Journal of Earth Sciences and Geotechnical Engineering, vol. 4, no. 4, 2014, 53-69
ISSN: 1792-9040 (print), 1792-9660 (online)
Scienpress Ltd, 2014

Investigating the Effect of Fracture on Rock Fragmentation Efficiency: A case study of Kopec Granite Quarries, South Western, Nigeria

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Abstract

Investigating the effects of fracture on rock fragmentation efficiency in selected quarries in South Western, Nigeria is imperative for economical operation. In data collection for fracture characterization, both scanline and window mapping with the aid of compass clinometers were used. AutoCAD model was utilized to generate the in-situ block size model. The blast efficiency was determined using standard methods. From the fracture characterization carried out on the selected sites, it was observed that two main joints are predominant in Kopec Ikere, Kopec Ibadan as well as Kopec Ife granites. Two main joints with random are predominant in Kopec Ikole. The results of empirical estimation of average in-situ bock size distribution using joint spacing, block volume and volumetric joint count methods, all agreed that Kopec Ikere is having the biggest average in-situ block size with Kopec Ife having the smallest average in-situ block size. The results of numerical modelling also agreed with the results of empirical estimation with Kopec Ikere having biggest average block size and Kopec Ife being the smallest. The results of rock mass classification shows that all the rocks under consideration falls between very good to good rock. The results of the Schmidt hammer test shows that the rock under consideration have uniaxial compressive strength of 130MPa. The results of blast efficiency obtained for the selected sites show that Kopec Ikere with lowest fracture index is having the lowest blast efficiency while Kopec Ife with highest fracture Index is having highest blast efficiency. From the correlation of measured variables, it was observed that there is a good correlation between blast efficiency and average fracture index. It was observed that blast efficiency increases with increase in fracture index. Good correlation was observed between blast efficiency and RMR. It was observed that blast efficiency decreases with increase in RMR value. Similarly, blast efficiency decreases with increase in GSI value.

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Keywords: granite, blast design, fracture characterization, in-situ block size distribution, blast efficiency, uniaxial compressive strength

1 Introduction

Rocks are aggregates of crystals and amorphous particles joined by varying amounts of cementing materials. Rock is made up of minerals of a more or less invariable composition bounded together by forces of molecular interaction (cohesion) that arise either at the sites of direct contact of mineral with one another or at the sites of their contact with mineral particles of extraneous cementing substances.

Rock is an important geotechnical material which has found usage in virtually all aspects of human's technological development. Rocks form the essential part of the earth crust. Rock as one of the most commonly used construction material is very complex and difficult to describe and define[1]. A good understanding of rock behaviour and how to control it especially when subjected to loading will minimize its susceptibility to structural failure. Rock is rarely continuous in nature. It contains many natural breaks, such as, faults, joints, bedding planes, schistosity planes etc, which may be either filled or open. Due to the enormous variety of occurrences, discontinuities show a wide range of physical behavior [2]. Generally, only a few joint sets in a rock mass are dominant. They mainly control 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 on the size distribution of the blocks [2]. 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 [3].

Several methods were proposed to evaluate the jointing degree of rock masses. Pettifer and Fookes [4], proposed the fracture spacing index expressed by fractures per meter or mean spacing, estimated after spacing measures along two perpendicular scan-line surveys. Interest in the strength and deformation characteristics of rock materials has increased in these last decades because they are directly applicable to the design of large underground structures, and to the studies of rock mining, tunneling, drilling, cutting, crushing and blasting, and sometimes indirectly applicable to consideration of the behaviour of large jointed rock masses[4]. The study of rock fractures is an important factor that should be considered in any urban planning and / or development. Fractures can be a cause of landslides, collapses and ground subsidence, in addition to many other geo-hazards [6]. The presence of discontinuities in rocks have played a significant role in rock behaviour under loading condition. Discontinuities in rocks affect greatly the way rock materials are detached from the rock mass. One of the most common types of discontinuities in rock masses is fracture.

2 Materials and Methods

The following materials are used; Measuring tape, Masonry nails, Marker, Compass Clinometers, Geological Hammer, Schmidt Hammer, Digital Camera.

The chosen study area was visited with a view to collecting relevant data. The process of acquiring comprehensive information about the fracture network of an outcrop involves the mapping of the outcrop using standard surveying methods. The method in use here are scanline mapping and window mapping. The data collated is then used to generate a model of the fracture network of the outcrop using AutoCAD@ computer model.

Scanline Mapping

A scanline is a line set on the surface of the rock mass, and the survey consists of recording data for all discontinuities that intercept the scanline along its length [7]. It is carried out by placing a measuring tape along the face of the outcrop to be measured, usually at the waist height, and the measurement of every noticeable feature that cuts the tape, whilst recording its position. It must be noted that the scanline mapping only take into account the fractures that intercepts the line while ignoring those that does not intercept the line. Line lengths are normally between 50 to 100 meters [8]. If the ends of the line are surveyed, then the location of all the discontinuities can be determined. The tape is thus surveyed and the features geo-referenced.

As noted by Saliu [9], this system maps only the fractures that intercept the line, many fractures that do not fall on the line will be left out or unmapped. With the required detailed fracture density for dimension stone evaluation, scanline mapping can be inadequate for collecting sufficient data for the study area.

The procedure for obtaining scanline map for an outcrop begins with the setting up of tools and materials for the process. Tools and materials in use for this procedure are;

Measuring Tape

A measuring tape is a calibrated tape used as a survey instrument to obtain the length or distance of something from a reference position.

