OPTIMUM POWDER FACTOR SELECTION IN BLAST HOLES AT DANGOTE LIMESTONE QUARRY, OBAJANA, NORTH-CENTRAL NIGERIA

[1]Salati, L. K. and [2]Mark, G. O.

[1]Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna, Nigeria

[2]Symbol Mining Company, Gwana, Alkeleri, Bauchi State, Nigeria

Abstract

This study examined the selection of powder factor in blast holes at Dangote limestone quarry, located in Obajana, Kogi State, North-Central Nigeria. After preliminary field studies, ten (10) blasts with varying designs and powder factors were studied and three (3) rock samples carefully collected from the limestone quarry for laboratory determination of their uniaxial compressive strength (UCS) and loads at failure. Large blast holes diameters of 150 mm were maintained throughout the study, while burden was kept at 4 m and spacing varied between 4 m and 4.5 m. The stemming height and sub-drill were equally kept constant at 3 m and 1 m respectively. Primer charge of 0.25 kg and bulk charge of 25 kg per carton were used as a unit for each blast hole. The ten (10) blasts indicated a range of powder factors from 0.556 kg/m^3 to 0.659 kg/m^3 or 0.22kg/ton to 0.26kg/ton. Results of the study, therefore, showed that the company's quarry has limestone of medium strength range of 30Mpa-50Mpa which requires a powder factor of between 0.4kg/m^3 and 0.6kg/m^3 or 0.22kg/ton and 0.26kg/ton. Hence, an average powder factor of 0.58kg/m^3 or 0.24kg/ton is considered optimal for blasting operation in the company. The rock fragment size was observed visually to be very good with fewer boulders. The average UCS of the company's limestone is, therefore, found to be 31.2Mpa with maximum load at failure of 49.9kN.

Keywords: Blasting operation; blast holes; powder factor; explosives; productivity.

1. Introduction

Rock blasting in open pit mining requires good fragmentation control through effective blast design and optimum powder factor for higher productivity. Blasting engineers often face challenges caused by inadequate knowledge of actual explosive energy released in the blast hole and rock's physico-mechanical properties, as well as varying initiation practices in the blast design and their effects on explosive energy release characteristics. Poor rock fragmentation can constitute a lot of nuisance in the production of mine materials. This is possible especially if important properties such as the rock structural features are known in size, shapes and locations on the rock, which are necessary data for production optimization (Pragyan, 2012). These problems directly or indirectly increase the cost of rock fragmentation and production which can be addressed when the rock properties are studied and optimum powder factor is selected for rock fragmentation.

Optimisation of drilling and blasting phase is essential as the fragmentation obtained affects the cost of the entire production processes (Rout and Parida, 2007). The primary purpose of this phase is to fracture rocks and prepare the material for excavation and subsequent haulage. Nenuwa and Jimoh (2014) observed that the fragmentation of rocks as a result of blasting is influenced by various factors. For example, rock strength decreases or increases the fragmentation. It is also affected by the blast-ability index, porosity, and the geological disturbances. In cases of discontinuities, the shock waves are reflected causing higher alternation in a smaller area leading to boulder formation.

Bhandari (2004) also observed that many empirical formulae have been used over 200 years for the solution to proper charge size and other parameters for good fragmentation. But for blasting efficiency and uniform fragmentation, there should be uniform distribution of explosives in holes. Hence, Mireku-Gyimah and Boateng (2018), while working on the selection of blast design for a mining pit in Mali, established a simple approach of fragmentation improvement by increasing explosive by unit volume of rock at additional marginal cost towards reasonably optimizing total drilling and blasting cost.

The term powder factor is defined as the quantity of explosive required for the fragmentation of a unit cubic metre of rock ($1m^3$). Optimum powder factor results in good fragmentation, having less throw and less ground vibration. According to Mohamed *et al.* (2015), powder factor can serve as an indicator for rock hardness, cost of explosives used or as a guide to shot firing plan. Higher energy explosives, such as those containing large amounts of aluminum powder, higher density can break more rock per unit weight than lower energy explosives. Most of the commonly used explosive products have similar energy value and thus, have similar rock breaking capacities. Hence, soft and low density rock requires less explosive energy than hard, dense rocks. Large blast holes diameter requires less explosives per volume of rock as a larger stemming height is usually left as compared to small blast hole diameter.

