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Correlation between Blast Efficiency and Uniaxial Compressive Strength

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ABSTRACT

The study investigates the correlation between blast efficiency of explosives and uniaxial compressive strength of some selected rock types. To achieve the set objectives, granite samples were collected from Julius Dinga Ltd Iyuku, calcitic marble samples from Geoworks Ltd Igarra and dolomitic marble samples from Freedom quarry Ikpeshi all in Akoko-Edo in Edo state of Nigeria. These samples were collected for uniaxial compressive strength test. The result of uniaxial compressive strength reveals that granite has 133.55MPa, calcite has 78.91MPa and dolomite has 71.17MPa. From the correlation of measured variables, it was observed that there is a good correlation between blast efficiency and uniaxial compressive strength. It was observed that blasting efficiency increases with decrease in uniaxial compressive strength.

Keywords: *Blast efficiency, explosives, uniaxial compressive strength, correlation, calcite, dolomite, granite.*

1. INTRODUCTION

Fragmentation is a major concern of any blasting operation. Information on the degree and size distribution of fragments within a blasted rock mass is essential for efficient rock loading and crushing operations. The factors that are important to the fragmentation process are classified into three namely; explosive parameters, rock parameters and charge-loading parameters or blast geometry (Chiappetta, 1991; Thornton, 2002). The explosive parameters include density, detonating velocity, detonation impedance, detonation pressure, gas volume, and available energy. The charge - loading parameters are diameter, length, stemming, decoupling, type of initiation, and point of initiation which play important role in the fragmentation process. Rock parameters that have considerable influence on fragmentation process include density, propagation velocity, characteristics impedance, energy absorption, compressive and tensile strength, variability and structure of the rock (Brady and Brown, 1993). One of the important characteristics of rock that is crucial to the fragmentation process is a high ratio of compressive strength to tensile strength.

The ratio has been defined as blastability coefficient because it measures the susceptibility of a rock to tensile failure by stress pulse reflection (Olofsson, 1999). According to Akande and Lawal (2013) an increase in the rock strength increases volume of rock blasted decreases, resulting to increase in the cost of blasting because more explosive energy will be required to break the rock. An increase in the strength of rock means increase in the amount of explosive required for the fragmentation of such rock. It is therefore imperative to determine the strength of rocks before embarking on blasting operations this will enable us to know the suitable explosive needed to achieve required fragmentation. This research work therefore correlates between the blasting efficiency and uniaxial compressive strength of different types of rock with a few to finding a lasting solution to the wrong selection of explosive.

1.1 Geology of the Study Area

The Igarra area lies within Latitudes $7^0 00^{\prime}$N – $7^0 30^{\prime}$N and Longitudes $6^0 00^{\prime}$ - $6^0 30^{\prime}$ at the northern fringe of Edo State, Nigeria (Figure 1). It is underlain in the north by Precambrian Complex and in the south by Cretaceous and Tertiary sediments. The northern part is rich in industrial and metallic minerals which are currently at various stages of exploitation. The area has been sufficiently be studied by (Odeyemi, 1990: Rahaman, 1988) due to the relatively unweathered and well-exposed outcrops.