Masonry Nail

These are small rod-like metal fastener, pointed and often headed or grooved which are hammered to join or anchor materials, primarily wood and stone or other building materials.

Marker

This is an object used to indicate the position of something for easy identification.

Hammer

A hammer is a hand tool or instrument consisting of a shaft with a metal head at right angles to it, and it is used in prying nails or other similar materials. It comes in different sizes, shapes and types depending on the task for which it is used.

Compass Clinometer

A clinometer is a handheld surveying instrument used for measuring angles of inclination, slope or elevation of an object. In this case, we use it to determine the dip, dip direction and strike of a rock fracture. It is calibrated between 0^0 and 360^0 with its magnetic pointer pointing to the earth's magnetic pole. The measuring tape is fixed to the rock face by short length of wire attached to mansory nails hammered into the rock. A space of about 3m intervals is left between the nails along the tape and it is kept as taut as possible. For the purpose of effective exercise, the scanline is assigned a number after it has been established. The location, scanline number, date, rock type, face orientation, sacnline orientation and other necessary information are recorded in a sheet of paper. Some of the features for each discontinuity recorded are;

(i) distance along the scanline to the point at which the fracture intersects the scanline
(ii) number of endpoint of the fracture observed on the face
(iii) dip and dip direction of the fracture
(iv) planarity of the fracture
(v) trace length of the fracture

Digital Camera

Digital photography is a method of making images without the use of a digital camera. The camera functions as a 35-millimeter camera but records the picture information as pixels or digital dots of colour. It is designed to make images without the use of conventional photographic film. An inbuilt scanner receives visual information and converts it into a code of ones and zeros that can be read by a computer. The digital camera was used to take pictures of the scanned area of the granite outcrop. Since taking reading of the dimension of the outcrop, the measuring tape was placed at the base of the formation and set at 2m and camera shots were taken to cover the target area. The picture generated was used calculate the dimension of the area under review.

Window Mapping

Window mapping comprises mapping all discontinuities within a representative segment or 'window' of fixed size, spaced at regular intervals along the exposure. Window mapping is an alternative approach to scanline. This is done by measuring all discontinuities within a defined area on the rock face. The length is usually set at 10m. The intervening areas are examined for similarity of structures. The procedure for acquiring data through window mapping is pretty much the same as that of scanline mapping. The results are then used to generate the block size distribution of the outcrop using AutoCAD$^{@}$ model.

Table 1: Classification of block volume (After Palmstrom [10])

Very small block	V_b = 10-200 cm^3
Small block	V_b = 0.2-10 dm^3
Moderate block	V_b = 10-200 dm^3
Large block	V_b = 0.2-10 m^3
Very large block	V_b > 10 m^3

The Auto CAD$^{@}$ Model

The AutoCAD$^{@}$ is an automatic computer aided design software used for generating graphic representation of a model. These may be structural or non-structural model. AutoCAD$^{@}$ has become a standard program for producing technical drawings of all types [11].

AutoCAD$^{@}$ has the capacity for creating a 3D model for engineering drawings which can thus be incorporated into geomechanical fracture model. Required geotechnical data for this model include:

(a) the relative position of the outcrop on the surface of the earth
(b) the spacing of the joints
(c) the persistence of the fracture
(d) the orientation of the joint sets

Stages involved in creating this model as suggested by Saliu [9] is as described below:

(a) Pole plot of the fracture data to classify the fractures into sets
(b) Determination of Fisher k factor in order to know how parallel the joint in a given set are. The higher the k factor, the more parallel the fractures in a given set.
(c) Generate a rectangle with the same surface area (to scale) as the outcrop under consideration using AutoCAD$^{@}$ and plot the strike of each of the fracture as they occurred along the scanline using the relationship between the dip direction and strike i.e. strike (given as dip direction - 90^0)

(d) Individual blocks generated by the intercept of the joints are banded together and extruded to the required height based on the distance between sub-vertical features.
(e) From the model created, the surface area and the volume of each block is estimated to generate in situ block sizes distribution of the blocks within the required outcrop.

Table 2: Meaning of rock mass classes determined from total ratings, Bieniawski [12]

Rock Mass Rating	Rock class
100 – 81	Very good
80 – 61	Good
60 – 41	Fair
40 – 21	Poor
<20	Very poor

3 Results and Discussion

3.1 Fracture Characterization

This section describes the results obtained from fracture characterization of the selected Kopec granites outcrops which includes empirical block size estimation, AutoCAD block size distribution and rock mass classification.

3.1.1 Empirical Block Size Estimation

The general joint pattern of the selected Kopec granites outcrops are as shown in Figure (1 and 2). These indicated that two main joint sets are dominant throughout the area except in Kopec Ibadan where there is occurrence of random joint as shown in Table 3. This agreed with the work of Kogbe [13] who observed that there are two main predominant joint sets in South Western Nigerian granites.