Although it can be expressed through several possible combinations (Prasad *et al.,* 2017), powder factor for a single hole is given by this relation which considers powder column, density of explosive, drilled holes diameter, burden, spacing and bench height:

$PF = PC \times 0.34P \times D^2/B \times S \times (H/27)$ ………..equation (i)

Large holes pattern requires less explosive per volume of rock because a large portion of stemming is used.

Hence, $PF = \frac{\text{Quantity of Explosive}}{\text{Volume of blasted rock}}$ equation (ii)

For a specified blast condition to minimize the overall mining cost, optimum powder factor must be selected. Presently, the optimum powder factor is established through trial blasts. However, powder factor may be approximated using rock blast design and explosive parameters. Cardu *et al* (2015) used a specific method to establish the powder factor to achieve a fragmentation with the desired top-size. This method was developed by study conducted by Clerici in 1974 based on the analysis of the results of over 250 blasts in Italian limestone quarries for different applications. For Italian limestone such as the one encountered in the Alps, therefore, the value of minimum powder factor ranges between 0.15 and 0.2 kg/m^3.

According to Singh *et al* (2016), higher powder factor causes oversize, while lower powder factor results in crushed rock. Thus, a reasonable balance has to be maintained between extremely high and low powder factors in rock blasting. Although the study by Singh *et al*. (2016) showed that the general trend reveals increase in powder factor and decrease in the mean fragment size, this phenomenon remains an important parameter in blast design and has a vital influence on the resultant fragmentation.

Adebayo and Umeh (2007) studied the blast casting technique that utilizes explosive energy to fragment the rock mass and cast a portion of it directly into previously worked out pits. The technique depends on bench height thereby helping in efficient trajectory of thrown rocks and height- to -width ratio. It is most effective with explosives that maximize ratio of heat energy, strain energy and higher powder factor. Blasting in-situ rock to its desired fragment size requires both controllable (bench height, hole diameter, spacing, burden, hole length, bottom charge, specific charge) and uncontrollable (rock strength, discontinuity spacing and orientation, rock density) parameters for mining cycle optimization (Ninepence, *et al.,* 2016). According to Prasad *et al.,* (2017), the non-controllable parameters are geological properties such as joint, dips, strike and strength which cannot be controlled by a mining engineer.

Nenuwa and Jimoh (2014) also studied the cost implication of explosives consumption in some selected quarries in Ondo and Ekiti States in South-Western Nigeria with the observation that the quarries are consuming more explosives than required. This translates to higher cost of production which could be minimized by adopting ideal blasting parameter and design. The excess explosive consumed, however, represents wasted energy which would make the blasting operation to be associated with environmental problems like high ground vibration, excess fly rocks, dust and undesirable air blast. Consequently, poor blasting has an effective cost that is several times the cost of the entire blast itself (Afum and Temeng, 2015).

According to Choudhary and Sonu (2013), the aim of rock blasting is to achieve optimum fragmentation without generating any other nuisances. Nuisances may be controlled by the use of proper quality of explosives, its generated energy and finally optimum powder factor. Hence, such fragmentation optimization ensures quality control, consistent, safe and efficient blasting (Akande and Lawal, 2013). Yet, Jethro *et al.* (2016) agree that such production blasting is mainly targeted at optimum fragmentation.

However, the entire optimization could be jeopardized unless selection of powder factor is matched with well-planned drilling and blasting parameters as well as study of rock physico-mechanical properties. This study is, therefore, aimed at selecting optimum powder factor for rock fragmentation at Dangote limestone quarry in Obajana, Kogi State, North-Central Nigeria. The study involves the selection of suitable amount of explosives for rock blasting in the company; study of rock parameters with a view to determining optimum powder factor in rock blasting; determination of the relationship between powder factor and uniaxial compressive strength (UCS) and development of a computer programme for selecting optimum powder factor for rock blasting to improve limestone production.

2. Materials and Methods

2.1 Description of the Study Area

Dangote Cement Company is situated at Obajana village, near Lokoja, Kogi State, North Central Nigeria. The limestone deposit is located at Oyo-Iwa village which is approximately 9 km North-East of Obajana town. Obajana is located about 25km from old Kabba road junction off Okene highway. The mine location is on Latitude 7059.880 N and Longitude of 6026.4380 E as established by a hand-held global position system on one of the already established Jakura Marble bench marks (Figure 1).