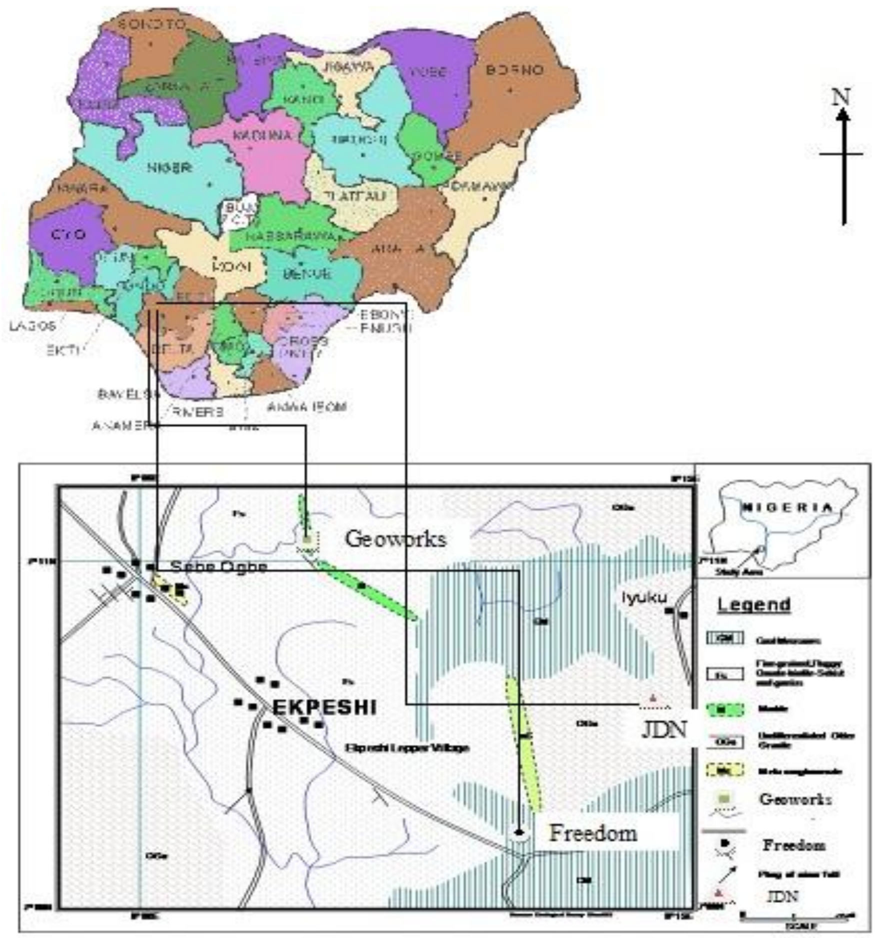

Figure 1.1: Geological Map of the Study Areas (Inserted Map of Nigeria)

2. MATERIALS AND METHODS

2.1 Uniaxial Compressive Strength Test

The uniaxial compressive strength test is the most widely used measure of the strength, deformation and fracture characteristics of the rock because of its accuracy. The uniaxial compressive strength test (UCS), is relatively costly, time consuming and uses standard equipment, but the results are more reliable than other test methods and it is required for much detailed design (Brook, 1993).

The procedure for the test is as stated in ISRM (1979). Uniaxial compressive strength test is typically characterized by loading a cylindrical sample with a diameter of approximately 50mm and length to diameter ratio of 5:2 axially until the specimen fails.

The strength of the rock is given by ISRM (1978) as follows:

$$\sigma_c = {P_{max}}/{A} \qquad (1)$$

where σ_c is the uniaxial compressive strength (UCS) of the rock (MPa), P_{max} is the peak load (kN) and A is the initial cross sectional area of specimen (m^2).

Where the core length constrains results with L/D values less than 2, it is recommended that the test results be recorded as both uncorrected measurements and values corrected to a normal value using following formula (Brook, 1993).

$$\sigma_{c2} = {8\sigma_c}/{(7 + {2D}/{L})} \qquad (2)$$

Where σ_c is the uncorrected measured uniaxial compressive strength (MPa), D is the specimen diameter (mm), L is the specimen length (mm) and σ_{c2} is the corrected uniaxial compressive strength (MPa) of the specimen under test.

Young's modulus is calculated as the ratio between the axial stress and axial strain change as below in the near linear region of the steepest curve (after bedding in and before yield).

$$E = {Stress}/{Strain} \qquad (3)$$

Where E is the Young's modulus (GPa)

The relationship between uniaxial compressive strength and Young's modulus was investigated by Begonha and Sequeire Braga (2002) and it was observed that the modulus of elasticity increases with the uniaxial compressive strength. Granites with low strength were observed to be of low modulus of elasticity.