Table 3: Summary of Joint Orientation in the selected Kopec granites Outcrop

SITE		JOINT SETS		
		J1	J2	RANDOM
IKERE		84/318	84/025	-
IKOLE		86/032	86/302	-
IBADAN		87/299	87/037	02/296
IFE	86/321	82/041	-	

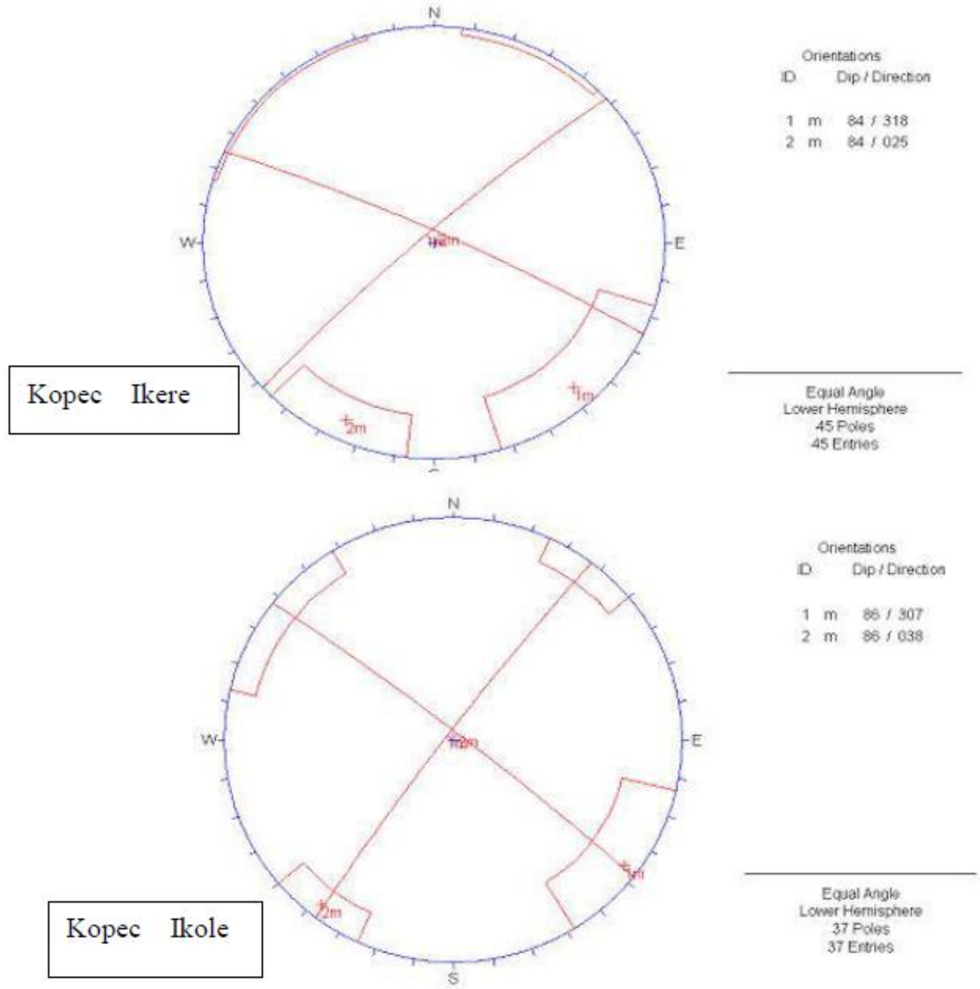

Figure 1: Plane of fractures in Kopec Ikere and Kopec Ikole

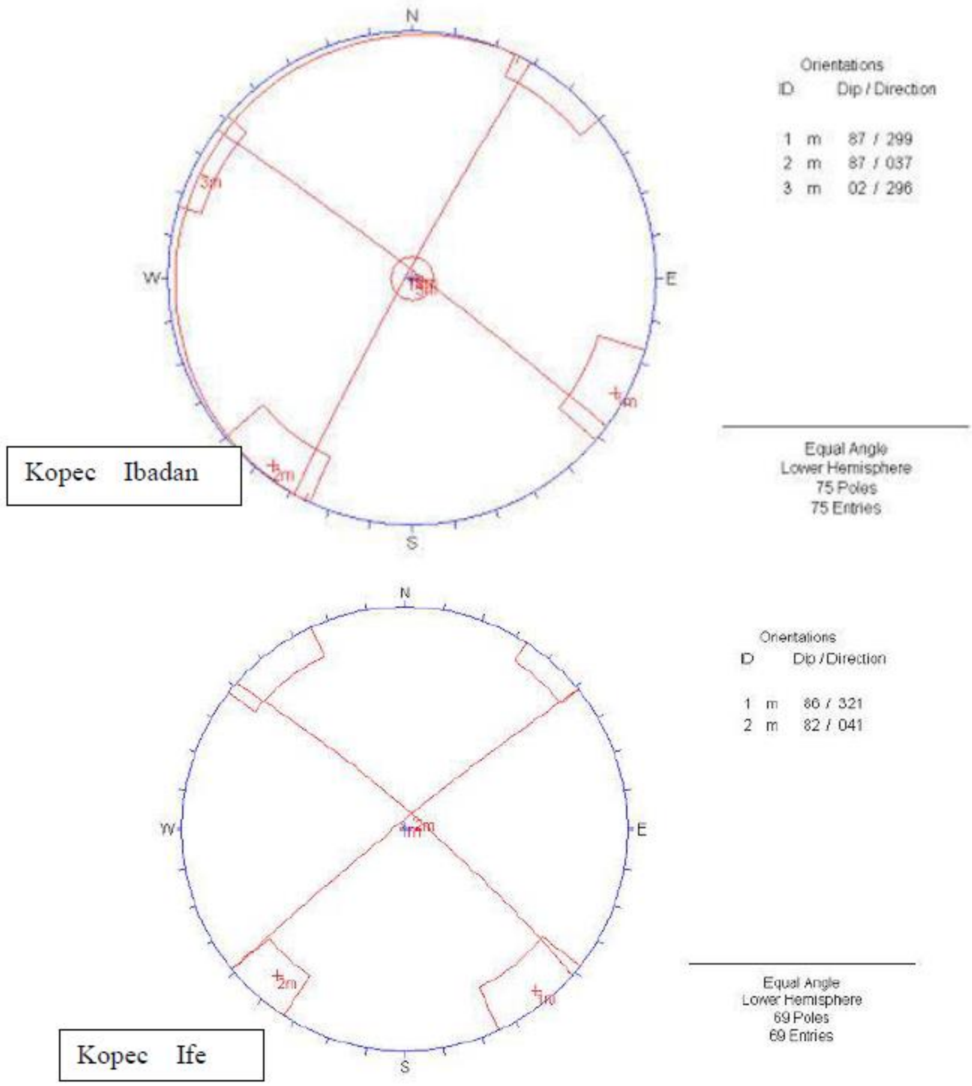

Figure 2: Plane of fractures in Kopec Ibadan and Kopec Ife

The results of empirical block size estimation of Kopec Ikere, Kopec Ikole, Kopec Ibadan and Kopec Ife granite outcrops are as shown in Table 4. From the results as shown in Table 4, it can be observed that the average block size in Kopec Ikere and Kopec Ikole are bigger than that of Kopec Ibadan and Kopec Ife. This can be attributed to the fact that the average spacing of Kopec Ikere and Kopec Ikole are both wider than those of Kopec Ibadan and Kopec Ife.

This observation agreed with the work of Sousa [14] who noticed that bigger blocks are always associated with outcrop with wider spacing of discontinuities.

Table 4: Summary of Empirical Block Sizes Estimation of Selected Kopec Granite Outcrops.

