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Comparative Analysis of the Influence of Powder Factor and Energy Factor in Blast Design

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Abstract: *Blast design is critical to blasting operations' cost efficiency and productivity. A key factor in estimating the cost efficiency of a blast design is the powder factor, which measures the volume of rocks fragmented by a unit explosive. Debate on charge density's influence on blast productivity has led to assumptions that the energy generated by explosives should be considered rather than the mass. Thus, this study aims to compare the influence of energy and powder factors on blast design and determine the most appropriate approach to blast planning. Data obtained from existing quarries were the burden, drilled-hole diameter, spacing, drilled-hole depth, mass of explosives, stemming, number of holes blasted, and the uniaxial compressive strength. These data were used to estimate the power and energy factors. Multivariable regression analysis was used to predict burden using drilled-hole diameter, uniaxial compressive strength energy factor, and powder factor. The results show that the burden prediction model using energy factor has a coefficient of determinants (R^2) value of 0.8741, a standard error of 0.24, and a significance factor of 3.47E-09, while the prediction involving powder factor value is 0.8781, the standard error is 0.24, and the significance factor is 2.52E-09. The study concluded that the powder and energy factors influence blast design similarly. However, in this study, the use of powder factor is recommended because of its ease of estimation.*

Keywords: Blast design, drilled-hole diameter, energy factor, powder factor, uniaxial compressive strength.

1. INTRODUCTION

Rock blasting in mining engineering aims to achieve fragmentation that will be cost-effective and safe. These are achievable with proper blast design based on several parameters that are either moderated or uncontrollable [1]. A good blast design accommodates the influences of all these parameters. Achieving this will be an enormous task due to the heterogeneous nature of rock mass. Parameters that can be moderated to achieve desired fragmentation operations are referred to as geometric parameters. They include the drilled-hole diameter, spacing and burden, drilled-hole depth and inclination, as well as drilled-hole pattern and stemming length [2]. Research has shown that the drilled-hole diameter and burden are the most critical parameters because all other parameters depend on them.

Burden is among the most essential controllable parameters in blast design. It is the distance between a blast hole and the nearest free face or between two successive rows of drilled holes [3]. Burden prediction is a vital task in the production blasting, but the results of empirical models often need to be more accurate and experimental adjustments are required. Excessive and insufficient burdens can significantly negatively impact blast results. When the burden is too short, flyrock, air blast, and improper fragmentation are eminent [4].

On the other hand, when the burden is too long, poor fragmentation, ground vibration, toe crisis, unsatisfactory displacement, backbreak and uneven faces are some of the numerous unwanted situations that may arise. In extreme cases, it can lead to the interlocking of fragments, and swelling may not occur [5]. In order to predict burden, parameters such as drilled-hole diameter, rock mass characteristics, explosive properties and the required fragment sizes have to be considered. Since all blast parameters such as spacing, stemming, sub-drill, drilled-hole depth, delay timing, and fragment size distribution depend on the chosen burden, accurate burden prediction can lead to the success of the whole blasting operation [6].

In previous research on the prediction of blast pattern design [7], the drilled-hole diameter was categorized as the significant controllable parameter and determined the burden, while other controllable parameters, in turn, depend on the burden. Findings about drilled-hole diameter show that smaller drilled-hole diameters often lead to more holes, thus increasing the total estimated costs for drilling to achieve good fragmentation for expected fragment volume [3, 7]. It also leads to an increase in the number of labourers that will be needed and does not permit the usage of bulk trucks. However, it helps to achieve better distribution and usage of explosive energy and permits selective blasting [7]. In contrast, a larger diameter increases the cost of drilling but reduces the overall blasting cost by improving the performance of drilling and haulage equipment [8]. It stabilizes the velocity of charged explosives' detonation and permits bulk trucks to move explosives [3]. Therefore, optimization of blasting performance depends on how well the burden and the drilled-hole diameter can be adjusted. The drilled-hole diameter depends on the bit size, also a function of the drilling equipment. Hence, the burden must be estimated to suit the drilled-hole diameter, the specific rock properties, and other geometric parameters.

