Prediction of Blast Efficiency of a Typical Granite Quarry

[1]K. A. Idowu, [2]B. M. Olaleye, [2]M. A. Saliu
[1]University of Jos, Nigeria
[2]The Federal University of Technology, Akure, Nigeria

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Abstract

Blasting is an important aspect of mining activities in which fragmentation is the key component that determines its efficiency. Blasting efficiency can be evaluated by different design methods. In this study, model was developed for predicting the blast efficiency using artificial neural network (ANN) method. Rock samples were collected from five different blasts of the study area and uniaxial compressive strength test was carried out on the samples in accordance with international standard. The average uniaxial compressive strength (UCS) obtained from the rock samples at ENL quarry is 151.64 MPa and the in-situ block size distribution obtained vary from 1 m^2 to 3.08 m^2. The determination of the fragment size is achieved using Split-Desktop image analysis. The average percentage value of F_{50} obtained from the Split-Desktop analyses is approximately 73.16 cm. The results obtained from the UCS, in-situ block size distribution, image analysis of the blasted rocks and the total charge were used to develop a model for prediction of blast efficiency. The prediction of the proposed model using artificial neural network (ANN) is compared with the measured efficiency of five different blasts and the value of R^2 obtained is 0.9733. The findings showed that, the model can give a close prediction to the blasting efficiency in the study location. However, most models are usually site specific; hence, there may be differential performance of a model from location to location. It is therefore very imperative to assess the suitability of these models on the various sites.

Keywords: Granite Quarry, Blast Efficiency, ANN, Split-Desktop, AutoCAD.

1 Introduction

The primary purpose of blasting is rock fragmentation and displacement of the broken rock. Blasting efficiency can be evaluated by different design methods. The definition of efficient blasting is based on the idea that increased energy expenditure is required in blasting to obtain better fragmentation, but better blasting lowers the cost of loading, hauling, crushing and protecting newly opened slope faces thus assisting the next drilling and blasting operation.

In the study of prediction of blast fragmentation using multivariate analysis procedures by Hudaverdi *et al*., (2011), showed that adoption of multivariate analysis procedures to predict rock fragmentation by blasting can be achieved by filling the gaps between the defined blocks using mathematical procedures known as morphological dilation and erosion (Bleines *et al*., 2013). Generally, only a few joint sets in a rock mass are dominant controlling mainly the breakage of rock mass from blasting. Discontinuity sets intersect one another and form isolated blocks. The efficiency of a blast in fracturing a rock mass depends on the block size and the size distribution of the blocks (ISRM, 1999). The strengths of the joint sets generally are so small compared to the intact rock strength that most of the fracturing occurs along the joints rather than through the rock (Engelder, 1987).

Blasting operation is usually accompanied by various problems such as flyrocks, slope instability, back-break, environmental pollution and vibration. However, these problems can be ameliorated with a detailed study of rock mass and good blasting (Saliu and Idowu, 2014; Lawal, 2020).

A global trend in fragmentation is emerging in which mining companies are subcontracting out the total blasting services (including drilling) due to poor blasting efficiency. According to Frank (2014), some companies have subcontracted all work functions at the mine and processing plant. Obviously, for profitable quarrying, a rock mass with an appropriate degree of jointing is essential (Selenon *et al.*, 2000). The results of the work of Idowu *et al.*, (2021), prove that models are important in predicting blast fragmentation in order to maintain a normal operating level and desired degree of fragmentation by blasting. Hence, it is very essential to study the fragmentation of the rocks using suitable models to predict the blast fragmentation for optimum recovery.

1.1 Description of the study area

The study area is located at Akinyele Local Government, Ibadan, Oyo State, Nigeria. Fig. 1 shows the geological map of ENL quarry in Ibadan, Oyo State, Nigeria as extracted from the geological map of Nigeria. ENL quarry is located geographically between the latitude 7^0 30' 0" N to

7^0 40' 0" N and longitude 3^0 50' 0" E to 4^0 00' 0" E at 302 m above the sea level.

