from laboratory test. After preliminary field studies, ten (10) blasts with varied powder factors were studied and their overall effects on granite productivity examined. Three (3) rock samples were carefully collected from the quarry and subjected to laboratory analysis for UCS and bulk density tests. With spacing and burden kept between 1.7 m and 1.8 m and stemming height also varied between 1.5 m and 2 m, charge columns of between 4.5 m to 6.5 m were maintained, while number of holes drilled per blast was between 64 and 88. Results obtained from the test revealed that the average UCS of the granite samples was 80.67 MN/m^2 while the average bulk density was 2465.67 kg/m^3. Therefore, considering ten (10) blasts with varied powder factors of between 0.77 kg/m^3 and 0.97 kg/m^3, total volumes of rock of between 1,109.76 m^3 and 2,280.96 m^3 was produced. Hence, varied powder factors have been found to have huge effects on rock fragmentation sizes and by extension, granite productivity.

Keywords: Powder factor variability, explosives, granite productivity, blasting.

1 Introduction

Efficiency of blasting operations in underground and surface mines determines, to a large extent, utilization of equipment, productivity and economics. Proper fragmentation of blasted rocks improves the efficiency of downstream operations by loading and crushing to desired sizes. An optimal blast not only results in proper fragmentation but also reduces undesirable effects in ground vibration, fly rock and formation of toe in quarry benches. Drilling and blasting are the first unit operations in the mining process and have a major impact on the performance and cost of subsequent unit operations (Comakli *et al*., 2017; Eshun *et al*., 2016; Akande and Lawal, 2013).

According to Salati and Mark (2020), powder factor can be defined as the quantity of explosives needed to fragment a unit cubic metre of rock (1m^3). Hence, optimum powder factor results in good fragmentation, having less throw and less ground vibration. It can serve as an indicator for rock hardness, cost of explosives used or as a guide to shot firing plan (Mohamed *et al*., 2015).

Improved fragmentation gives loading equipment a higher rate of productivity; hence, it results in lower cost per tonne or cubic yard moved. The effect of wear and tear also decreases giving lower operating cost per hour under similar condition of haul, lift, size and type of truck. Haul/load road condition, truck production per hour also increase with greater degree of fragment due to faster shovel or loader longing rate and a decrease in bridging at the crusher. Therefore, there is a consequent decrease in cycle time. Fragmentation optimization involves breaking of rock to ensure quality control, safe, consistent and efficient blasting (Jethro *et al*., 2016). Subsequently, boulder or the opposite, excess fines, result from poorly selected drilling and blasting patterns. A well selected pattern would produce fragmentation that can be accommodated by available loading and hauling equipment and crushing plant with little or no need for secondary blasting. Therefore, it is a well acknowledged fact that the performance of mining operations such as excavation and crushing reeves on fragmentation has been pre-conditioned by blast designs (Liu *et al.,* 2020; Mkumbwa, 2017; Jethro *et al*., 2016).

The effectiveness of hard rock blasting is measured with two basics indices namely, oversize generation and blast hole productivity. Cost per tonne of rock blasted is another index that measures the effectiveness of blasting and is dependent on rockiness and blast design parameter such as hole diameter, burden, spaces among others (Agyei and Owusu-Tweneboah, 2019; Afum and Temeng, 2015). Such parameters differ from one mine to the other and some of the blast design parameters could be regulated to deliver the desired blasting effectiveness. The individual influence of the determinant parameter on blasting has been studied by several authors but their cumulative influence on the same is yet to be formulated. However, the huge statistical data generated from the well organized and documented large scale hard rock surface mines operating variables condition worldwide constitute the only readily available resources which could be used for the analysis and regression model of indices that determine effectiveness of blasting of rock blasted on uncontrollable and controllable blasting parameters (Akande and Lawal, 2013). Efficiency of drilling and blasting operations must contribute to the best overall economics of a quarry (Vladimir et al., 2015; Bhatawdekar *et al*., 2019); therefore, variability of powder factor has potentials to improve surface mines' productivity (Agyei and Nkrumah, 2021; Salmi and Sellers, 2021). Hence, there is need to study the effect of powder factor variability in the productivity of granite quarrying. To achieve this aim, the study seeks to determine the effect of powder factor variability on granite productivity at Tutu Quarry in Kujama, Southern part of Kaduna State, North-western Nigeria. The study is an attempt to achieve the following specific objectives:

i. To determine the relationship between the powder factor and uniaxial compressive strength at the quarry.
ii. To determine the effect of varying powder factor in the fragmentation of rock; and
iii. To recommend ways to improve the productivity of granite in the quarry.