Granite location	Aver. spacing (J_1) (m)	Aver. spacing (J_2) (m)	Aver. spacing of all sets, S_a (m)	Joint count (J_v) (1/m)	Joint spacing method (m^3)	Block volume method (m^3)	Volumetric joint count method (m^3)	Aver. In-situ block sizes (m^3)	Aver. In-situ block sizes (m^2)
Kopec Ikere	3.26	2.0	2.25	1.47	11.39	9.78	9.44	10.20	6.8
Kopec Ikole	2.70	2.38	2.19	1.46	10.50	9.64	9.64	9.92	6.61
Kopec Ibadan	2.31	1.90	1.90	1.63	6.86	6.58	6.92	6.79	4.52
Kopec Ife	1.36	2.0	1.62	1.90	4.25	4.08	4.37	4.23	2.82

3.1.2 Numerical Modelling

The overall results of the numerical modelling of the in – situ block size distribution of selected Kopec granites outcrops, using AutoCAD.

From the AutoCAD model of the selected Kopec granite outcrops as shown in Figures 3 and 4, it can be observed that in Kopec Ikere, Kopec Ibadan and Kopec Ife, two regular sub – vertical fractures existed throughout the outcrop while in Kopec Ikole, occurrence of random joint was observed in addition to the two sub – vertical joints Figures 3 and 4.

From the AutoCAD model, it can be observed that Kopec Ikere and Kopec Ikole still experience bigger block sizes than Kopec Ibadan and kopec Ife despite the occurrence of random joint in Kopec Ikole. This can be associated with the wider spacing of Kopec Ikere and Kopec Ikole respectively. This agreed with the earlier observation from the empirical block size estimation.