Attempts to evaluate the cost efficiency of blast design in the past have resulted in the estimation of the powder factor (PF). It is the factor of the total quantity of explosives used for fragmentation to the quantity of blasted rock. It had been the basis for blast design for several years before a school of thought said evaluating cost efficiency based on the energy produced by explosives would be more appropriate [2]. Thus, there is a need to change from using powder factor to energy factor for blast design. A drawback in the use of powder and energy factors for blast design is that they make blasting look like an art rather than science. Several trial blasting must have been done before arriving at an appropriate powder and energy factor for a specific location. It is one of the reasons most prediction models for blast design are site-specific.

In the blast design model of Langefors [9], a range of factors were given to predict burden as a function of hole diameter to accommodate differences in rock strength properties, confirming the guesswork in previous models. A sufficient powder and energy factor value will lead to better fragmentation, secondary blasting, and a higher cost of mucking and loading. At the same time, an excessive value will result in overthrow and fly-rock, backbreak, production of fines and wastage of explosives [1]. This paper attempts to improve the Langefor burden prediction model by incorporating the rock strength property and the cost-efficiency factors of blast design. The burden prediction was done using the drilled-hole diameter, energy factor, and powder factor. A comparison between the burdens measured and predicted using powder and energy factors was done to determine better predictive parameters using a multivariable regression model.

2. METHODOLOGY

2.1 The Case Study

Data collection was from twenty-four blasting sites in Southern Nigeria as shown in Figure 1, which were involved in aggregate production, to achieve the specific objective of this study. The physiographical study of the research locations falls within the Precambrian assemblage of igneous and metamorphic underlying stratifying rocks of south-western Nigeria. Notwithstanding dissimilarities in lithological descriptions, the rocks that comprise the basement are classified loosely into three groups: the migmatite-gneiss complex, the schist orogens and the unified African granites [10]. The schist belts comprise low-grade meta-sediments and meta-bare rocks developed in distinctly N-S gravitating informal trenches folded into the crystalline migmatite-gneiss complex, ranging from 2.0 to 3.0 Ga [11, 12]. It is the oldest and most present rock type in the basement, resulting from several tectonothermal activities that have assembled rocks of diverse origins. The older granites show the most pervasive tectonic fabric, indicating igneous reactivation resulting from the Pan-African activities [13]. The older granite is a fine-medium-grained to coarse porphyritic rock composed of tonalite and granodiorite to granite syenite [14]. The selected blasting sites used ammonium nitrate granules mixed with fuel oil (ANFO) and dynamite cartridges for column and priming charge, respectively. The blasting engineers are well experienced and have, over time, used trial-by-error methods to arrive at suitable blast designs for each site. The appropriate evaluation of burden, which is the primary link between all controllable blast parameters, is essential for the overall economics of the operations. Thus, in this study, rock properties thought to influence appropriate burden prediction were carefully assessed following standard procedures suggested by the International Society of Rock Mechanics [15]. Also, blast geometry parameters were measured on the field for each selected location, whilst powder and energy factors for each blast were estimated.

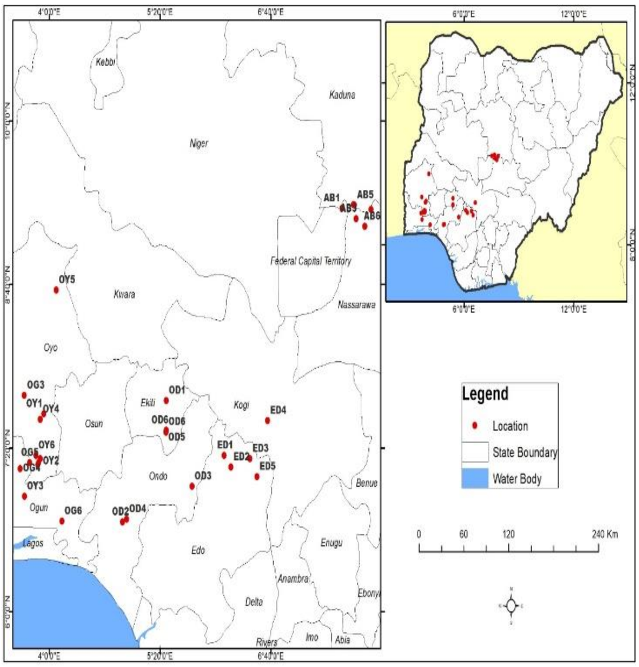

Figure 1: The study area

2.2 Parameters for Burden Prediction

Parameters used in this study for burden prediction include drilled-hole diameter (D), uniaxial compressive strength (UCS), powder factor (PF), and energy factor (EF). These parameters were selected due to a large body of evidence from the literature that they significantly impact blasting operation efficiency and blast economy.