2.2 *In-situ* Block Size Distribution

The block size is an extremely important parameter in rock mass behaviour (Barton, 1988; ISRM, 1978). The following are methods used in determining the in- situ block size estimation.

2.2.1 Joint Spacing (S) Method

An average joint spacing is used where more than one joint set occurs, the following expression are used:

$$V_b = (S_a)^3 \quad (4)$$

Here, V_b = block volume in m³.

Some rock engineers apply the following expression for the average spacing of the joint sets:

$$S_a = (S_1 + S_2 + S_3 + \cdots + S_n)/n \quad (5)$$

where S_1, S_2, S_3, etc. are average spacing's for each of the joint sets. But Equation (5) does not correctly characterize the joint spacing.

2.3.2 Block Volume (V_b)

For small blocks or fragments having volumes in cubic decimetre size or less, this measurement is often the quickest of the methods, as it is easy to estimate the block size compared to registration of the many joints involved.
Where three joint sets occur, the block volume is

$$V_b = S_1 \times S_2 \times S_3 / \sin\gamma_1 \times \sin\gamma_2 \times \sin\gamma_3 \quad (6)$$

where S_1, S_2, S_3 are the spacing's in the three joint sets, and γ_1, γ_2 and γ_3 are the angles between the joint sets.

Table 1: Block Volume for Various Angles between the Joint Sets

all angles = 90°	two angles = 90° one angle = 60°	one angle = 90° two angles = 60°	all angles = 60°	all angles = 45°
$V_b = V_{b_o} = S_1 \times S_2 \times S_3$	$V_b = 1.16\ V_{b_o}$	$V_b = 1.3\ V_{b_o}$	$V_b = 1.5\ V_{b_o}$	$V_b = 2.8\ V_{b_o}$

2.3.3 Volumetric Joint Count (J_v)

The volumetric joint (Jv) count was introduced by Palmstrom in 1982. Earlier, a similar expression for joint density measurements was applied as the number of joints in a blast round. Being a 3-dimensional measurement for the density of joints, Jv applies best where well-defined joint sets occur.
J_v is defined as the number of joints intersecting a volume of one m³. Where the jointing occurs mainly as joint sets

$$J_v = 1/S_1 + 1/S_2 + 1/S_3 + \cdots 1/S_n \quad (7)$$

Where S_1, S_2 and S_3 are the average spacing's for the joint sets.

2.3 Determination of Explosive Performance

The explosive performance was calculated using Equation 8.

$$\text{Performance of Explosives} = 100 - \left(\frac{\text{Muckpile block size}}{\text{In situ block size}}\right) \times \frac{100}{1}\% \quad (8)$$

2.3.1 Block Size Distribution of Muck Pile

The methodology of blasting efficiency in this study is to compare physical and mechanical properties of the rock mass and block fragmentation under the same blasting conditions in granite, dolomitic marble, and calcitic marble at Julius Dinga Ltd Iyuku, Freedom Group of Company and Geoworks Ltd Igarra all in Edo State of Nigeria. Intact rock properties, block size of rock mass before blasting and muck pile after blasting were found to measure blasting efficiency. Firstly, intact rock properties, which are unit volume weight, water absorption, uniaxial compressive strength, tensile (Brazilian) strength, cohesion and internal friction angle, were tested for each mining bench. Secondly, pile photos were taken in order to determine Block Fragmentation (BF) which is to separate the rock mass block size by blasting and that of the corresponding muck pile. Thirdly, statistical analysis between rock mass properties and block fragmentation were developed and these analysis test results have shown that a good relation between block fragmentation and Brazilian tensile strength and internal friction angle were found. As a result, block fragmentation in the same blasting conditions and other rock properties can be estimated from the best empirical correlations with the rock properties.