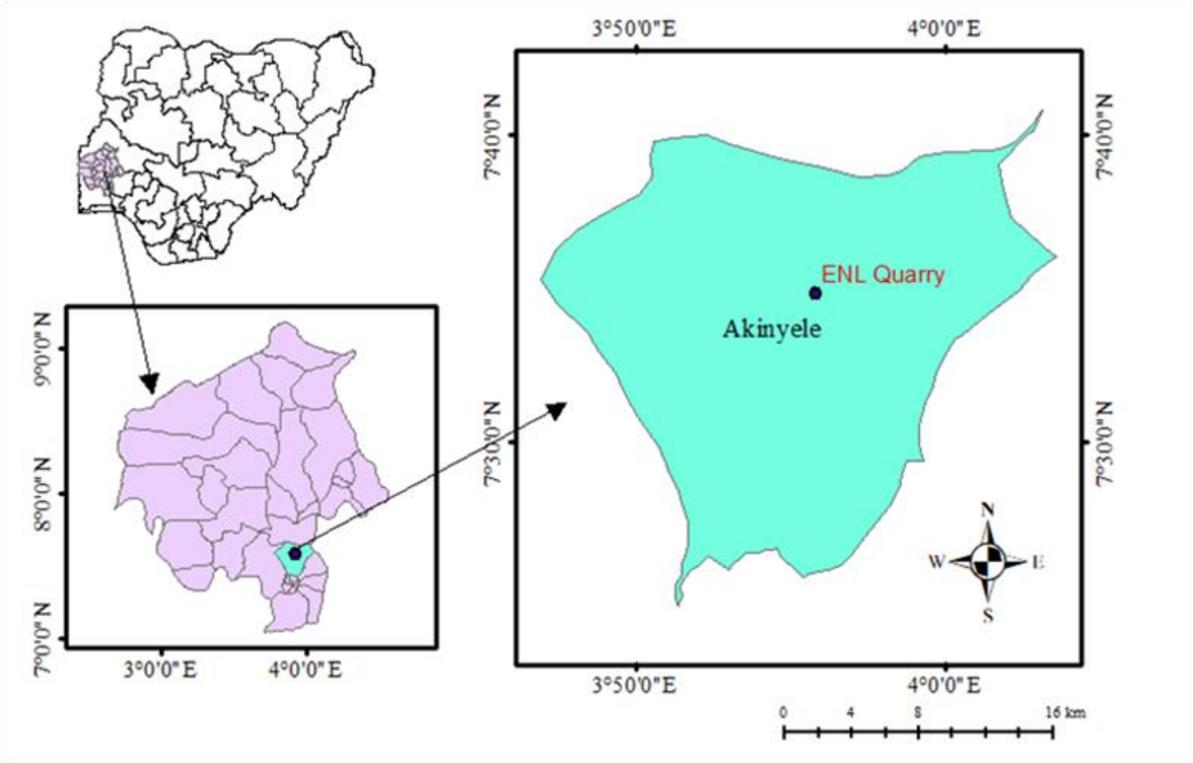


Fig. 1Map of Study Area

2 Materials and Methods Used

The mechanical property of rock considered is the uniaxial compressive strength, and it is determined by loading a cylindrical rock sample with a diameter of 50 mm and length-to-diameter ratio of 2.5:1 axially until the sample fails under the compressive testing machine.

The in-situ block sizes of the rock mass are determined with the use of AutoCAD tool, while the fragment sizes of the blasted rocks are determined by the use of Split-Desktop digital image analysis.

The blast design parameter for the blast operations at ENL is presented in Table 1. It has a bench height of 5.5m and a powder factor of 0.2 kg/ton.