The appraised parameters would give optimum blasting results through the regression model generated using indices such as oversize generation and geometric volume of the blasted rock on blast design parameters.

2 Materials, Methods Used

2.1 Location and Accessibility of the Study Area

Tutu quarry is located in Pamfura-Magashanu, Kaduna State, North-Western Nigeria. The area is on Latitude 10^{0}28'21''N and Longitude 07^{0}38'07''E, and Elevation of 732m. Pamfura-Magashanu is located in Kujama, the headquarters of Chikun Local Government Area of the State with an approximate population of 1300 inhabitants. The community is accessed through an untarred road which is about 2km from Kachia express road. The quarry has a good access road and comprises the granite outcrop under study.

Fig. 1 Access Road leading to Tutu Quarry's Premises

2.2 Climate, Vegetation and Relief

Temperatures in Kaduna areas within which the study area in Kujama falls often increase from 0.2 to 0.5ºC. A study of rainfall trend and variation characteristics across Kaduna State using eleven selected stations in the Southern, Central and Northern parts of the State for a period of 50 years (1966-2015) was carried out and the climatic condition of the study revealed that the Southern part of Kaduna State (Kujama inclusive), has the highest total rainfall, yet there was not any significant trend in the five decadal periods that were analyzed (Abaje and Oladipo, 2019). From the early 1970s to the late 1990s the rainfall was below the long-term mean. The rainfall of the remaining years nearly approximates the long-term mean (Ati *et al*., 2009).

According to Ladan (2014), Kujama is an extension of Kagoro forest which is a natural rain forest type of vegetation within the savanna due to the location of the forest on the windward side of the Jos Plateau experiencing more rainfall of more than 1550mm than the surrounding areas. It has two distinct seasons namely: rainy and dry season. The annual rainfall is between 80cm and 100cm. The temperature variation throughout the year varies from 20^0 to 27^0. The area also experiences two kinds of wind yearly; they are tropical maritime air mass and the tropical continental air mass. The vegetation in this area is Guinea Savannah which is characterized by long and short grasses as well as low trees and shrubs. These are sparsely distributed and there is dense vegetation along streams and river channels.

2.3 Brief Geology of the Area

The area consists of rocks that range in age from Pre-Cambrian to Lower Palaeozoic and Quaternary period. Four groups of rocks can be distinguished for the Basement Complex Terrain in the area. The crystalline basement rocks which consist of gneisses and migmatites with different varieties of the gneisses like the banded gneiss, granite gneiss, biotite gneiss, hornblende gneiss and ortho genesis (Hassan *et al.*, 2016). Figure 2 shows the exposure of the granite outcrop of the study area.

Fig. 2 Exposure of Tutu Quarry's Granite Outcrop Showing its Relief

Kujama area belongs to the Older Granite of Northern Nigeria, which is underlain by the Precambrian Basement Complex rock. Porphyritic granite is the most common basement rock and intrudes both magnetite and metasediments. The older granite occupies the whole of Kujama area and the most common of them is the porphyritic granite, granodiorite and aplite. Pegmatites are widely distributed throughout the Precambrian Basement Complex of Northern Nigeria (Abere *et al*., 2020). Those of Kujama are part of the Northern Nigeria; they are extremely coarse igneous bodies closely weathered and are spaced to large masses plutonic rock. They consist of quartz, feldspars and muscovite (Yusuf, 2019). Kujama granite forms part of the crystalline Basement Complex rock and it is the most widely spread rock in this area. They are elliptical to elongated shape, which is seen to be elevated to the forsian emplacement.