3. RESULTS

3.1 Uniaxial Compressive Strength

The result of uniaxial compressive strength obtained from laboratory test is shown in Table 2.

Table 2: Average Compressive Strength of Tested Rock Samples

	Maximum load on specimen (kN)	Average specimen diameter (m)	Uniaxial compressive strength, UCS (MPa)
GRANITE A1	170.79	0.04	135.55
A2	172.79	0.04	137.14
A3	168.79	0.04	133.96
AVERAGE A			**135.55**
CALCITIC MARBLE B1	99.41	0.04	78.90
B2	97.45	0.04	77.34
B3	101.41	0.04	80.48
AVERAGE B			**78.91**
DOLOMITE MARBLE C1	90.44	0.04	71.78
C2	92.45	0.04	73.37
C3	87.45	0.04	69.40
AVERAGE C			**71.57**

3.2 Muckpile Block Size, *In-situ* Block Size and Efficiencies of Explosives

Tables 3, 4 and 5 show the values of muckpile block size, in-situ block size and efficiencies of different explosives on selected rocks and Plates 1 to 12 shows the pictorial view of the products obtained on the field.

Table 3: Values of Muckpile Block Size, In-situ Block Size and Efficiencies of different Explosives on Selected Rock Types

Rock Sample	Type of Explosive	Muckpile Block Size (m^3)	In situ Block Size (m^3)	Efficiency (%)
Granite	Special Gel	5.00	13.86	64
	Emulsion	6.93	13.86	50
	Slurry	8.00	13.86	42
	ANFO	10.01	13.86	28
Calcitic Marble	Special Gel	1.00	10.47	90
	Emulsion	4.01	10.47	62
	Slurry	5.20	10.47	55
	ANFO	7.01	10.47	33
Dolomitic Marble	Special Gel	0.21	4.12	95
	Emulsion	1.01	4.12	76
	Slurry	1.50	4.12	63
	ANFO	2.50	4.12	39

Table 4: Efficiency of each Explosive Used

Rock types		Explosive type			
		Special Gel	Emulsion	Slurry	ANFO
Granite	Efficiencies	64%	50%	42%	28%
Calcite		90%	62%	55%	33%
Dolomite		95%	75%	63%	39%

Table 5: Performance of each Explosive Used

Rock types		Explosive type			
	Performances	Special Gel	Emulsion	Slurry	ANFO
Granite		Excellent	Good	Fair	Poor
Calcitic marble		Extreem	Excellent	Good	Fair
Dolomitic marble		Extreem	Extreem	Excellent	*Fair*