2.2.1 Calculation of powder factor (PF)

The powder factor was calculated using the conventional method of the ratio of the charge quantity to the volume of the expected fragment, as shown in Equation (1). The volume of blasted rock is calculated by multiplying the area of the blast with the average drilled-hole depth.

$$PF = \frac{Q_e}{V} \tag{1}$$

where Q_e is the total quantity of explosive used to blast the rock (kg), V is the volume of the blasted rock (m^3) and PF is the powder factor (kg/m^3).

2.2.2 Estimation of energy factor (EF)

Energy factor (EF) was used rather than the popular powder factor (PF). Although EF is similar to the PF method in terms of the ability to rank levels of explosive energy input into blasts, it differs in that it considers the actual explosive energy input, unlike the PF method, which considers the weight of the explosive used. Baudin [16] determined the energy factor as described in Equations (2) to 5.

$$EF = \frac{Charge\ Energy}{Tonnage\ of\ Blasted\ Rock} \tag{2}$$

$$CE = 0.454\,(CW \times AWS) \tag{3}$$

$$CW = (H + Sd - St) \times LD \tag{4}$$

$$LD = 0.3405(ED \times D_e^2) \tag{5}$$

where EF is energy factor, CE is charging energy, CW is the charge weight, AWS is the average weight strength, LD is the load density, St is the stemming, ED is explosive density, D_e is drilled-hole diameter, and Sd is the sub-drill.

2.2.3 Estimation of uniaxial compressive strength (UCS)

The intact strength of the rocks in the selected locations was determined mainly for strength classification. Five samples of the selected rocks were tested, and the failure load was recorded for each test. The failure was observed axially in a Riedligen testing machine capable of loading up to 3000 kN at a rate conforming to the ISRM [15], and the UCS values were calculated using Equation (6).

$$C_0 = \frac{P}{A} \tag{6}$$

where C_0 is the compressive strength (MPa), P is the load at failure (N) and A is the cross-sectional area of the sample (mm^2).

3. RESULTS AND DISCUSSION

3.1 Estimated Powder and Energy Factor

Blast design works for the distribution of explosive energy and other accessories needed for a blast to be successful. In this study, the drilled-hole diameter, burden, spacing, blast-hole depth, and stemming were the primary geometric parameters used to estimate powder and energy factors. Table 1 shows the geometric parameters data used. Ammonium Nitrate and Fuel Oil (ANFO) were used for column charge, while gelatine was used as a bottom charge in the selected sites, as shown in Table 1. From Table 1, four sites used only ANFO for charging.

The power factor is often used in blast design instead of the energy from the explosive that shattered rock. However, the energy factor may be more appropriate when planning blasting with different explosives for bottom and column charges. For example, Table 2 shows that site 4 has the lowest values for powder factor (0.393 kg/m^3), followed by site 15 (0.396 kg/m^3), but the energy factors for site 4 (1.465 MJ/m^3) are higher than that of site 15 (1.405 MJ/m^3). However, energy and powder factors were estimated to increase linearly for sites where a single type of explosive was used (sites 8, 17, 19 and 20). When the powder factor is used for the blast design while the same explosive is used for the column and bottom charge, the resultant design will be equivalent to the energy factor.

3.2 Burden Prediction

Multivariable regression analysis was used to predict burden using drilled-hole diameter, uniaxial compressive strength energy factor and powder factor. The first prediction model involves the energy factor, excluding the powder factor, while the second model is vice versa. The analysis of variance for the first prediction model shows that the coefficient of determinants (R^2) value is 0.8741, the standard error is 0.24, and the significance factor is 3.47E-09. Also, for the second model with the powder factor, the R^2 value is 0.8781, the standard error is 0.24, and the significance factor is 2.52E-09. The first and the second prediction models are presented mathematically in Equations 7 and 8, respectively. This analysis of variance shows that there is little difference between the models as their standard error is the same; they both show a high level of significance. The coefficient of determination of approximately 87 and 88 per cent shows a high correlation between the predicted and the measured burden. However, the model with the powder factor is a better predictor of burden with a lesser significance factor and higher coefficient of determination as shown in Equations (7) and (8).

$$B = 2.27 - 0.43EF - 0.008UCS + 0.02D \tag{7}$$

$$B = 2.41 - 1.66PF - 0.008UCS + 0.02D \tag{8}$$

where B is the burden (m), EF and PF are the energy (MJ/m^3) and powder factor (kg/m^3) respectively, UCS is the uniaxial compressive strength in MPa, and D is the drilled-hole diameter in mm.