Figure 1: Satellite imagery of Dangote Cement Plant, Obajana, Kogi State.

The limestone deposit can be accessed through Obajana Oyo-Iwa road and is motor-able even during raining season. The elevation of the area ranges between 278.80 m in the Southern part and 377.5 m in the Northern-Eastern part. The area is drained mainly by Mimi River (the marble is found in the Mimi River bed). Its tributaries form a dendritic pattern of drainage and discharge their water South-wards into River Niger. The major means of transportation of limestone is road which conveys cement, men and materials from the town and across Kogi State. The limestone quarry of the cement plant is situated at about 10km away from the cement plant.

2.2 Brief Geology of the Study Area

Obajana falls within the Basement Complex of South-western part of Nigeria, which contains gneiss, schist, magnetite, quartzite, and pegmatite. Roughly, two third of the area is overlain by crystalline strongly folded rocks assigned to the Basement Complex. The remaining area is overlain unconformable by gently chipping cretaceous and tertiary sediments, which overlie the Basement Complex (Kolawole *et al.*, 2017; Ogbe *et al.*, 2018).

The magnetite gneiss complex occupies the central part of the area underlain by Basement Complex and consists of fairly uniform biotite and biotite horn blended gneiss inter-located by amphibolites and quartzite. It differs from the migmatite-gneiss complex of the extreme eastern part of the South-western Nigeria Basement Complex (Imasuen *et al.*, 2013). The concession area falls within the metal sedimentary iron formation belonging to the Igara-Kabba-Jakura formation (Bolarinwa, 2018). Figure 2 shows the location of the study area on the geological map of Nigeria.

Fig. 2: The Geological Map of Nigeria Showing the Location of Dangote Cement Plant

2.2 Field Studies and Data collection

Several blasting operations were observed and monitored in the study area with a view to studying blasting parameters such as burden, spacing, depth of hole and diameter of blast hole, as well as physical condition of the quarry, types and quantity of explosives and blast design used. Visual examination, personal observations and field measurements were also used in estimating the size of fragmented rocks. Global Positioning System (GPS) was used to take coordinates from different points in the study area, while digital camera was employed to capture the various scenes of drilling and blasting operations in the study area.

Both primary and secondary data were collected in this study. Field data from the observed blasts, measurements and other raw data formed the sources of primary data. Three (3) samples of blasted boulders were collected at three different faces of the quarry. The samples were obtained after blasting and later cut to rectangular shape using cutting machine.

2.3 Sample Preparation

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 required axial loading. The measurement of the specimen dimensions was made with a sliding caliper and a metre rule. Their level of tolerance was 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). The sample was cut using cutting machine to a dimension suitable for UCS (i.e. Uniaxial Compressive Stress) 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.

2.4 Laboratory Analysis

2.4.1 Determination of Uniaxial Compressive Strength (UCS)

The ASTM test procedure (39-71) was adopted in this study. The specimen was placed in the ELE ADR 2000 compression machine. The load was 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 (uniaxial) compressive strength of the rock samples 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 samples until it failed.

Squared samples were used for this test. The four sides of each sample were ground flat, smooth and perpendicular to axis, parallel to each other. Each of the 4cm x 4cm cube specimens was cut from block samples supplied (in the absence of core samples which are commonly used). The platens on the compression machine were altered to suit this configuration. The edges of the samples were cut to shape and smoothened by polishing them with carborundum powder. The unconfined uniaxial compressive strength of the rock samples was obtained by dividing the maximum load at pressure by the cross sectional area of the specimen.

3 Results and Discussion

3.1 Field Observations and Findings

Statistical analysis of data collected in this research work was done using Microsoft Excel. Therefore, the analysed data appear in form of tables and charts. From Table 1, the trend in the spread of GPS coordinates of limestone samples collected indicates that the samples were taken at relatively close intervals. Table 2 shows the area of specimen (in m^2) as well as the load at failure of the sample which is an indication of variation in the strength (UCS in Mpa) of limestone.

Also, the areas (m^2) of the collected Samples with a constant value of 0.04 x 0.04 (m^2) indicate that the samples were prepared with the same dimension and tested by the same machine (Table 2). It also implies that the various loads at failure which are 48MN, 48.8MN and 52.8MN are for samples 1, 2 and 3 respectively.