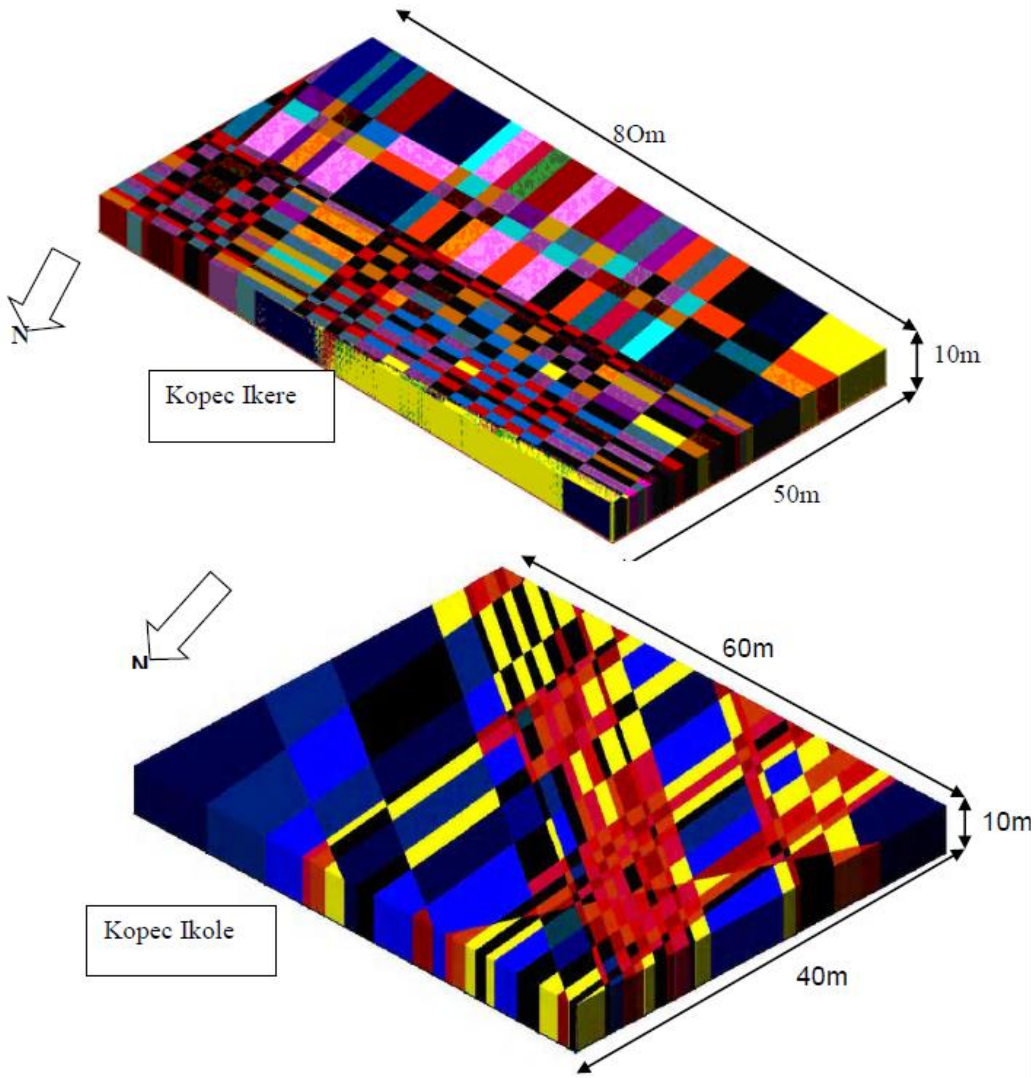

Figure 3: AutoCAD of block size distribution of Kopec Ikere and Kopec Ikole outcrops

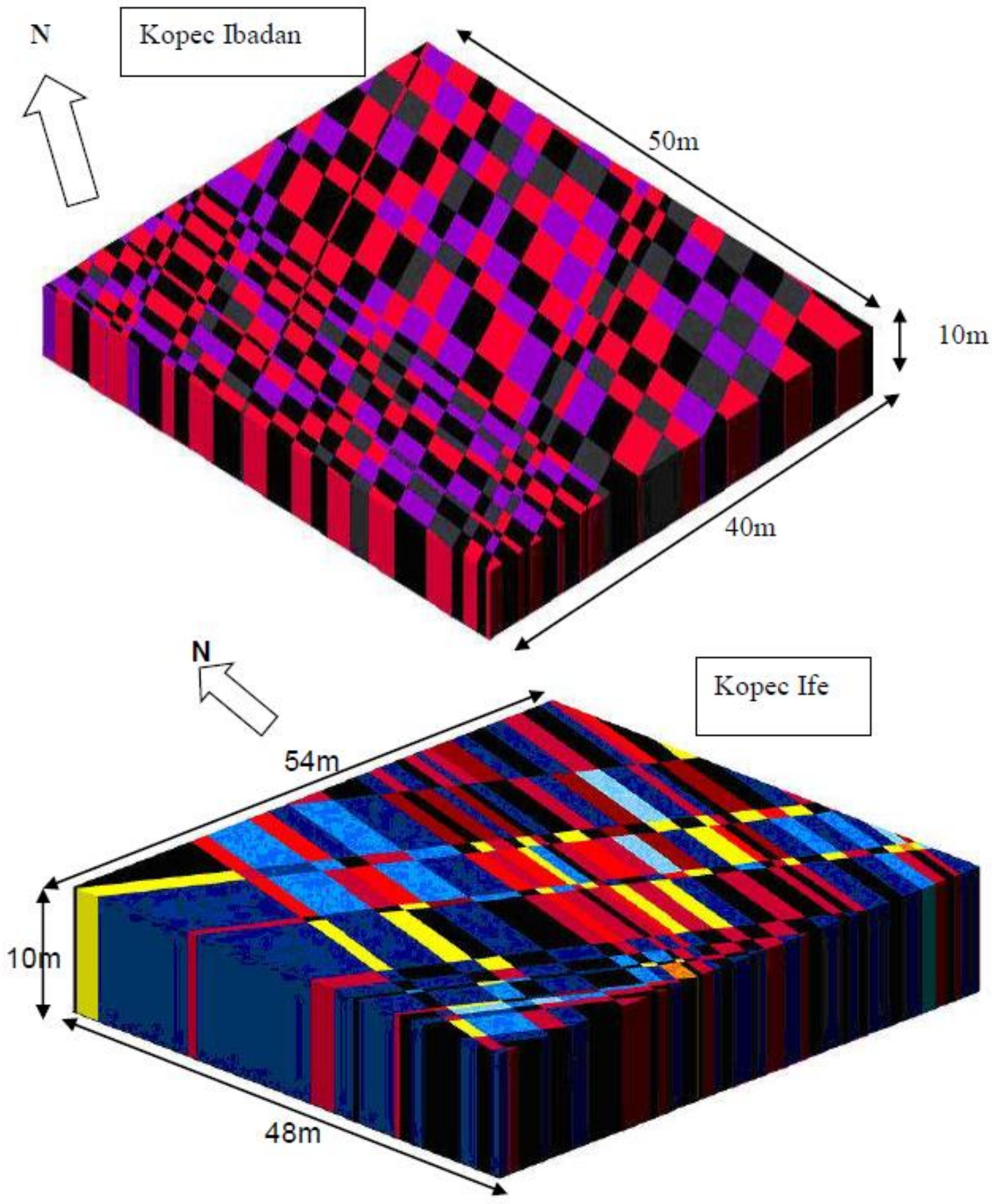

Figure 4: AutoCAD of block size distribution of Kopec Ibadan and Kopec Ife outcrop

3.2 Rock Mass Classification

Rock mass classification of selected Kopec granite outcrops were conducted using Q' RMR and GSI systems respectively. The summary results of these classification are shown in Table 5.