3.3 Correlation between Uniaxial Compressive Strength and Blasting Efficiency

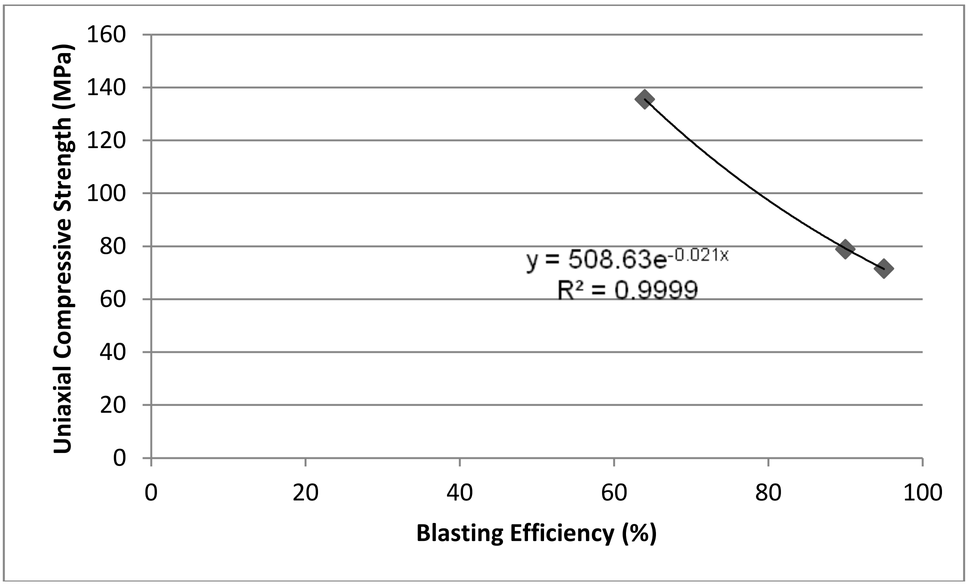

Figure 2: Correlation between Efficiency and Uniaxial Compressive Strength when Using Special Gel

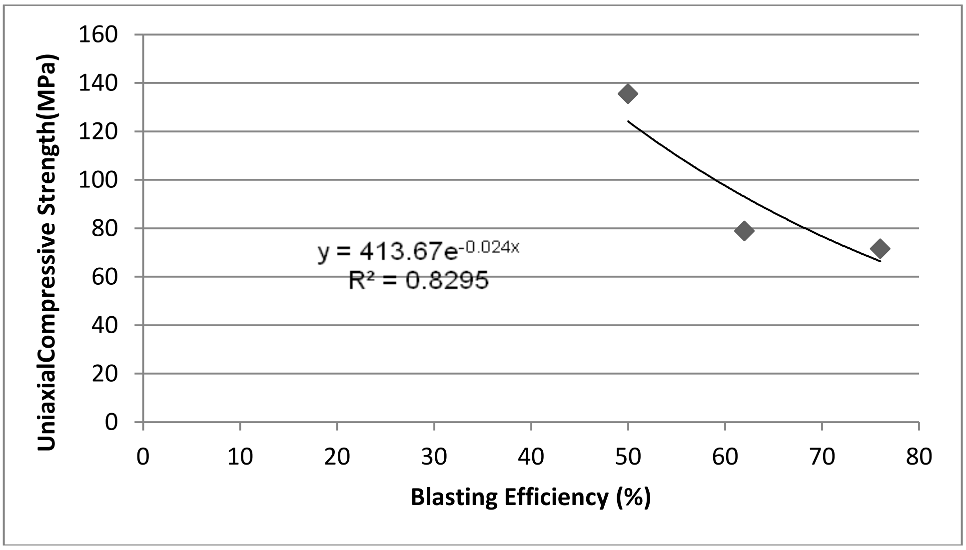

Figure 3: Correlation between Efficiency and Uniaxial Compressive Strength when using Emulsion

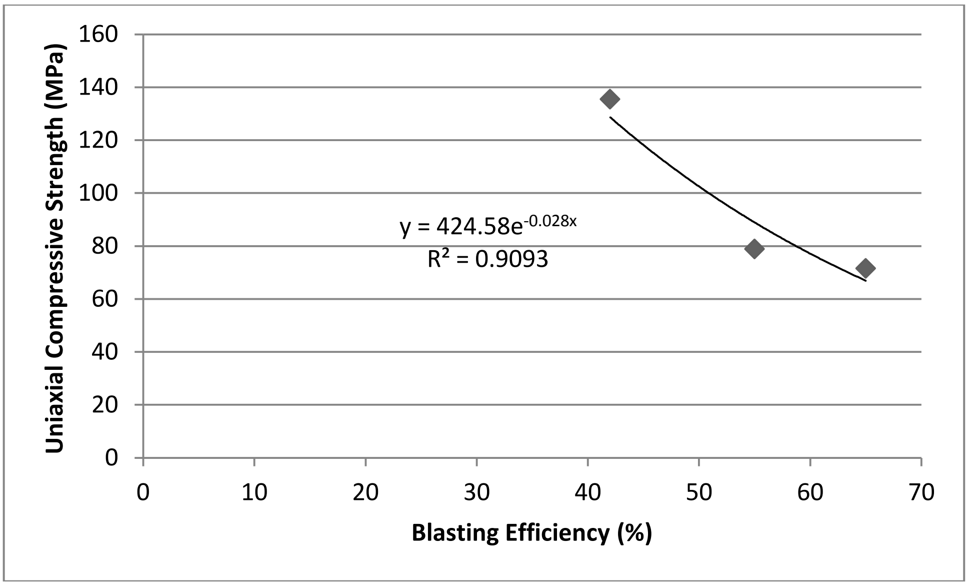

Figure 4: Correlation between Efficiency and Uniaxial Compressive Strength when Using Slurry