Table 3 shows the classification of the Uniaxial Compressive Strength (UCS) of rock by the American Society for Testing and Materials (ASTM). The rock strength characterization attempts to segment rock strength with the required powder factor that would be needed to fragment such rock effectively. Results in the Table indicate that the limestone deposit falls within the medium to high strength of between 25Mpa to 30Mpa and 30Mpa to 50Mpa, thereby implying that powder factor requirement for such rock is between 0.4kg/m^3 to 0.5kg/m^3 and 0.7kg/m^3 to 0.8kg/m^3 for medium and high strength respectively. As shown in Tables 4 and 5, the average burden, spacing, hole depth, sub-drill height and number of holes drilled are 4m, 4.5m, 12m, 1m, 11m, and 100.6m respectively for the ten (10) blasts observed.

Table 1: The coordinates of samples collected.

SAMPLE	LATITUDE	LONGITUDE
S1	N26^0 51'8.4"	E007^0 59' 81.2"
S2	N26^{0}51'11.1"	E007^{0}59'85.5"
S3	N26^0 51'13.8"	E007^{0}59'87.5"

Table 2: Results of Uniaxial Compressive Strength test carried out on the samples

S/N	SAMPLE	LOAD AT FAILURE (MN)	AREA (M^2)	UCS (MN/m^3)
1	S1	48	0.04 X0.04	30
2	S2	48.8	0.04 X0.04	30.5
3	S3	52.8	0.04 X0.04	33

Table 3: American Society for Testing and Material (ASTM) Classification of Rock Strength

Rock Type	**UCS (MPa)**	**P.F (kg/m^3)**
Very Low Strength	1 – 5	0.15 – 0.25
Low strength	5 – 25	0.25 – 0.35
Medium Strength	25 – 30	0.4 – 0.5
High Strength	50 – 100	0.7 – 0.8
Very High Strength	100 - 150	0.8 – 1.1
Extremely High Strength	>250	1.1 - ∞

Table 4: Summary of Drilling and Blasting Parameters

Parameters	blast1	blast 2	blast 3	blast 4	blast 5	blast 6	blast 7	blast 8	blast 9	blast10	average
burden (m)	4	4	4	4	4	4	4	4	4	4	4
Spacing	4.5	4	4.5	4.5	4	4.5	4.5	4.5	4.5	4	4.35
hole depth	10.5	10.5	13.5	13.5	10.5	10.5	13.5	13.5	13.5	10.5	12
sub-drill	1	1	1	1	1	1	1	1	1	1	1
bench height	9.5	9.5	12.5	12.5	9.5	9.5	12.5	12.5	12.5	9.5	11
Stemming height	3	3	3	3	3	3	3	3	3	3	3
Number of holes	88	110	126	92	105	100	115	84	80	106	100.6

Table 5: Details of Drilling and Blasting Parameters

PARAMETERS	BLAST 1	BLAST 2	BLAST 3	BLAST 4	BLAST 5	BLAST 6	BLAST 7	BLAST 8	BLAST 9	BLAST 10
Burden (m)	4	4	4	4	4	4	4	4	4	4
Spacing (m)	4.5	4	4.5	4.5	4	4.5	4.5	4.5	4.5	4
Hole Depth (m)	10.5	10.5	13.5	13.5	10.5	10.5	13.5	13.5	13.5	10.5
Sub-Drill (m)	1	1	1	1	1	1	1	1	1	1
Bench Height (m)	9.5	9.5	12.5	12.5	9.5	9.5	12.5	12.5	12.5	9.5
Number of Holes	88	110	126	92	105	100	115	84	80	106
Carton of Explosive Used	352	440	630	460	420	400	575	420	400	424

Bulk Explosive Rating (Kg)	25	25	25	25	25	25	25	25	25	25
Prime Explosive Rating	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Explosive Quantity Used (Kg)	8822	11027.5	15781.5	11523	10526.25	10025	14403.75	10521	10020	10626.5
Bulk Charge (Kg)	8800	11000	15750	11500	10500	10000	14375	10500	10000	10600
Prime /Column Charge (kg)	22	27.5	31.5	23	26.25	25	28.75	21	20	26.5
Powder Factor (Kg/m3)	0.586257	0.659539	0.556667	0.556667	0.659539	0.586257	0.556667	0.556667	0.556667	0.659539
Volume of Blasted Mat. (m3)	15048	16720	28350	20700	15960	17100	25875	18900	18000	16112
Stemming height (m)	3	3	3	3	3	3	3	3	3	3
Type of Explosives	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel	pen+gel
Carton of Explosives per Hole	4	4	5	5	4	4	5	5	5	4