From these results, Kopec Ikere, Kopec Ikole, Kopec Ibadan and Kopec Ife are all classified as good rocks. Comparing these results with that of block size distribution as undertaken earlier, it can be seen that the results agreed with the previous work which indicated that the wider the spacing the better the rock quality.

Table 5: Summary Tables of Engineering Rock Mass Classification of Selected Kopec Granite Outcrops

Location	Q	RMR	GSI
Ikere Kopec	45	83	78
Ikole Kopec	30	79	75
Ibadan Kopec	45	81	75
Ife Kopec	45	80	75

3.3 Mechanical Property

In this section of the project, only one mechanical property of the selected Kopec granite outcrops is considered in order to be sure of their similarity. In this case Schmidt hammer test is conducted on all the selected rock samples to evaluate the UCS of the rocks and the results are as shown in Table 6.

The results of the average Schmidt hammer reading and corresponding density (as obtained from the company) of the selected rocks are presented in Table 6. From these results, it can be observed that the average rebound value is 47 for all the rocks and thus equivalent UCS of 133MPa was obtained as shown in Table 7. This indicated that the rocks under consideration have almost similar strength which make them appropriate for comparison for the scope of the work.

Table 6: Schmidt hammer rebound value for Equivalent UCS

Granite Location	Number of Tests	Average Schmidt hammer reading	Average density (g/cm3)	Equivalent UCS (MPa)
Kopec Ikere	5	47	2639	130
Kopec Ikole	5	47	2625	130
Kopec Ibadan	5	47	2625	130
Kopec Ife	5	47	2638	130

3.4 Blast Efficiency

In this section the blast efficiency for the primary blasting done in each of the site were computed. This is based on the fact that the bench height and all other blasting data remain the same for the four sites. The fractures Index and efficiency of fragmentation for the selected Kopec granite outcrop were obtained. Table 7 is a summary of average fracture index, average In – situ block size, average block size of the muck pile and the equivalent efficiency of fragmentation. From Table 8, Kopec Ikere is having average fracture index of 30 fractures per 100m with average in-situ block sizes of 6.8m^2 and average block size of muck pile of 3.4m^2 with the resultant efficiency of fragmentation of 50%. Similarly, Kopek Ikole, Kopec Ibadan and Kopec Ife area having equivalent values as shown in Table 8. From these results, it can be observed that Kopec Ife with highest fracture index is also having highest efficiency of fragmentation while Kopec Ikere with the least fracture Index is having least efficiency. This observation agreed with the work of Killc et al. [15] who observed that the closer the fracture, the higher the fracture Index and the higher the degree of fragmentation and thus the higher the negative effects of blasting expected if the charge density is not adjusted.

Table 7: Summary of average fracture index, average In-situ block sizes, average block size of muck pile.

Granite location	Aver. Fracture index (Fractures/ 100m)	Aver. In-situ block sizes (m^2)	Aver. Block size in muck pile (m^2)	Efficiency of fragmentation (%)
Kopec Ikere	30	6.8	3.40	50
Kopec Ikole	48	6.61	3.96	60
Kopec Ibadan	53	4.52	2.93	65
Kopec Ife	66	2.82	1.97	70

3.5 Correlation between the Measured Variables

The correlation that exists between the measured variables that affect the blast efficiency are shown in Table 8. The correlation between Fracture Index and blast efficiency is as shown in Figure 5. From Figure 5, it can be observed that the higher the fracture index, the higher the efficiency. This indicated that if an outcrop is having higher fracture index, the charged density should be reduced by variable so as to reduce the amount of unused charge in the hole.

Similarly the correlation between the efficiency of blast and RMR is as shown in Figure 6. It can be observed that the higher the RMR value the lower the efficiency. This agreed with the previous work by Bieniawisk [12] who stated that the higher the RMR value the more competent the rock and the better the utilization of blast charge with less waste of energy.

The correlation between blast efficiency and GSI is as shown in Figure 7. It can be observed that the higher the GSI value, the lower the blast efficiency. This agreed with the work of Bieniawisk [12] who observed that the rocks with higher GSI values are more competent than those with lower GSI values.

Table 8: Summary of Measured Variable for correlation of Selected Kopec Granite Outcrops

Location	**Fracture Index(Fractures/100m)**	**RMR**	**GSI**	**Blast Efficiency(%)**
Ikere Kopec	30	83	78	50
Ikole Kopec	48	79	75	60
Ibadan Kopec	53	81	75	65
Ife Kopec	66	80	75	70