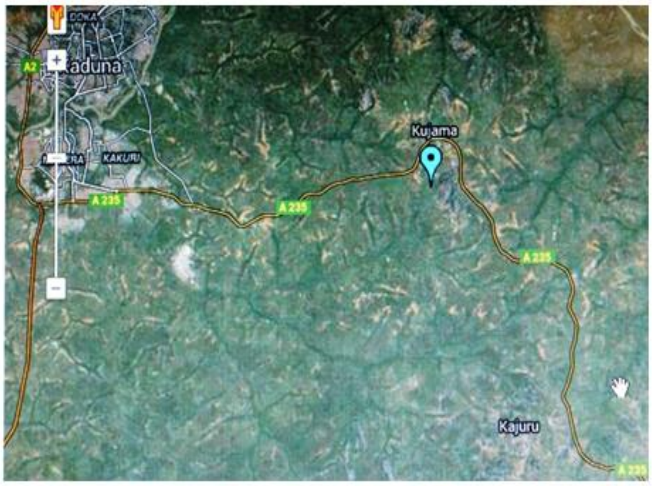

Fig. 3: Satellite Imagery of Kujama Area, Kaduna State, North-western Nigeria

2.4 Field Studies and Data Collection

The operation of the study site was studied in order to obtain information about the various explosives, drilling machines, blasting parameters such as burden, spacing and depth of hole. Their physical condition and quantity available were studied. Observation was also made to estimate the size of fragmented rocks. Three samples of blasted boulders were collected at three different faces of the quarry in the study area. The coordinates of each location were taken and recorded with the aid of global positioning system (GPS). Figure 4 shows parts of Tutu quarry where drilling and blasting operations take place.

Fig. 4: Operating Site of Tutu Quarry

2.5 Drilling/Blasting and Powder Factor Variability Procedures

As shown in Tables 2 to 11, the various drilling and blasting parameters used at Tutu quarry including the parameters for burden and spacing, depth of blast holes, column charge, base charge, tonnage factor, quantity of material blasted and their corresponding powder factors adopted for rock fragmentation are presented for ten (10) blasting operations.

Details of the variability results are follows:

Drilling pattern adopted
Staggered

Explosive type used
High explosive (Gelatin) + ANFO

Hole depth
6.30 m – 9.5 m

Hole diameter
76 mm (constant)

Burden-spacing pattern
1.7 x 1.7 – 1.9 x 1.9

Stemming height
1.2 m – 2.7 m

Charged column
4.0 m – 7.0 m

Number of holes
58 – 102

Total weight of explosives
1,119.00 kg – 1,931.48 kg

Volume of rock blasted
1,165.25 m^3 – 2,366.50 m^3

Varied PF
0.77 – 0.97

Constant TF
2.7

2.6 Sample Preparation and Laboratory Analysis

A circular saw with a diamond blade was used to cut the specimens to their final lengths. The surfaces were then ground after cutting in a grinding machine in order to achieve a high-quality surface for the axial loading. The measurement of the specimen dimensions was made with a sliding caliper and metre rule. Furthermore, the tolerances were checked by means of a dial indicator and a stone face plate. The specimen preparation was carried out in accordance with ASTM test procedure (ASTM, 39-71) and as adopted by Vandergrift, Jr. and Schindler (2005) in their experiment. The sample was cut using cutting machine to a dimension suitable for uniaxial compressive stress (UCS) test. The specimen was placed in horizontal direction but perpendicular to the direction of cutting edge of the blade. Then the vice was used to hold the specimen firmly to obtain a smooth surface as accurately as possible. The machine was switched on and the necessary shield applied. Water was allowed to lubricate the blade during the cutting process.

2.6.1 Procedure for Uniaxial Compressive strength Test

The ASTM test procedure (39-71) was adopted. The specimen was placed in the ELE ADR 2000 compression machine. The load is continuously applied on the specimen until it failed. The failure mode was noted as well as the pressure or load at failure. The type of failure and the maximum load carried by the specimen were recorded. The unconfined UCS of the rock sample was obtained by dividing the maximum load carried by the cross-sectional area. Testing machine of standard recommended ASTM C 39-71 was used to load the squared sample until it failed.