Table 1: Geometric parameters for the selected locations

Site	S (m)	B (m)	H (m)	D (mm)	St (m)	AN (kg)	Gel (kg)	NH
OD1	2.0	2.0	12.0	89.0	2.0	20.0	12.0	105
OD2	2.0	2.0	14.0	89.0	3.0	30.0	7.0	60
OD3	3.0	3.0	16.0	101.6	2.0	75.0	10.8	60
OD4	3.0	2.5	12.0	76.2	3.0	27.0	8.4	42
OD5	3.0	3.0	12.0	101.6	1.0	40.0	24.8	74
OD6	3.0	2.0	21.0	76.2	1.0	88.0	20.0	64
OG1	3.5	3.0	12.0	101.6	2.0	70.0	5.6	75
OG2	2.5	2.5	12.0	76.2	2.5	45.0	0.0	22
OG3	4.5	2.0	6.0	89.0	1.0	30.0	6.8	105
OG4	3.0	3.0	12.5	89.0	2.5	40.0	11.5	19
OG5	3.0	2.5	15.0	89.0	2.0	55.0	12.4	14
OY1	2.5	2.0	10.0	89.0	1.8	30.0	1.0	16
OY2	2.5	2.5	11.0	76.2	3.0	25.0	2.0	45
OY3	2.5	2.0	12.0	89.0	1.0	40.0	4.2	102
OY4	3.0	3.0	15.0	89.0	3.0	45.0	8.4	9
ED1	1.5	1.1	3.5	25.4	0.2	3.8	0.3	312
ED2	1.5	1.1	5.0	25.4	0.5	5.5	0.0	250
ED3	2.5	2.5	12.0	89.0	1.5	40.0	2.4	23
ED4	1.5	1.5	2.0	25.4	0.1	2.7	0.0	105
ED5	1.5	1.1	2.0	25.4	0.6	2.0	0.0	125
AB1	2.5	2.0	8.0	89.0	1.0	25.0	8.9	135
AB2	3.0	3.0	21.0	101.6	3.0	95.0	6.3	28
AB3	3.0	3.0	12.0	101.6	2.8	60.0	20.5	68
AB4	2.5	2.5	15.0	89.0	2.0	37.5	14.0	58

S is the spacing, B is the burden, H is the drilled-hole depth, D is the drilled-hole diameter, St is the stemming length, NH is the total number of holes blasted, AN is ANFO and Gel is gelatine.

3.3 Power and Energy Factor

It is essential to understand the relationship between powder and energy factors. From the estimation, it is evident that the energy factor is a function of the powder factor. Therefore, correlation analysis was done to evaluate the relationship between them. The result shows a very high correlation between the powder factor and the energy factor with an R^2 value of 0.9747, as shown in Figure 2. Estimation of the energy factor was also modelled mathematically using Equation (9).