Table 6: Comparison of UCS results with ASTM rock classification standard

Rock Type	USC (Mpa)	P.F (kg/m^3)	Sample results UCS (Mpa)	Sample P.F (kg/m^3)	Remark
Very Low Strength	1 – 5	0.15 – 0.25	-	-	
Low strength	5 – 25	0.25 – 0.35	-	-	
Medium Strength	25 – 30	0.4 – 0.5	30	0.556	Within the range
High Strength	50 – 100	0.7 – 0.8	30 .5 – 33	0.557 - 0.660	Within the range of between (0.4- 0.7)
Very High Strength	100 - 150	0.8 – 1.1			
Extremely High Strength	>250	1.1 - ∞			

3.2 Discussions

Results from this study have shown the level of relationship between the strength of rock and powder factor. For instance, it can be deduced from Figures 4.1 and 4.2 that the Uniaxial Compressive Strength (UCS) of rock increases as the powder factor increases. This is also true in the reverse case as powder factor reduces. In the same vein, keeping UCS as a constant, powder factor increases as volume of blasted materials increases which is also true for the reverse case.

From Figure 4.4, it is evident that powder factor increases as the volume of blasted rock increases. Thus, more volume of rocks mean higher powder factor to fragment rock. Therefore, more explosives are charged in the holes to get the required results as the volume of rock increases. Also as shown in Figure 4.6, it can be deduced that to maintain the rock fragmentation size for best utilization of excavators, the ratio of burden to spacing must be carefully selected. Therefore, fragmentation size increases as burden and spacing ratio increases.

As evident from Figures 4.5, 4.6, 4.7 and 4.8, more explosives are consumed when the volume of fragmented rock increases. Consequently, blast optimization parameters such as powder factor, drill hole diameter, cost of explosives and number of holes required for blasting result in cost reduction and optimum blast. They are, therefore, required for optimum blast selection and higher productivity.