2.6.2 Test specimens

Squared samples were used for this test. The four sides of each sample were ground flat, smooth and perpendicular to axis, that is they were parallel to each other .4cm * 4cm cube specimen were cut from block samples supplied (in the absence of core which are commonly used). The platens on the compression machine were altered to suit this configuration. The edges were cut to shape and smoothened by polishing them with carborundum powder.

3 Discussion of Results

Findings from field studies and observations as shown in Table 1 have revealed that the trend in the spread of GPS coordinates of granite samples collected indicates that the samples were taken at relatively close intervals. Results shown in Tables 2 to 11 also indicate the various specifications of drilling and blasting parameters as used in Tutu quarry, Kujama Kaduna State. From the tables it can be deduced that the stemming heights, burden and spacing, and column of charged holes were varied as the depth of blast holes increases. It is also shown that the number of explosives charged per hole indicates an increase in the depth of hole drilled, thereby increasing more explosives consumption and equally implying that more volume of granite has been fragmented. The PF for the ten (10) blasts was not the same, which means that it was varied at different times of the blast as shown in Table 14.

Results from this study have shown the level of relationship between the strength of rock and PF. For instance, it can be deduced from Figures 5 to 7 that the Uniaxial Compressive Strength (UCS) of rock increases as the PF increases. This is also true in the reverse case as PF reduces. In the same vein, keeping UCS as a constant, PF increases as volume of blasted materials increases which is also true for the reverse case.

From the figures, it is evident that PF increases as the volume of blasted rock increases. Thus, more volume of rocks means higher PF to fragment the rock. Therefore, more explosives are charged in the holes to get the required results as the volume of rock increases. It can be deduced that to reasonably vary the PF of rock, the ratio of burden to spacing must be carefully selected with a view to increasing its productivity. Hence, PF variability becomes more effective with careful and staggered increment of burden and spacing.

As evident from Figures 2 to 4, more explosives are consumed when the volume of fragmented rock increases. Therefore, varied PF with carefully varied and selected drilling and blasting parameters are required for optimum blast and higher productivity.

4 Conclusions and Recommendations

The PF used at Tutu quarry has being examined for ten (10) blasts to ascertaine its effects on the level of granite productivity in the quarry. It can therefore be concluded that:

i. PF variability can lead to increase or decrease in the level of productivity of granite.
ii. PF selection and variability can lead to higher cost of productivity; and
iii. The strength of granite influenced the PF selected at the quarry.

Also, the quantity of explosives for some of the sizes of the fragmented rock at the quarry was not insufficient, while for some, it is optimal for the blast. Hence, it can be concluded from the observed blasts that the productivity of granite at Tutu quarry can be improved for optimum economic benefit, if the PF is varied as appropriate for any blast design and the quality and properties of the explosives selected are adequate for the strength of the rock to be blasted.

Having observed and examined the effects of PF variability on the level of granite productivity at Tutu quarry, Kujama, Kaduna State, the following measures are hereby recommended for optimum rock fragmentation:

1) The strength of granite should be examined before selecting a suitable PF.
2) Since the PF variability has great impact on the productivity of granite, there is a need to employ the services of trained and qualified personnel in its selection.
3) Economy and productivity of quarry have potentials for improvement when serious attention is given to the blast design and study of explosive characteristics and properties.

Table 1: Coordinates of Samples collected.

SAMPLE	LATITUDE	LONGITUDE
1	N26^0 51’7.2”	E007^0 59’ 71.4”
2	N26^{0}51’8.1”	E007^{0}59’75.5”
3	N26^0 51’13.3”	E007^{0}59’64.5”

Table 2: Blast Number One

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	6.30	m

4	Diameter	76.00	mm
5	Burden	1.70	m
6	Spacing	1.70	m
7	Stemming Height	1.60	m
8	Charged Column	4.70	m
9	Number of Holes	64.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	4.00	-
12	High Explosive	400.00	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	719.00	Kg/Hole
15	Total Weight of Explosive	1,119.00	Kg
16	Volume of Rock	1,165.25	m^3
17	**Powder Factor**	**0.96**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 3: Blast Number Two