$$PF = 3.7518EF - 0.0589 \tag{9}$$

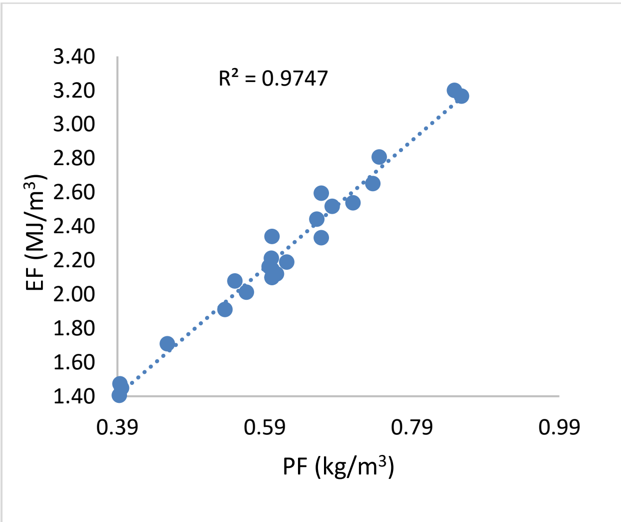

Figure 2: Energy and powder factor

3.4 Predicted and Measured Burden

The relationship between the measured and the predicted burden using energy and powder factors is presented in Figures 3 and 4. The predicted burden's relationship shows a very high correlation between them, close to 1 as shown in Figure 5. The positive and linear relationship has no notable difference between the predicted burdens. A comparison between the measured and predicted burdens, as shown in Figure 6, indicates that the energy factor model overestimated the burden even though the estimation follows the sequence of the measured burden. At the same time, the powder factor model is shown to be a better predictor.

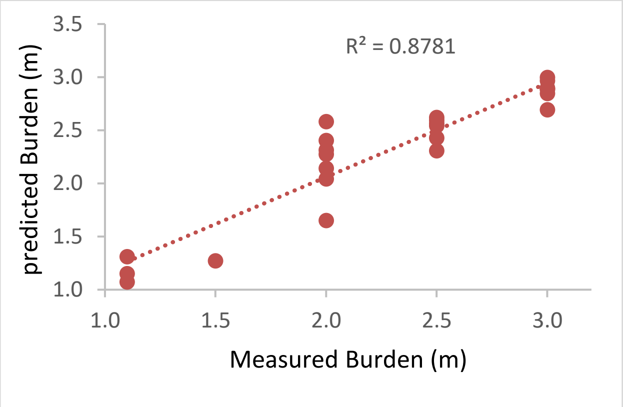

Figure 3: PF predicted and measured burden

Table 2: Burden prediction parameters and their corresponding predicted burdens

Sites	**B** (m)	**D** (mm)	**UCS** (MPa)	**EF** (MJ/m^3)	**B_{EF}** (m)	**PF** (kg/m^3)	**B_{PF}** (m)
OD1	2.0	89.0	140.25	2.596	2.5	0.667	2.1
OD2	2.0	89.0	125.10	2.444	2.7	0.661	2.3
OD3	3.0	101.6	101.50	2.164	3.3	0.596	2.8
OD4	2.5	76.2	105.20	1.475	3.0	0.393	2.6
OD5	3.0	101.6	95.20	2.341	3.2	0.600	2.9
OD6	2.0	76.2	127.00	3.167	2.1	0.857	1.7
OG1	3.0	101.6	82.00	2.147	3.4	0.600	3.0
OG2	2.5	76.2	98.30	2.100	2.8	0.600	2.3
OG3	2.0	89.0	82.20	2.517	3.0	0.681	2.6
OG4	3.0	89.0	90.80	1.710	3.3	0.458	2.9
OG5	2.5	89.0	104.20	2.213	3.0	0.599	2.5
OY1	2.0	89.0	128.40	2.191	2.8	0.620	2.3
OY2	2.5	76.2	102.00	1.405	3.0	0.393	2.6
OY3	2.0	89.0	93.20	2.652	2.9	0.737	2.4
OY4	3.0	89.0	101.80	1.450	3.3	0.396	2.9
ED1	1.1	25.4	90.30	2.539	1.5	0.710	1.1
ED2	1.1	25.4	89.50	2.333	1.6	0.667	1.1
ED3	2.5	89.0	125.40	2.012	2.9	0.565	2.4
ED4	1.5	25.4	88.10	2.100	1.7	0.600	1.3
ED5	1.1	25.4	82.00	2.121	1.8	0.606	1.3
AB1	2.0	89.0	115.30	3.200	2.5	0.848	2.0
AB2	3.0	101.6	98.88	1.911	3.4	0.536	3.0
AB3	3.0	101.6	90.01	2.808	3.1	0.745	2.7
AB4	2.5	89.0	111.98	2.079	3.0	0.549	2.6

UCS is the uniaxial compressive strength, B_{EF} and B_{PF} are the predicted burdens using energy and powder factor values respectively.