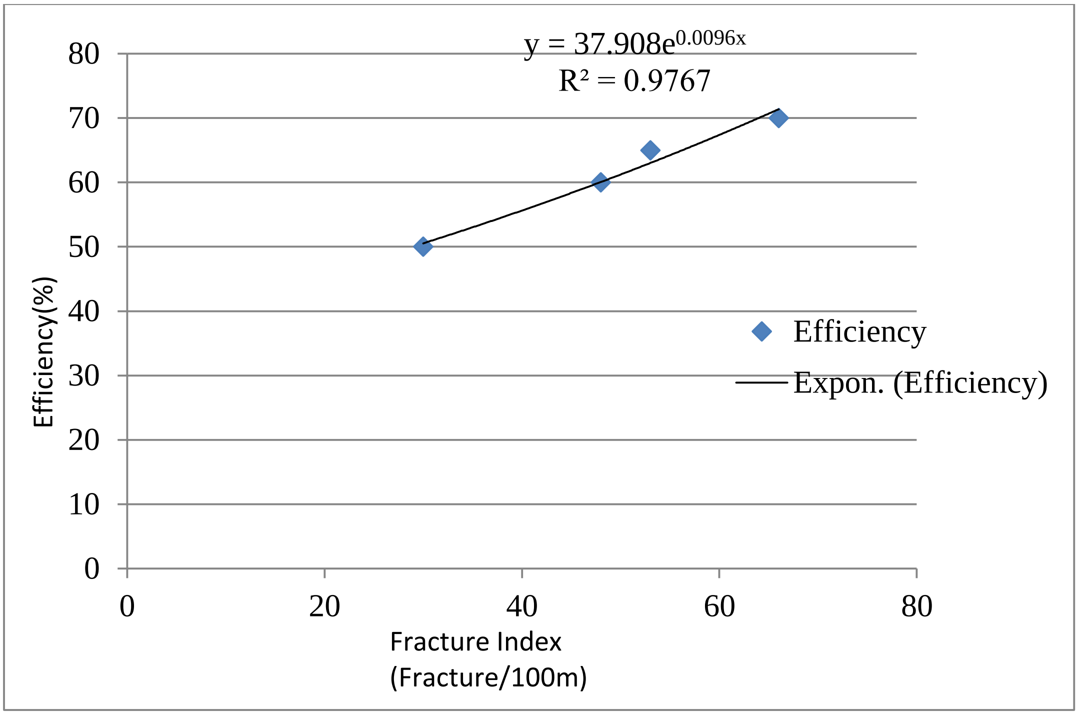

Figure 5: Graph of Efficiency (%) against Fracture index(Fracture/100m)