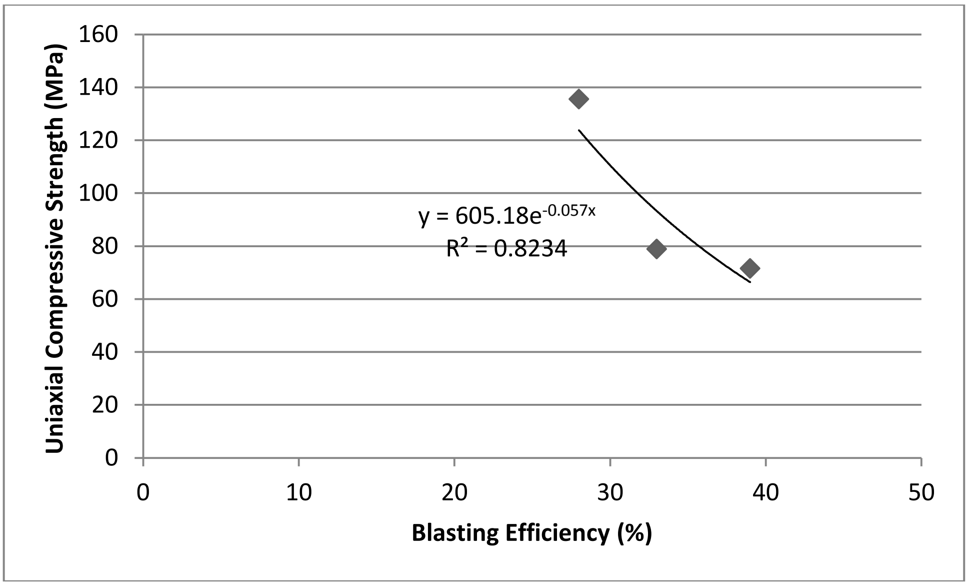

Figure 5: Correlation between Efficiency and Uniaxial Compressive Strength when Using ANFO

4. DISCUSSION

4.1 Uniaxial Compressive Strength

Uniaxial compressive strength tests were carried out on the selected rock types. For Iyuku granite a 426 KN load cells was used while for Geoworks' calcite and Freedom dolomite 248 KN and 224 KN load cell were used respectively, because of the differences in the rock types. The UCS value of the sample from Iyuku granite is the highest because the rock sample is igneous rock.

4.2 Correlation between Blast Efficiency and Uniaxial Compressive Strenght

The correlation between the uniaxial compressive strength and blast efficiency for different explosives under consideration were critically investigated from the research work Figures 1, 2, 3, and 4.

Figure 2 shows the correlation between uniaxial compressive strength and blast efficiency, the equation of the graph is as written in Equation 9.

$$y = 508.63e^{-0.021x} \quad (9)$$

where y is the uniaxial compressive strength in MPa and x is the blast efficiency in %. The coefficient of correlation (R^2) is 0.9999 indicating very strong correlation between them.