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	7.90	m
4	Diameter	76.00	mm
5	Burden	1.80	m
6	Spacing	1.80	m
7	Stemming Height	2.00	m
8	Charged Column	5.90	m
9	Number of Holes	88.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	6.00	-
12	High Explosive	825.00	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	1,106.48	Kg/Hole
15	Total Weight of Explosive	1,931.48	Kg
16	Volume of Rock	2,252.45	m^3
17	**Powder Factor**	**0.86**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 4: Blast Number Three

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	6.80	m
4	Diameter	76.00	mm
5	Burden	1.90	m
6	Spacing	1.90	m
7	Stemming Height	1.50	m
8	Charged Column	5.30	m
9	Number of Holes	74.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	4.00	-
12	High Explosive	462.50	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	996.51	Kg/Hole
15	Total Weight of	1,459.01	Kg

	Explosive		
16	Volume of Rock	1,816.55	m^3
17	**Powder Factor**	**0.80**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 5: Blast Number Four

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	9.50	m
4	Diameter	76.00	mm
5	Burden	1.80	m
6	Spacing	1.80	m
7	Stemming Height	2.50	m
8	Charged Column	7.00	m
9	Number of Holes	58.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	7.00	-
12	High Explosive	634.38	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	875.99	Kg/Hole
15	Total Weight of Explosive	1,510.36	Kg
16	Volume of Rock	1,785.24	m^3
17	**Powder Factor**	**0.85**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 6: Blast Number Five

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	6.00	m
4	Diameter	76.00	mm
5	Burden	1.70	m
6	Spacing	1.70	m
7	Stemming Height	2.00	m
8	Charged Column	4.00	m
9	Number of Holes	102.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	4.00	-
12	High Explosive	637.50	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	880.30	Kg/Hole
15	Total Weight of Explosive	1,517.80	Kg
16	Volume of Rock	1,768.68	m^3
17	**Powder Factor**	**0.86**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 7: Blast Number Six

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	8.00	m
4	Diameter	76.00	mm
5	Burden	1.80	m
6	Spacing	1.80	m

7	Stemming Height	2.10	m
8	Charged Column	5.90	m
9	Number of Holes	81.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	6.00	-
12	High Explosive	759.38	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	1,018.46	Kg/Hole
15	Total Weight of Explosive	1,777.84	Kg
16	Volume of Rock	2,099.52	m^3
17	**Powder Factor**	**0.85**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 8: Blast Number Seven

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	6.00	m
4	Diameter	76.00	mm
5	Burden	1.90	m
6	Spacing	1.90	m
7	Stemming Height	1.20	m
8	Charged Column	4.80	m
9	Number of Holes	74.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	4.00	-
12	High Explosive	462.50	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	858.87	Kg/Hole
15	Total Weight of Explosive	1,321.37	Kg
16	Volume of Rock	1,602.84	m^3
17	**Powder Factor**	**0.82**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 9: Blast Number Eight

S/N	Parameters	Numeric Value	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	9.00	m
4	Diameter	76.00	mm
5	Burden	1.80	m
6	Spacing	1.80	m
7	Stemming Height	2.30	m
8	Charged Column	6.70	m
9	Number of Holes	58.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	7.00	-
12	High Explosive	634.38	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	811.26	Kg/Hole
15	Total Weight of Explosive	1,445.63	Kg

16	Volume of Rock	1,691.28	m^3
17	**Powder Factor**	**0.85**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 10: Blast Number Nine

S/N	**Parameters**	**Numeric Value**	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	6.30	m
4	Diameter	76.00	mm
5	Burden	1.70	m
6	Spacing	1.70	m
7	Stemming Height	1.53	m
8	Charged Column	4.77	m
9	Number of Holes	64.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	4.00	-
12	High Explosive	400.00	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	735.67	Kg/Hole
15	Total Weight of Explosive	1,135.67	Kg
16	Volume of Rock	1,165.25	m^3
17	**Powder Factor**	0.97	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Table 11: Blast Number Ten