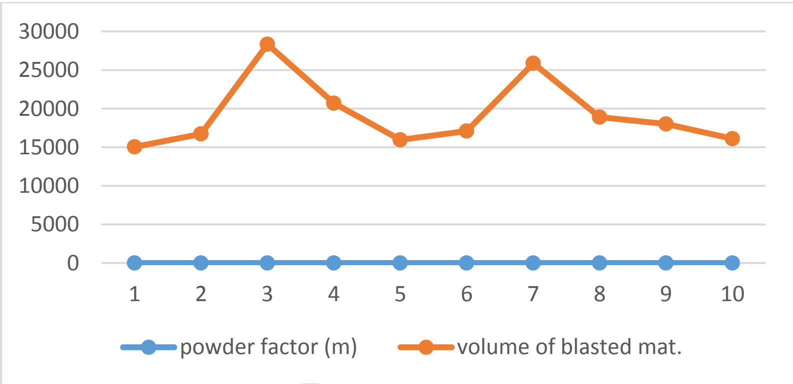

Figure 4.5: Relationship between PF and Volume of Blasted Materials

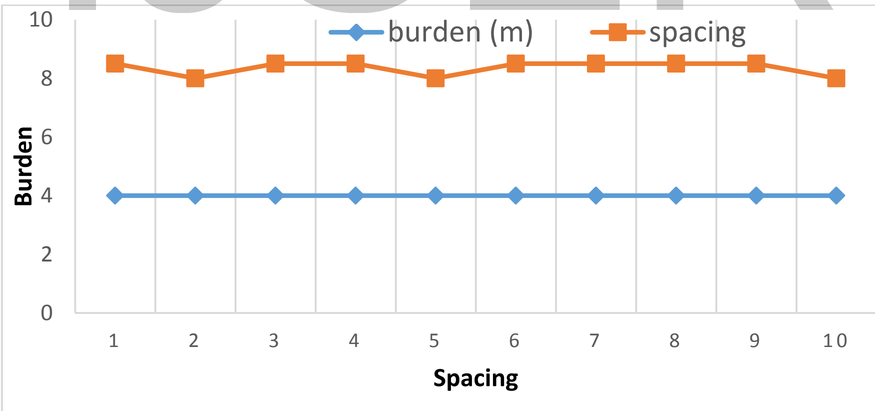

Figure 4.6: Relationship between Blast Holes Burden and Spacing

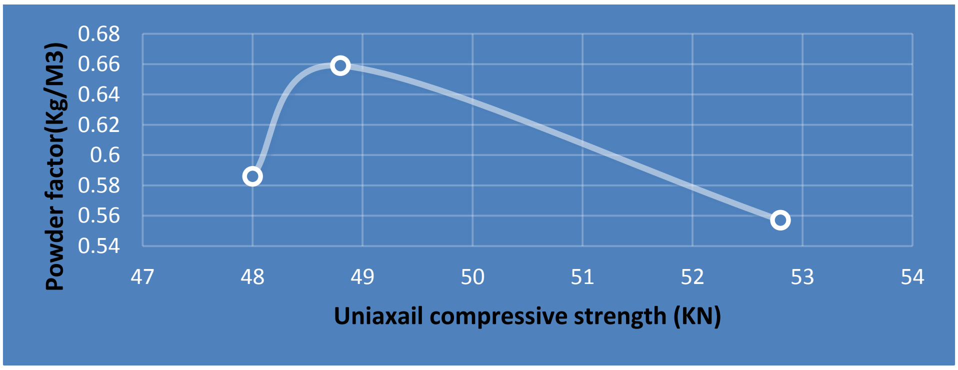

Figure 4.7: **Relationship between Powder Factor and Unixial Compressive Strength.**

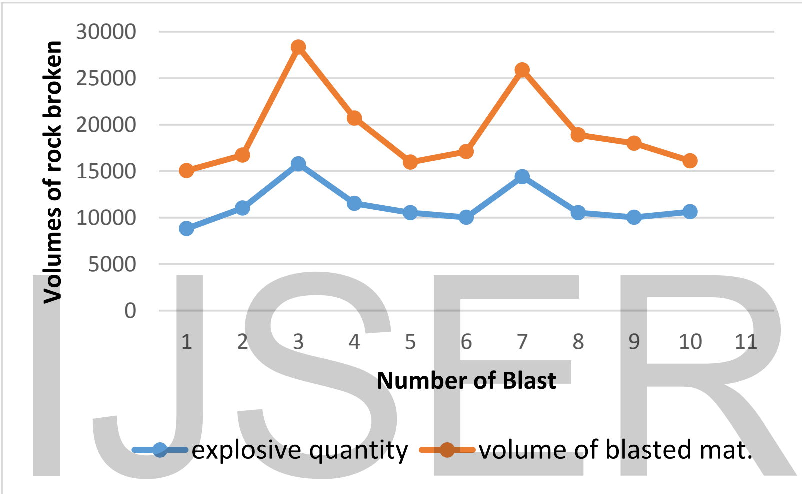

Figure 4.8: **PF Graph of Obajana Cement PLC**

4 Conclusions

The study on the selection of powder factor in blast holes at Dangote limestone quarry, located in Obajana, Kogi State, North-Central Nigeria, has shown that correct blast design and matching the right explosive type and quantity with the right volume of rock and strength are essential for optimization of rock fragmentation. Hence, good knowledge of the rock characterization, explosives strength, blast design and initiation systems are essential for optimum powder factor, rock fragmentation and productivity. It can, therefore, be concluded as follows:

i. The quantity of explosive consumed increases as the volume of rock blasted increases;

ii. The powder factor increases as the uniaxial compressive strength of the rock increases;

iii. Regardless of the hole diameter, the quantity of explosives consumed increases as depth increases;

iv. The number of blast holes increases as the volume of materials increases, likewise the quantity of explosives consumed;

v. An average powder factor of 0.598kg/m^3 or 0.24Kg/tonne is considered optimal for Dangote limestone quarry blasting operations;

vi. The average uniaxial compressive strength considered for Dangote limestone is 31.2Mpa with maximum load at failure of 49.9kN.

vii. Dangote limestone has medium strength of 30Mpa-50Mpa which requires a powder factor of 0.4kg/m^3 - 0.6kg/m^3 Or 0.22Kg/tonne -0.26kg/tonne.

viii. Relationship between powder factor and uniaxial compressive strength of the limestone from the study is of direct proportion.