Table 1 Blast Design parameters of ENL Quarry

S/N	Parameter	Value at ENL
1	Burden (m)	2.2
2	Spacing (m)	2.2
3	Bench height (m)	5.5
4	Hole diameter (mm)	65
5	Stemming (m)	1
6	Sub-drill (m)	0.2
7	Powder factor (kg/tons)	0.2
8	Quantity of Explosive per meter	ANFO = 3.75 kg
9	Explosive type	Ammonium nitrate and Bulk emulsion
10	Delay time/interval	20 ms

3 Results and Discussion

The average uniaxial compressive strength (UCS) obtained from the five samples of the quarry is 151.64 MPa as shown in Table 2.

Table 2 Uniaxial Compressive Strength of Rock Samples from ENL

Sample No.	Failure Load (KN)	Cross Sectional Area (mm^2)	Mass before Test (g)	Compressive Strength (MPa)	
ENL 1	450	22.8	395	196.72	
ENL 2	290	22.8	254	127.05	
ENL 3	290	22.8	254	127.05	
ENL 4	470	22.8	412	204.92	
ENL 5	235	22.8	206	102.46	
			Average	**151.64**	**High Strength**

Mean = 151.640; and Standard Deviation = 105.806

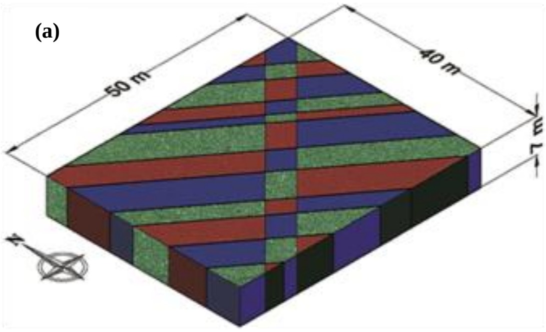
The UCS of rock samples from the granitic quarry vary from 102.46 MPa to 204.92 MPa.

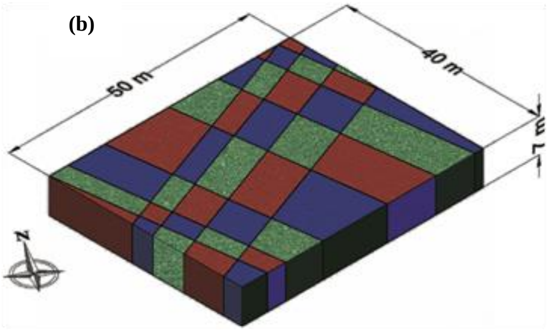
According to Deere and Miller (1966) and Hassan *et al*., (2019), the UCS classification of the rocks is of high strength.

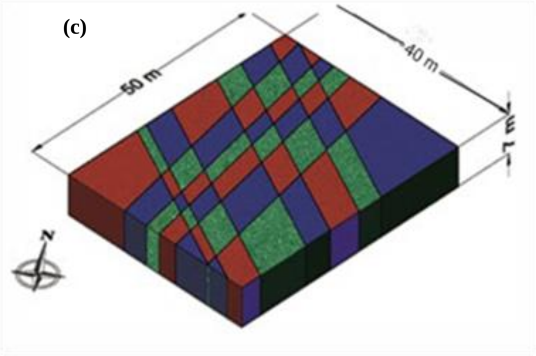
3.1 In-situ block size distribution

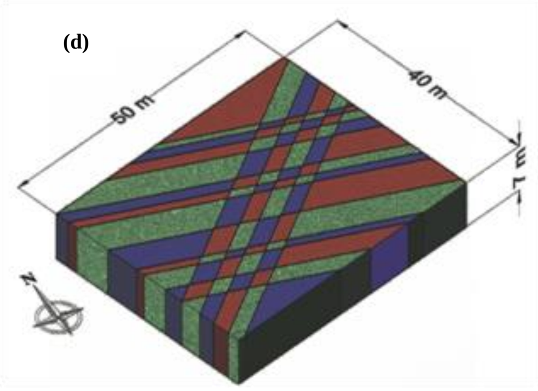
For the in-situ block size distribution of the rock type, AutoCAD software was used. At the study location, the in-situ rock mass conditions for the five different blasts with similar dimensions were modeled and their cumulative graph curves were plotted to obtain the average in-situ block size distribution.