S/N	**Parameters**	**Numeric Value**	
1	Explosive Used	High Explosive + ANFO	
2	Drilling Pattern	Staggered	
3	Hole Depth	8.30	m
4	Diameter	76.00	mm
5	Burden	1.80	m
6	Spacing	1.80	m
7	Stemming Height	2.70	m
8	Charged Column	5.60	m
9	Number of Holes	88.00	-
10	High Explosive	1.56	Kg/Cartridge
11	Number of explosives used per hole	6.00	-
12	High Explosive	825.00	Kg/Hole
13	ANFO	3.72	Kg/m
14	ANFO	1,008.27	Kg/Hole
15	Total Weight of Explosive	1,833.27	Kg
16	Volume of Rock	2,366.50	m^3
17	**Powder Factor**	**0.77**	**Kg/m^3**
18	Tonnage Factor	2.70	T/m^3

Figure 5: Variability of the Stemming Height across the Blasts

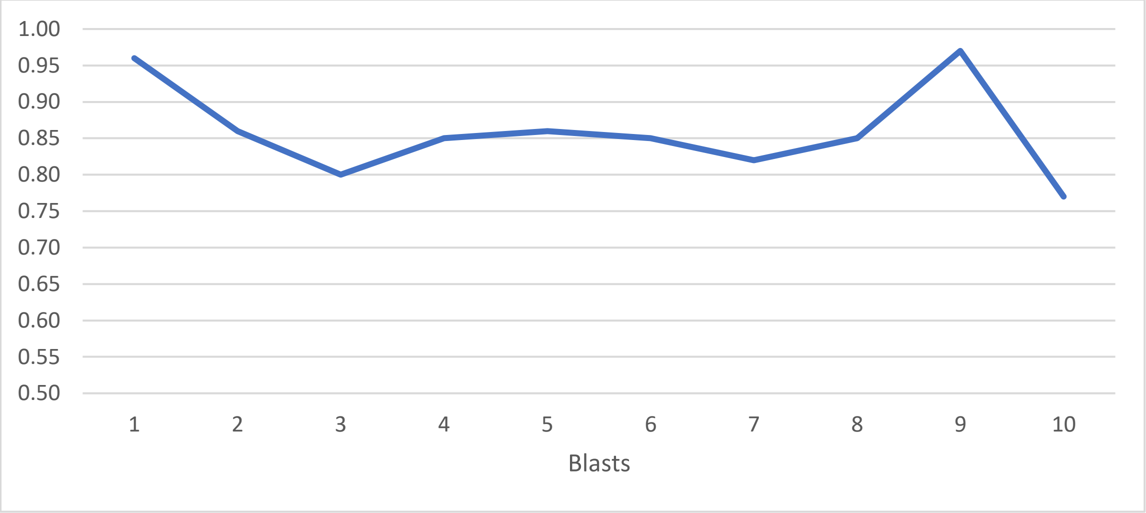

Figure 6: Powder Factor (PF) across the Blasts

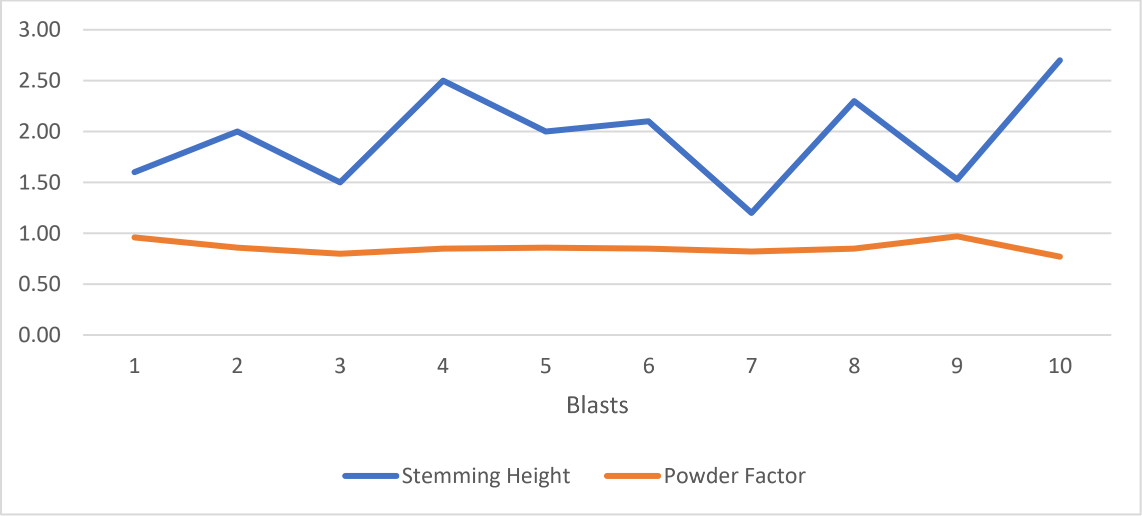

Figure 7: Variability of the Stemming Height and Powder Factor (PF) across the Blasts

Table 12: Uniaxial Compressive Strength (UCS) MN/m^3

SAMPLE	Maximum Load (KN)	Specimen Length (m)	Specimen Width (m)	Cross sectional Area (m^2)	Uniaxial Compressive Strength (MN/m^2)

1	133.2	0.06	0.03	0.0018	74
2	145.8	0.06	0.03	0.0018	81
3	157.5	0.06	0.03	0.0018	87.5

Table 13; Bulk Density of Tutu Quarry Granite

Sample ID	Mass of specimen (g)	Height of specimen (m)	Width of specimen (m)	length of specimen (m)	volume of specimen (m^3)	Bulk density (Kg/m^3)
1	2742.6	0.1	0.1	0.1	0.001	2743
2	2742.4	0.1	0.1	0.1	0.001	2742
3	2183.3	0.1	0.1	0.1	0.001	2183

Table 14: Powder Factors and Volume of Rock Produced

S/N	Powder Factor (Kg/m^3)	Volume of Rock Produced (m^3)
1	0.96	1,165.25
2	0.86	2,252.45
3	0.80	1,816.55
4	0.85	1,785.24
5	0.86	1,768.68