Acknowledgement

The authors express deep appreciation to the management of Dangote Cement PLC, Obajana, Kogi State, North-Central Nigeria, for allowing access to the company's quarry in the course of this research. The site engineers and other quarry workers are equally acknowledged and appreciated for their full cooperation.

References

Adebayo, B. and Umeh E. C. (2007), "Influence of Some Rock Properties on Blasting Performance – A Case Study", *Journal of Engineering and Applied Sciences*, Vol. 2, No. 1, pp. 41 – 44.

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.

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.

Bhandari, A. (2004), "Indian Mining Industry: Need for Adoption of Technology for Better Future", *The Indian Mining & Engineering Journal*, December, pp. 40 - 49.

Bolarinwa, A. T. (2018), "Petrography and Geochemistry of the banded Iron Formation of the Ganfelum Area, North-eastern Nigeria", *Earth Science Research,* Vol. 7, No. 1, pp. 25 – 34.

Cardu, M., Seccatore, J., Vaudagna, A., Rezende, A., Galvao, F., Bettencourt, J. and de Tomi, G. (2015), "Evidences of the influence of the detonation sequence in rock fragmentation by blasting – Part I", *Rem: Rev. Esc. Minas,* Vo. 68, No. 3, pp. 331 – 335.

Choudhary, B. S and Sonu, K. (2013), "Assessment of Powder Factor in Surface Bench Blasting using Schmidt Rebound Number of Rock Mass", *International Journal of Research in Engineering and Technology,* Vol. 2, Iss. 12, pp. 132 – 138.

Imasuen, O. I., Olatunji, J. A. and Onyeobi, T. U. S. (2013), "Geological Observations of Basement Rocks Around Ganaja, Kogi State, Nigeria", *International Research Journal of Geology and Mining,* Vol. 3, No. 2, pp. 57 – 66.

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 & Engineering Research,* Vol. 7, Iss. 4, pp. 608 – 620.

Kolawole, M. S., Onimisi, M. and Olobaniyi, S. B. (2017), "Field Occurrence and Structural Characteristics of Basement Rocks Around Kabba-Bunu Area in Part of Kabba-Lokoja-Igarra Schist Belt, South Western Nigeria', *Global Journal of Pure and Applied Sciences,* Vol. 23, pp. 263 – 274.

Mireku-Gyimah, D. and Boateng, K. S. (2018), "Selection of Blast Design for Kofi C Pit of Endeavour Mining Corporation, Mali, *Ghana Mining Journal,* Vol. 18, No. 2, pp. 30 – 36.

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.

Nenuwa, O.B. and Jimoh B.O. (2014), "Cost Implication of Explosive Consumption in Selected Quarries in Ondo and Ekiti States, *International Journal of Engineering and Technology*, Vol. 4, No. 7, July, 2014 pp. 404 – 405.

Ninepence, J. B., Appianing, E. J. A., Kansake, B. A. and Amoako, R. (2016), "Optimisation of Drill and Blast Parameters Using Empirical Fragmentation Modelling", *4th UMaT Biennial International Mining and Mineral Conference*, pp.MP 25-29.

Ogbe, O. B., Olobaniyi, S. B., Ejeh, O. I., Omo-Irabor, O. O., Osokpor, J., Ocheli, A. and Overare, B. (2018), "Petrological and Structural Investigation of Rocks Around Igarra, South Western Nigeria', *Ife Journal of Science,* Vol. 20, No. 3, pp. 663 – 677.

Pragyan, A. (2012), "Evaluation of Blasting in an Opencast Mine", *Unpublished Bachelor of Technology Thesis,* National Institute of Technology, Rourkela, 36 pp.

Prasad, S., Choudhary, B. S. and Mishra, A. K. (2017), "Effect of Stemming to Burden Ratio and Powder Factor on Blast Induced Rock Fragmentation – A Case Study", *IOP Conference Series: Materials Science and Engineering*, 225, 9 pp.

Rout, M. and Parida, C. K. (2007), "Optimization of Blasting Parameters in Opencast Mines", *Unpublished Bachelor of Technology Thesis,* National Institute of Technology, Rourkela, 71 pp.

Singh, P. K., Roy, M. P., Paswan, R. K., Sarim, M. D., Kumar, S. and Jha, R. R. (2016), "Rock Fragmentation Control in Opencast Blasting", *Journal of Mechanics and Geotechnical Engineering*, Vol. 8, pp. 225 – 237.