The AutoCAD block size distribution for the five different blasts of the quarry is shown in Fig. 2. The AutoCAD model dimension of the in-situ rock mass for each blast at the quarry is 50 m × 40 m with a bench height of 7 m.









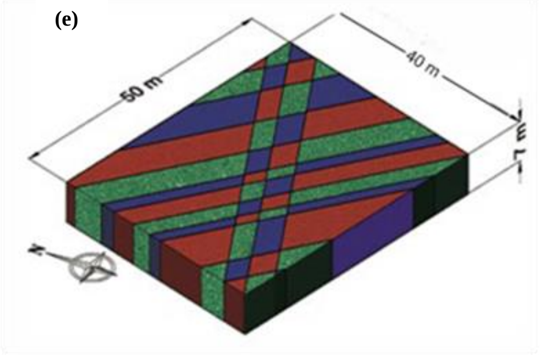
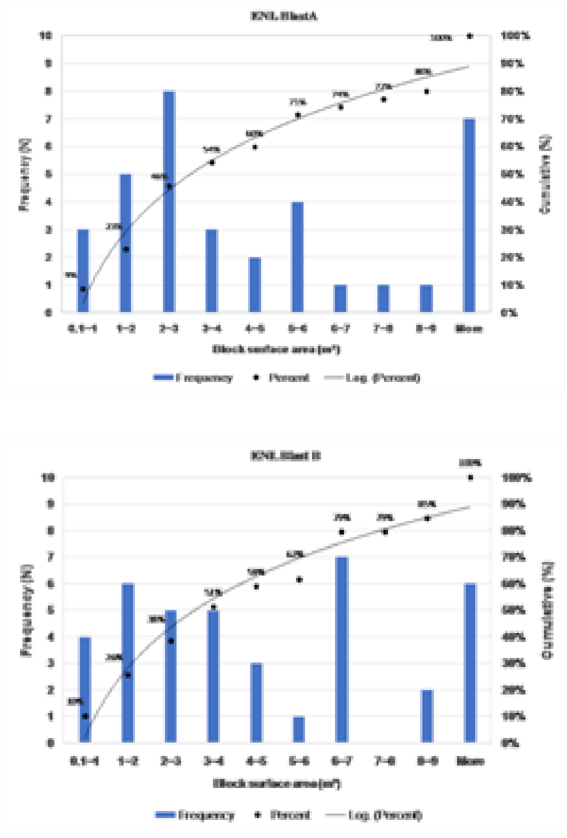


Fig. 2 AutoCAD Block Size Distribution of Blasts A - E at ENL

The cumulative graph curves of the in-situ block size distributions for the five blasts A to E at ENL quarry are presented in Fig. 3. At ENL, the in-situ block sizes vary from 1 m^2 to 3.08 m^2.