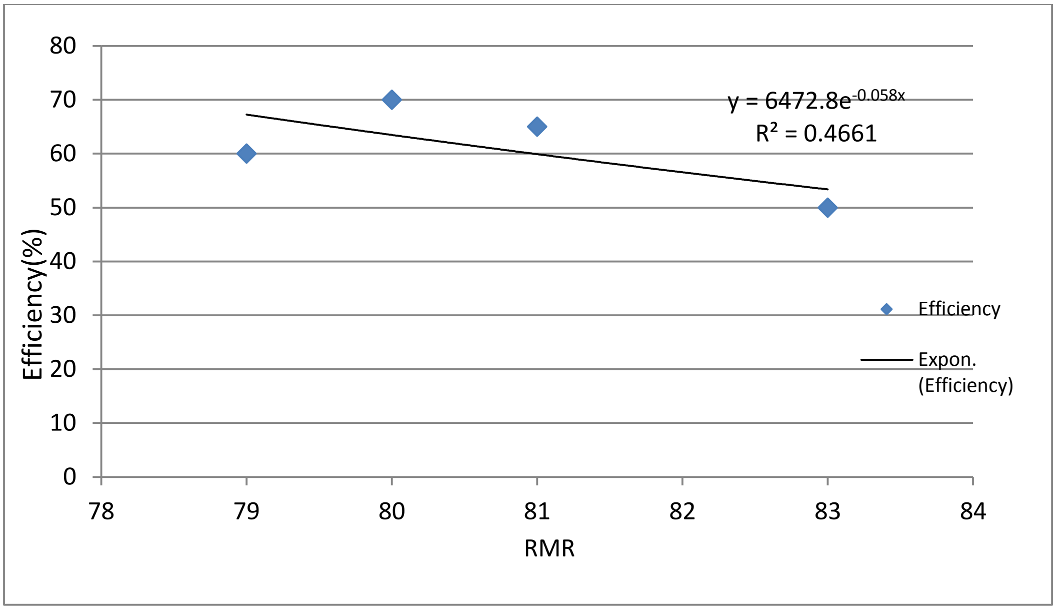

Figure 6: Graph of Efficiency (%) against RMR

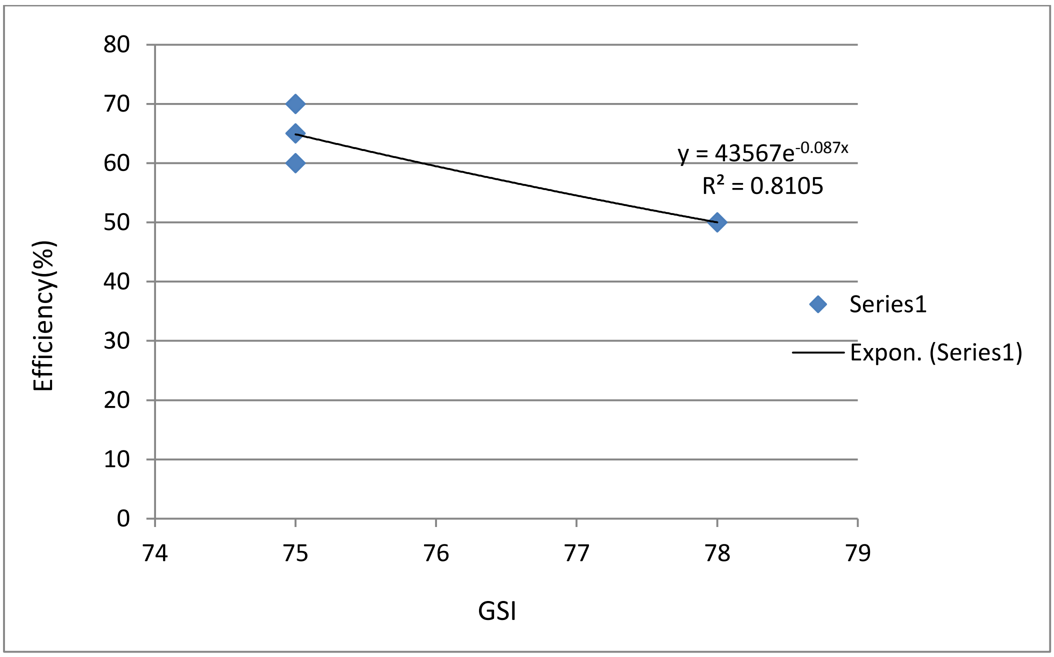

Figure 7: Graph of Efficiency (%) against GSI.

According to Kilic et al. [15] the most economic efficiency of fragmentation should not exceed 50% in order to avoid excessive fly rock, high vibration and noise and thus reduce wastage on the use of explosives.

From the above three correlations, it can be observed that Kopec Ikere outcrop with lowest fracture index is the one with the highest RMR and GSI values respectively and with resultant acceptable efficiency of fragmentation. Kopec Ikole outcrop is having efficiency of 60%. This is 10% above the economical efficiency as suggested by Kilic et al. [15]. Kopec Ibadan and Kopec Ife are having efficiency of 65% and 70% respectively which are 15% and 20% respectively above the economical efficiency as proposed by Kilic et al. [15].

From the above correlation, adjustment should always be introduced to the charge design when ever the efficiency is greater than 50%. The postulated adjustment is as shown below;

$$\text{Excess Charge} = [(X - 50)/2]/100 \times \text{Total charge} \tag{1}$$

Where X = The efficiency of blast under consideration.

4 Conclusion

The properties of rock discontinuities in the selected rocks were investigated and it was observed that no rock is free of discontinuities only that their degree of fracturing varies depending on the spacing of the discontinuities. This was observed to have significant effect on many design work in geotechnics such as blast design, slope stability as well as in dam construction. The fracture characterization was reviewed. This includes review of various methods of mapping discontinuities which include scanline mapping as well as window mapping. From the review work carried out, it was concluded that window mapping should be adopted for detail work such as this research work.

The review of various methods of empirical estimation of average in-situ block size estimation was carried out. The identified methods include joint spacing method, block volume method and volumetric joint count method. From the reviewed work done, it was noticed that using joint spacing method always gives exaggerated results which means care must be taken in using this method. Results from block volume and volumetric joint count look more reliable.

From the review of the numerical method of in-situ block size modelling, it was observed that the existing method such as the one by Latham et al. [16] and Ford [17] work on statistical simulation. The conditional simulation of the point by point occurrence of the fracture along the scanline may be impossible. This thus results to introduction of AutoCAD model by the author. This allows for conditional simulation of the fracture as they occurred along the scanline and within the window.

The review of the rock mass classification carried out shows that using Q, RMR and GSI will give accurate rock mass classification of the rock in–situ. It was observed that the higher the values of the classification, the better the quality of the rock. The review of various methods of determining the blast efficiency was carried out by the author which includes work done by Brady and Brown [7] as well as Kuznetsov [19]. The author prefer to use the most recent one by Kilic et al.[15]. In this method, the blast efficiency is obtained by dividing the average block size of muck pile by the average in-situ block size and multiply by 100.

The method and materials adopted for this research work was discussed. In data collection for fracture characterization, the author used both scanline and window mapping with the aid of compass clinometers. AutoCAD model was utilized to generate the in-situ block size model. From the fracture characterization carried out on the selected sites, it was observed that two main joints are predominant in Kopec Ikere, Kopec Ibadan as well as Kopec Ife. Two main joints with random are predominant in Kopec Ikole. The results of empirical estimation of average in-situ bock size distribution using joint spacing, block volume and volumetric joint count methods, all agreed that Kopec Ikere is having the biggest average in-situ block size with Kopec Ife having the smallest average in-situ block size.

The results of numerical modelling also agreed with the results of empirical estimation with Kopec Ikere having biggest average block size and Kopec Ife being the smallest. The results of rock mass classification showed that all the rock under consideration are competent rock while the results of the Schmidt hammer test shows that the rock under consideration have uniaxial compressive strength of 133MPa.

The results of blast efficiency obtained for the selected sites show that Kopec Ikere with lowest fracture index is having the lowest blast efficiency while Kopec Ife with highest fracture Index is having highest blast efficiency. From the correlation of measured variables, it was observed that there is a good correlation between blast efficiency and average fracture index. It was observed that blast efficiency increase with increase in fracture index. Good correlation was observed between blast efficiency and RMR. It was observed that blast efficiency decreases with increase in RMR value. Similarly, blast efficiency decreases with increase in GSI value.

From Kilic et al. [15], blast efficiency above 50% is not economical and environmental friendly. As a results of this, empirical relationship is established to take care of reduction that must be done on charge when fracture index is higher than expected 50% efficiency equivalent.

Excess charge = $[(X-50)/2]/100\times$ Total charge.

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