Figure 3 shows the correlation between uniaxial compressive strength and blast efficiency when using emulsion explosive, the equation of the graph is as written in Equation 10.

$$y = 413.67e^{-0.024x} \quad (10)$$

where y is the uniaxial compressive strength in MPa and x is the blast efficiency in %. The coefficient of correlation (R^2) is 0.8295 indicating very strong correlation between them.
Figure 4 shows the correlation between uniaxial compressive strength and blast efficiency when using slurry explosive, the equation of the graph is as written in Equation 11.

$$y = 424.58e^{-0.028x} \quad (11)$$

where y is the uniaxial compressive strength in MPa and x is the blast efficiency in %. The coefficient of correlation (R^2) is 0.9093 indicating very strong correlation between them.
Figure 5 shows the correlation between uniaxial compressive strength and blast efficiency when using slurry explosive, the equation of the graph is as written in Equation 12.

$$y = 605.18e^{-0.057x} \quad (12)$$

where y is the uniaxial compressive strength in MPa and x is the blast efficiency in %. The coefficient of correlation (R^2) is 0.824 indicating very strong correlation between them.

It can be observed that there is a very strong correlation between blast efficiency and uniaxial compressive strength of the rock under consideration. It can be observed that, for all the explosives under consideration, the higher the uniaxial compressive strength, the lower the blast efficiency. This indicated that more charge is required regardless of the type of explosives, when the rock is having high uniaxial compressive strength compare to the one with low uniaxial compressive strength.

5. CONCLUSION

The results of the uniaxial compressive strength show that average uniaxial compressive value of granite is 135.55 MPa, calcite is 78.91 MPa and dolomite has 71.57 MPa.

From the correlation of measured variables, it was observed that there is a good correlation between blast efficiency and uniaxial compressive strength. It was observed that blasting efficiency increases with decrease in uniaxial compressive strength.

The equations (9 to 12) generated in this study can be used to determine either uniaxial compressive strength of rocks tested in this study or blasting efficiency of each types of explosives used if either of the two variables is known.

REFERENCES

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" Journal of Scientific Research (Geomaterials), USA, Vol. 3, pp 28-29.

Brook, N. (1993): The Measurement and Estimation of Basic Rock Strength. Rock Testing and Site Charaterization – Compressive Rock Engineering, Ed: J. A. Hudson 3, pp. 41-66. Ekvivalent Core Diameter Method of Size and Shape Correction in Point Load Testing. Int. J. Rock Mech. Sci. & Geomech. Abstr., Vol. 22, No. 2, pp. 61 - 70.

Begonha, A. and Sequeira Braga, M. A. (2002): Weathering of the Oporto Granite; Geotechnical and Physical Properties. Catena 49, 57–76.

Chiappetta, R.F. (1991): Generating Site Specific Blast Designs with State-of-the-art Blast Monitoring Instrumentation and PC Based Analytical Techniques, Proc. 17th Conf. on Explosives and Blasting Technology, Las Vegas, pp. 79-101.

ISRM, (1979): Suggested Methods for Determining the Uniaxial Compressive Strength and deformability of Rock Materials. International Society for Rock Mechanics, Commission on Standardization of Laboratory and Field Tests. Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 16, 135-140.

ISRM, (1978): Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses. Int. J. Rock Mech. Min. Sci. Geomech. Abstr., **15**, pp. 319-368. 225

Odeyemi, I. B. (1990): The Petrology of A Pan-African Pluton in Igara Area, South Westeren Nigeria, Nigeria Journal of Sciences, Volume 24, No. 1 and 2, pp. 181-193.

Olofsson, S.O. (1990): Applied Explosives Technology for Construction and Mining. Applex,.

Palmstrom, A. (1982): The Volumetric Joint Count-A Useful and Simple Measure of Degree of Rock Mass Jointing. In IAEG Congress, New Delhi. Vol., pp 221-228.

Rahaman, M. A. (1988): Recent Advances in the Study of the Basement Complex of Nigeria, pp. 11-41.

Thornton, D., Kanchibolta, S. S., Brunton, I. (2002): Modelling the Impact and Blast Design Variation on Blast Fragmentation, The International Journal for Blasting and Fragmentation. 6(2) Swets and Zeitlinger, The Netherlands. pp. 171-172.