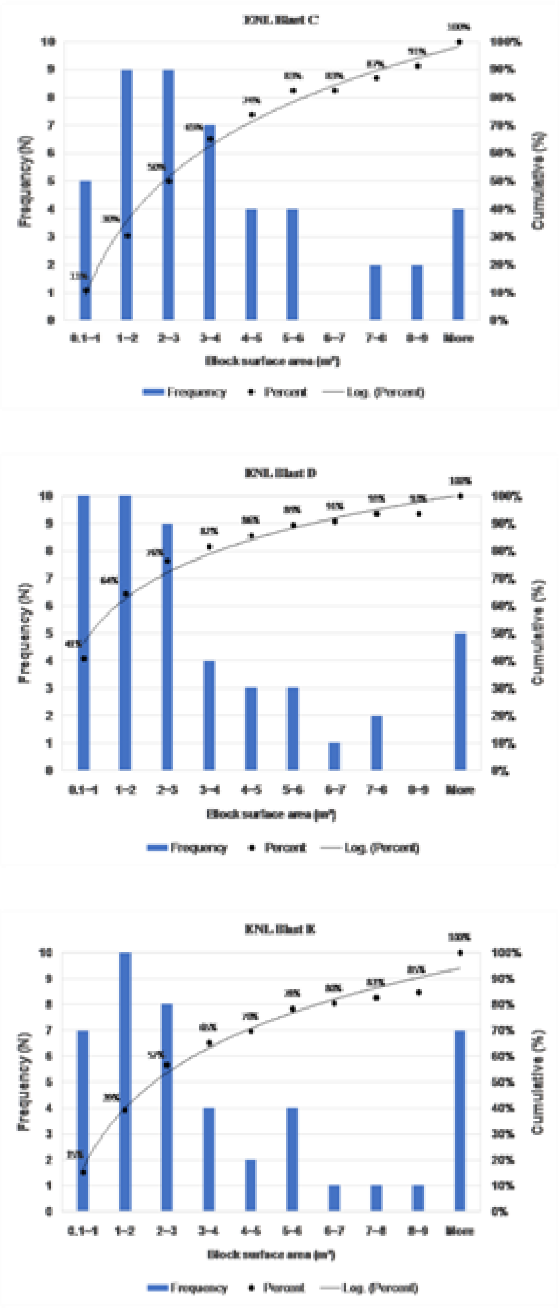
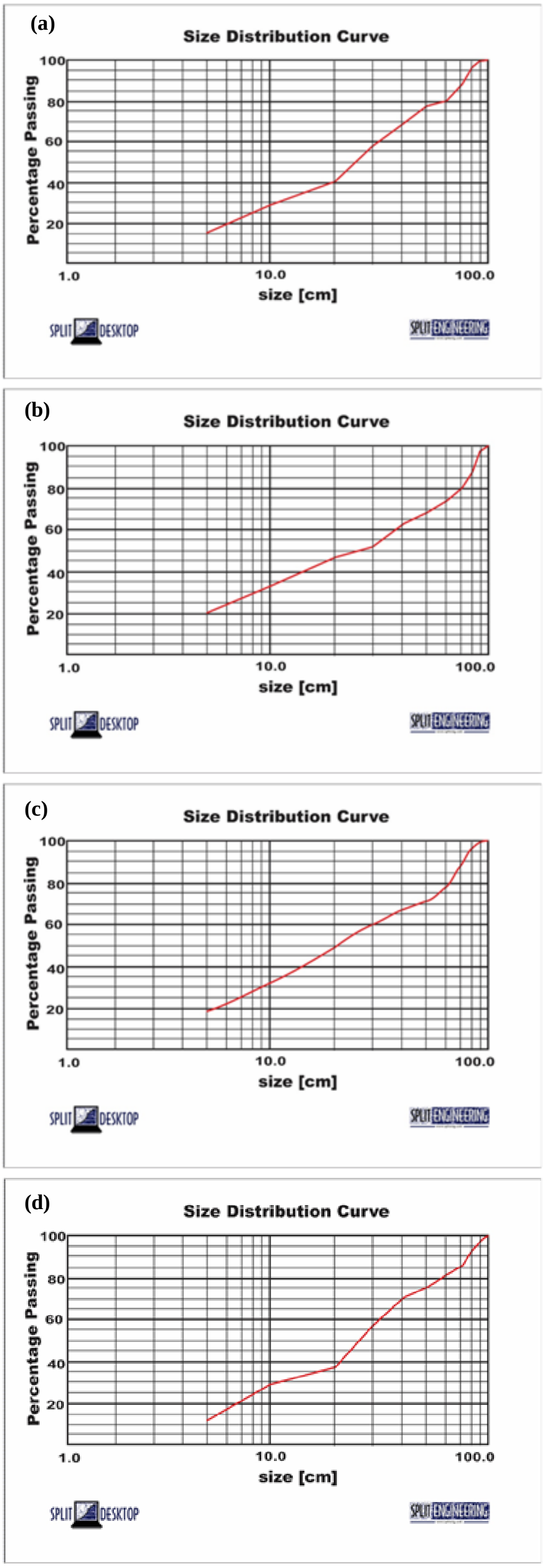