6	0.85	2,099.52
7	0.82	1,602.84
8	0.85	1,691.28
9	0.97	1,165.25
10	0.77	2,366.50

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References

Abaje, I. B. and Oladipo, E. O. (2019), "Recent Changes in the Temperature and Rainfall Conditions over Kaduna State, Nigeria", *Ghana Journal of Geography*, Vol. 11, No. 2, pp. 127- 157.

Abere, D. V., Oyatogun, G. M., Ojo, S. A., Abubakar, U. B. S., Otebe, S. I., Adejo, O. H., Gambo, C. and Ayeni, T. S. (2020), "Aggregate Quarry at Gidan Tagwaye, Dutse Local Government Area of Jigawa State", *Aspects in Mining and Mineral Science*, Vol. 5, No. 3, pp. 590 – 602.

Afum, B. O. and Temeng, V. A. (2015), "Reducing Drill and Blast Cost through Blast Optimisation – A Case Study", *Ghana Mining Journal*, Vol. 15, No. 2, pp. 50 – 57.

Agyei, G. and Nkrumah, M. O. (2021), "A Review on the Prediction and Assessment of Powder Factor in Blast Fragmentation", *Nigerian Journal of Technology*, Vol. 40, No. 2, pp. 275 – 283.

Agyei, G. and Owusu-Tweneboah, M. (2019), "A Comparative Analysis of Rock Fragmentation using Blast Prediction Results",*Ghana Mining Journal*, Vol. 19, No. 1, pp. 49 - 58.

Akande, J. M. and Lawal, A. I. (2013), "Optimization of Blasting Parameters Using Regression Models in Ratcon and NSCE Granite Quarries, Ibadan, Oyo State, Nigeria", *Geomaterials*, Vol. 3, pp. 28 – 37.

Ati, O. F., Stigter, C. J., Iguisi, E. O. and Afolayan, J. O. (2009), "Profile of Rainfall Change and Variability in the Northern Nigeria, 1953-2002", *Research Journal of Environmental and Earth Sciences*, Vol.1, No. 2, pp. 58-63.