https://doi.org/10.53982/ajeas.2024.0202.06-j

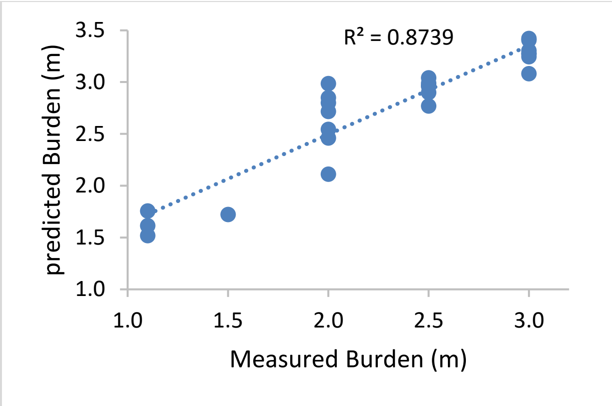

Figure 4: EF predicted and measured burden

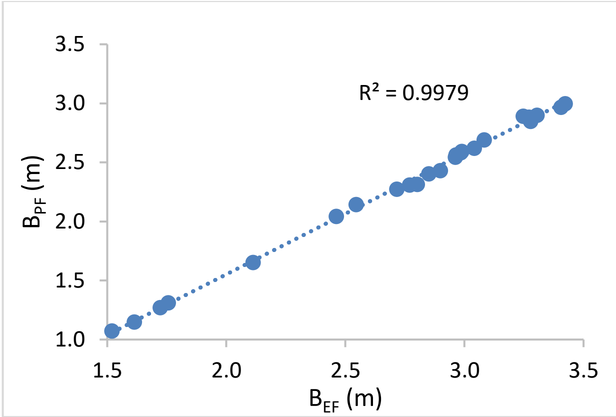

Figure 5: Burdens predicted by EF and PF

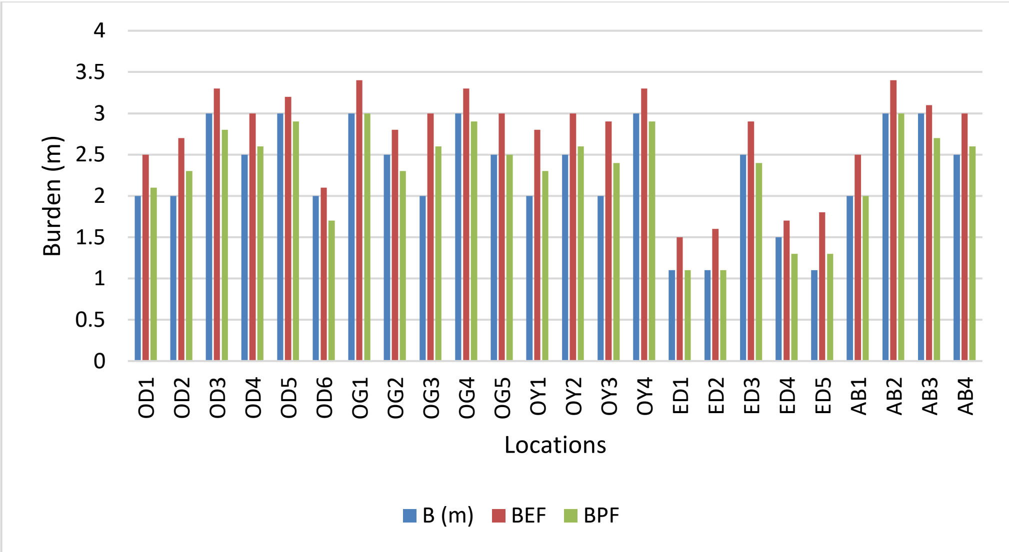

Figure 6: Predicted and measured burden for the location

4. CONCLUSION

The two models presented in this study, energy and powder factor, are essential parameters for estimating the cost efficiency of blast operation. The results suggested that the powder factor is most suitable when a type of explosive is used for both the column and bottom charge. In the case of different types of explosives for column and bottom charges, the energy factor is the most suitable. The powder factor model proved to be a better predictive model for burden in the combined analysis of charge with either different type of explosive for charging. This study has been able to modify the Langerfors' burden predictive model by incorporating the strength characteristics of the rock, the involvement of UCS, and the economic efficiency of the design by infusing either the powder factor or the energy factor. Future studies will focus on a larger dataset for charging with a single type of explosive and combined explosives.

REFERENCES

[1] Adesida, P. A. (2022). Powder factor prediction in blasting operation using rock geo-mechanical properties and geometric parameters. *International Journal of Mining and Geo-Engineering*, 56(1), 25-32. https://doi.org/10.22059/IJMGE.2021.310930.594870.