Fig. 3 Cumulative Graph of In-situ Block Size Distribution for Blasts A - E at ENL

3.2 Image Analysis

At the quarry, a total number of five (5) blasted muckpiles were analyzed. The particle size distribution curve analyses of the muckpiles were obtained from the five different blasts of the quarry using Split-Desktop model (Fig. 4). The results of the Split-Desktop analyses show that all the fragments of the muckpile are less than 100 cm benchmark, which is the gape of the crusher. The Split-Desktop analyses show a very closely related particle size distribution for the blasts with different uniformity indexes of 1.512 and 1.5352.



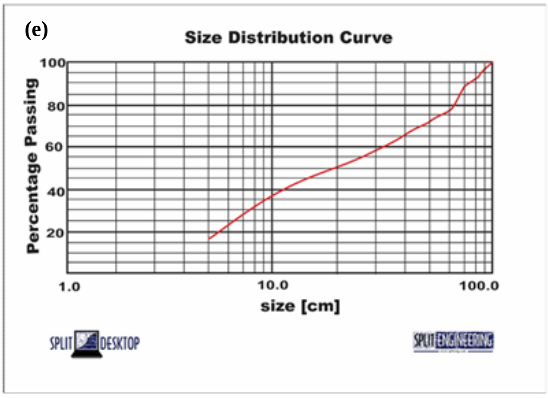


Fig. 4 Cumulative Grain Size Curves of Image Analysis of Blasts A- E

The average percentage passing of F_{50} values obtained from the Split-Desktop image analysis of the granitic rock of ENL quarry as shown in Table 3 is approximately 73.16 cm.

Table 3 Average 50% passing of fragment sizes for blasts A – E of ENL quarry

Blast	ENL (cm)
A	77.5
B	68.9
C	71.5
D	75.1
E	72.8
Average	**73.16**

3.3 Model Development for Prediction of Blast Efficiency

Table 4 shows the variables used for the blast prediction model development. A model is generated for predicting the blast efficiency using artificial neural network (ANN). The continuous quantitative variables were used to describe the analyses of the multiple data obtained and generated from the various analyses of the rock type as shown in Table 4. The obtained ANN model is as presented in Equation 1. The performance of the model was compared with the measured values as shown in Fig. 5.

Table 4 Variables for the blast prediction model development

S/N	Blast	Total Charge (Kg) [(i +ii)× n]	Average Size of Fragment 50% passing (cm)	UCS (MPa)	In-situ Block Size (m^2)
1	ENL Blast A	13,860	77.5	196.72	3.08
2	ENL Blast B	12,028	68.9	127.05	3.06
3	ENL Blast C	8,320	71.5	127.05	2.52
4	ENL Blast D	13,200	75.1	204.92	1.00
5	ENL Blast E	9,570	72.8	102.46	2.09

$$\%Eff = 7.8\tanh\left(\sum_{i=1}^{3} x_i + 30.3384\right) + 70.7 \qquad (1)$$

where,
$\%Eff$ is the blast efficiency, TC is the total charge, UCS is the uniaxial compressive strength of rock and IB is the in-situ block size of rock.
x_i in Equation 1 is as listed in Equations 2 – 4.

$$x_1 = 30.0798\tanh(0.012237TC - 0.4495UCS + 4.73568IB - 76.5322) \qquad (2)$$

$$x_2 = 30.4429\tanh(0.00438TC - 0.5088UCS + 0.82539IB + 6.140406) \qquad (3)$$

$$x_3 = 30.30669\tanh(-0.01582TC + 0.96968UCS - 13.89014IB + 69.52566) \qquad (4)$$