Bhatawdekar, R. M., Mohamad, E. T., Singh, T. N. and Armaghani, D, J. (2019), "Drilling and Blasting Improvement in Aggregate Quarry at Thailand – A Case Study", *Journal of Mines, Metals and Fuels*, pp. 357 – 362.

Comakli, R., Atici, U. and Dogangun, E. (2017), "Effect of Drilling and Blasting Performance on the Energy Consumption of a Jaw Crusher", *9th International Drilling and Blasting Symposium*, Ankara, Turkey, pp. 187 – 191.

Eshun, P. A., Afum, B. O. and Boakye, A. (2016), "Drill and Blast Performance Evaluation at the Obra Pit of Chirano Gold Mines Ltd, Ghana", *Ghana Mining Journal*, Vol. 16, No. 2, pp. 28 - 35.

Hassan, H., Waru, S. M., Bukar, G. A. and Abdullahi, K. M., "Groundwater Potentials Estimation of a Basement Terrain Using Pumping Test Data for Parts of Sanga Local Government Area, Kaduna State, Northwestern Nigeria", *Open Journal of Modern Hydrology*, Vol. 6, pp. 222- 229.

Jethro, M. A., Shehu, S. A. and Kayode, T. S. (2016), "Effect of Fragmentation on Loading at Obajana Cement Company Plc, Nigeria", *International Journal of Scientific and Engineering Research,* Vol. 7, Iss. 4, pp. 608 – 620.

Ladan, S. I. (2014), "Forests and Forest Reserves as Security Threats in Northern Nigeria", *European Scientific Journal*, Vol. 10, No. 35, pp. 120 – 142.

Liu, M., Liu, J., Zhen, M., Zhao, F., Xiao, Z., Shan, P., Wang, Y., Ou, C., Zheng, H. and Liu, Z. (2020),

"A Comprehensive Evaluation Method of Bench Blast Performance in Open-Pit Mine", *Applied Sciences*, Vol. 10, No. 5398, pp. 1 – 12.
Mohamed, F., Hafsaoui, A., Talhi, K. and Menacer, K. (2015), "Study of the Powder Factor in Surface Bench Blasting, *Procedia Earth and Planetary Science*, Vol. 15, pp. 892 – 899.
Mkumbwa, A. G. (2017), "Analysis of Drilling and Blasting Parameters to Achieve Optimum Rock Fragmentation at Songwe II Limestone Quarry at MCC", *Unpublished BSc Thesis*, University of Dodoma, 44pp.
Odekunle, M. O., Okhimamhe, A. A., Sanusi, Y. A. and Ojoye, S. (2019), "Local Climate Zone Classification of the Cites of Kaduna and FCT in Nigeria", *Journal of Research in Forestry, Wildlife and Environment*, Vol. 11, No. 4, pp. 27 – 40.
Salati, L. K. and Mark, G. O. (2020), "Optimum Powder Factor Selection in Blast Holes at Dangote Limestone Quarry, Obajana, North-central Nigeria", *International Journal of Scientific and Engineering Research*, Vol. 11, Iss. 1, pp. 1459 – 1476.
Salmi, E. F. and Sellers, E. J. (2021), "A Review of the Methods to Incorporate the Geological and Geotechnical Characteristics of Rock Masses in Blastability Assessments for Selective Blast Design", *Engineering Geology*, Vol. 281, pp. 1 – 37.
Vandegrift, Jr. D. and Schindler, A. K. (2005), "The Effect of Test Cylinder Size on the Compressive Strength of Sulfur Capped Concrete Specimens", *Final Report on Highway Research Center*, Auburn University, Alabama, Project 2 - 13399, 84pp.
Vladimir, M., Žarko, K., Miodrag, C. and Jovana, C. (2015), "Economic Cost Analysis of Drilling and Blasting Depend of Drilling and Blasting Parameters at Quarry "Dobrnja" Near Banja Luka", *Archives for Technical Sciences*, Vol. 13, No. 1, pp. 35 – 41.
Yusuf, M. F. (2019), ""Geology of Mahanga and its Environs Part of Sheet 103, Ikara SW Ikara Local Government Area, Kaduna State", *Unpublished BSc Thesis*, Ahmadu Bello University, Zaria, 61pp.

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