[2] Adesida, P. A. (2023). A rock engineering system approach to estimation of blast induced peak particle velocity. *International Journal of Mining and Geo-Engineering*, 57(1), 101-109. https://doi.org/10.22059/ijmge.2022.343687.594973.

[3] Fisonga, M., García, Y. D. and Besa, B. (2017). Burden Estimation using Relative Bulk Strength of Explosive Substances. *Applied Earth Science;* 126(1), pp. 31-37. https://doi.org/10.1080/03717453.2017.1296673.

[4] Zhang, Z., Qiu, X., Shi, X., Luo, Z., Chen, H. and Zong, C. (2023). Burden Effects on Rock Fragmentation and Damage, and Stress Wave Attenuation in Cut Blasting of Large-Diameter Long-Hole Stopes. *Rock Mechanics and Rock Engineering*, 56, 8657–8675. https://doi.org/10.1007/s00603-023-03512-y.

[5] Hustrulid, W.A. (1999). Blasting Principles for Open Pit Mining: General Design Concepts. Balkema Publications.

[6] Ebrahim F. 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 blast design. *Engineering Geology*, 281(105970). https://doi.org/10.1016/j.enggeo.2020.105970.

[7] Dhekne, P., Pradhan, M. and Jade, R. K. (2015). Assessment of the Effect of Blast Hole Diameter on the Number of Oversize Boulders Using ANN Model [online]. *J. Inst. Eng. India Ser. D.* Available at: https://doi.org/10.1007/s40033-015-0083-7.

[8] Abbaspour H., Drebenstedt, C., Badroddin, M. and Maghaminik, A. (2018). Optimized design of drilling and blasting operations in open pit mines under technical and economic uncertainties by system dynamic modelling. *International Journal of Mining Science and Technology*, 28(6), 839-848. https://doi.org/10.1016/j.ijmst.2018.06.009.

[9] Langefors, U. and Kihlström, B. (1978): *The Modern Technique of Rock Blasting.* John Wiley and Sons.

[10] Elueze, A. A. (2000). Compositional appraisal and petrotectonic significance of the Imelu banded ferruginous rock in the Ilesha schist belt, southwestern Nigeria. *J. Min. Geol.*, 36(1), pp.8-18.

[11] Dada, S. S. and Briqueu, L. (1998). Pb-Pb and Sr-Nd isotopic study of meta-igneous rocks of Kaduna: Implications for Archean mantle of Northern Nigeria. In: Abstracts of the 32nd annual conference, *Nigeria Mining and Geosciences Society*, p.57.

[12] Rahamam, M. A.., Ajayi, T. R., Oshin, I. O. and Asubiojo, F. O. (1988). Trace element geochemistry and geotechtonic setting of Ile-Ife schist belts. Precambrian geology of Nigeria. *GSN, Kaduna*, 241-256.

[13] Agunleti, Y. S. and Arikawe E. A. (2014): Groundwater Targeting Within the Basement Complex Rocks of Federal Capital Territory Abuja Using Remotely Sensed and Vertical Electrical Sounding Data. International Journal of Technology Enhancements and Emerging Engineering Research; 2(12): pp.38 – 47.

[14] Afolagboye, L. O., Talabi, A. O. and Akinola, O. O. (2016). Evaluation of selected basement complex rocks from AdoEkiti, SW Nigeria, as source of rock construction aggregates. *Bull. Eng. Geol. Environ.*, 75, pp.853-865. https://doi.org/10.1007/s10064-015-0766-1.

[15] ISRM (2007). The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006. International Society for Rock Mechanics, Commission on Testing Methods.

[16] Ogunsanwo, F. O., Olowofela, J. A., Okeyode, I. C., Idowu, O. A. and Olurin, O. T. (2019). Aeroradiospectrometry in the spatial formation characterization of Ogun State, south-western, Nigeria [online]. *Scientific African*, 6. Available at: https://doi.org/10.1016/j.sciaf.2019.e00204. (Assessed: 1 September 2024).

[17] Baudin, G., Lefrancois, A., Saurel, R., Petitpas, F., Le Metayer, O., Massoni, J., Belski, V. M. and Zotov, E. (2010). Toward a Thermal Disequilibrium Multiphase Model for High Explosives Containing Metallic Particles. *Journal of Energetic Materials*, 28, pp.154–179.