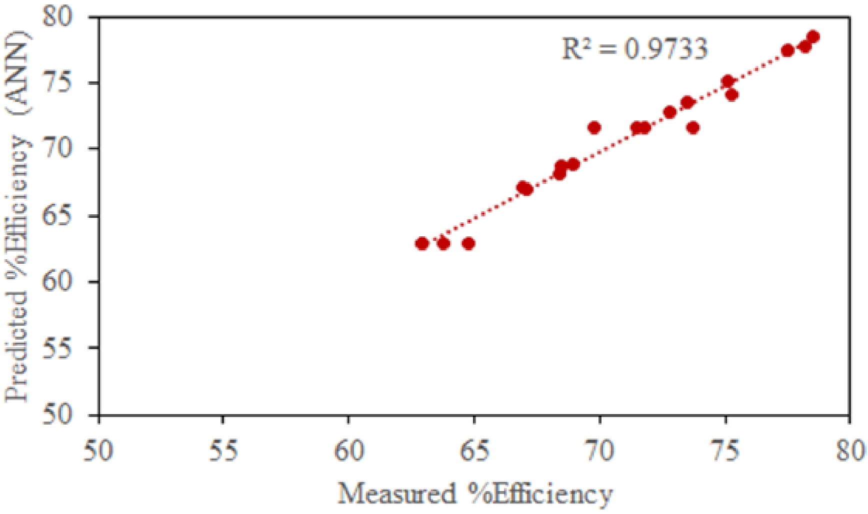


Fig. 5 Comparison of the Measured and Predicted Blasting Efficiency using ANN.

The coefficient of determination (R^2) value of 0.9733 is obtained for the prediction of the proposed model using ANN as compared with the measured efficiency.

Conclusions and Recommendation

The strength classification of the rock type in the study area is high as it averages 151.64 MPa which is an indication of the degree of coherence and level of competence of the rock. For the in-situ block size distribution of rock using AutoCAD, the dimension for the in-situ rock mass is 50 m x 40 m. The allowable and acceptable block size of 50% frequency of the cumulative graph of the in-situ block size distribution was recorded for each blast at the location.

The research also investigated the particle size distribution of blast-induced fragmentation of the ENL quarry using the digital image processing feature of Split-Desktop to evaluate the degree of fragmentation of muckpiles produced from the blasting operations.

These average values of F_{50} percentage passing of the muckpiles produced are considered suitable for the quarry operations in the study area as a result of the closeness of the values to the allowable value of 100 cm of the crusher.

The results obtained from the findings were used to develop a model for the prediction of blast efficiency. The prediction of the proposed model using ANN is compared with the measured efficiency and the value of coefficient of determination, R^2 obtained is 0.9733.

A more accurate application such as FracBlock software is recommended for further study to estimate the in-situ block size distribution to compare the results with that of AutoCAD as used in this work. It is hoped that this application will enhance more reduction of wastage in explosives usage and also increase the efficiency of blasting in quarries.

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References

Bleines, C., Bourges, M., Deraisme, J., Geffroy, F., Jeanne, N., Lemarchand, O., Perseval S., Poisson, J., Rambert, F., Renard, D., Touffait, Y. and Wagner, L. (2013): ISATIS Software. *Geovariances, Ecole des Mines de Paris, Paris*, p. 35.

Deere, D. U. and Miller, R. P. (1966): Engineering Classification and Index Properties for Intact Rock. Air Force Weapon Laboratory, New Mexico, *Tech. Rept., AFNL-TR*, pp. 65-116.

Engelder, T. (1987): Joints and Shear Fractures in Rocks. *Academic Press, New York*, p. 69.

Frank, R. C. (2014): Best Practices in Drill and Blast. *Mining Handbook, A Division of IQPC, Brisbane, QLD, Australia*, p. 5.

Hassan, N. F., Jimoh, O. A., Shehu, S. A. and Hareyan, Z. (2019): The Effect of Mineralogical Composition on Strength and Drillability of Granitic Rocks in Hulu Langat, Selangor Malaysia. *Geotechnics and Geological Engineering*, 37, pp. 5499-5505.

Hudaverdi, T., Kulatilake, P. and Kuzu, C. (2011): Prediction of Blast Fragmentation Using Multivariate Analysis Procedures. *International Journal of Numerical Analysis and Meth. Geomech.*, **35**(13), pp. 18-33.

Idowu, K. A., Olaleye, B. M. and Saliu, M. A. (2021): Analysis of Blasted Rocks Fragmentation using Digital Image Processing (Case study: Limestone quarry of Obajana Cement Company). Mining of Mineral Deposits, **15**(4), pp. 34-42.

International Society for Rock Mechanics (1999): Committee on Standardization of Laboratory and Field Tests. Suggested methods: Rock Characterization, Testing, and Monitoring. E. T. Brown, ed., *Pergamon Press, London, Great Britain*, p. 21.

Lawal, A. I. (2020): An Artificial Neural Network-Based Mathematical Model for the Prediction of Blast-Induced Ground Vibration in Granite Quarries in Ibadan, Oyo State, Nigeria. *Scientific African*, p. 8.

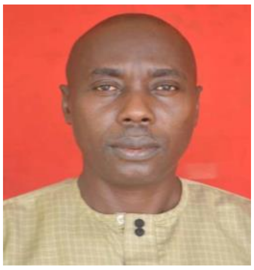
Saliu, M. A. and Idowu, K. A. (2014): Investigating the Effect of Fracture on Rock Fragmentation Efficiency; A Case Study of Kopec Granite Quarries in Southwestern Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, **4**(4), pp. 53-69.

Selenon, O., Luodes, H., Ehlers, C. (2000): Exploration for Dimensional Stone-Implications and Examples from the Precambrian of Southern Finland. *Engineering Geology*, 23, pp. 275-291.

Authors

K. A. Idowu is a Lecturer in the Department of Mining Engineering, University of Jos, Nigeria. He holds the degrees of B.Eng., M.Eng. and PhD in Mining Engineering from the Federal University of Technology, Akure, Nigeria. He is a Registered Engineer with Council for Regulation of Engineering in Nigeria (COREN) and a Member of the Nigerian Society of Engineers. He is also a Corporate Member of the Nigerian Society of Mining Engineers. His research and consultancy work covers Rock Mechanics, Drilling and Blasting; and Surface Mining.

B. M. Olaleye is a Professor of Mining Engineering and former Head of the Department of Mining Engineering at the Federal University of Technology, Akure, Nigeria. He holds the degrees of M.Eng and PhD in Mining Engineering from the Federal University of Technology, Akure, Nigeria. He is a Registered Engineer with the Council for Regulation of Engineering in Nigeria (COREN) and Council of Nigerian Mining Engineers and Geoscientists (COMEG). He is also a Fellow of the Nigerian Society of Mining Engineers. His research and consultancy work covers Rock Mechanic and Rock Engineering; Rock Characterization and Rock Slope Stability Investigation.



M. A. Saliu is a Professor of Mining Engineering and a Lecturer at the Federal University of Technology, Akure, Nigeria. He holds the degrees of B.Eng and M.Eng from the Federal University of Technology, Akure, Nigeria and PhD in Mining Engineering from the prestigious Camborne School of Mines, University of Exeter, United Kingdom. He is a Registered Engineer with the Council for Regulation of Engineering in Nigeria (COREN) and a Member of the Nigerian Society of Engineers. He is also a Corporate Member of the Nigerian Society of Mining Engineers. His research and consultancy work covers Rock Mechanics, Drilling and Blasting, Surface Mining and Blast Design.