

Application of Split Desktop Image Analysis and Kuz-Ram Empirical Model for Evaluation of Blast Fragmentation Efficiency in a Typical Granite Quarry*

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Abstract

Evaluation of fragmentation efficiency is an integral aspect of blasting operation. This study therefore assesses the efficiency of fragmentation size at Eminent granite quarry, Ibadan, Nigeria using Split Desktop software and Kuz-Ram empirical model. Five muckpiles of blasted rocks with the same blast design were analysed. The muckpile images were captured using smart high precision digital camera and uploaded into computer for Split Desktop analysis. The results of the fragment size distribution obtained from Kuz-Ram vary slightly with that of the Split Desktop but follow similar trend. The average values of F_{80} and F_{90} from the Split Desktop image analysis were 90.96 cm and 98.24 cm respectively. The Kuz-Ram model values for F_{80} and F_{90} were 88.52 cm and 92.95 cm respectively. The results of the Split Desktop were compared to the results obtained from the Kuz-Ram experiential model. The findings showed that the results obtained from Kuz-Ram empirical model were in conformity with the results from the Split Desktop software based on empirical relationship. Hence, the model is good for preliminary evaluation of blast design.

Keywords: Blasting, Particle Size Distribution, Split Desktop Software, Muckpile, Fragmentation Indicator

1 Introduction

Blasting is carried out in mining to reduce the *in-situ* rocks to smaller size fragments that can be easily handled by loading and haulage equipment. The process involves breaking or loosening the rock to extract largest possible size at a reduced cost. To achieve this objective, quantitative and qualitative requirements of blast fragmentation are essential conditions that must be met (Singh *et al.*, 2005 and Voulgarakis *et al.*, 2016). Fragmentation degree plays important role in control and reduction of loading, transportation and crushing costs (Siddiqui *et al.*, 2009; Akande and Lawal, 2013). Blasting could be seen as the first comminution process in quarrying and mining and thus, the size of fragments obtained should not exceed the gape of crusher for efficient operation (Shehu *et al.*, 2020; Lawal 2020; Lawal *et al.*, 2021). Elimination of extremely big fragments and minimisation of excessive fines in the muckpile are usually considered to essentially optimize blast fragmentation. Kuz-Ram model is commonly used to appraise blast design alternatives and minimise the number of trial blasts to ensuring required results (Strelec *et al.*, 2011). According to Kuznetsov (1973), Kuz-Ram model is an empirical relationship that evaluates blast fragmentation by incorporating blast design parameters such as: blast geometry, explosive characteristics, quantity of explosive used and rock factor. It measures fragmentation by estimating the 50% passing size of a muckpile. From the two major methods of blast fragmentation assessment which are direct and indirect methods, each of the methods has its

inherent issues. However, digital image analysis is a product of technological advancement and has become the most commonly used indirect method for evaluating the blast fragmentation (Bamford *et al.*, 2017; Lawal, 2021 and Siddiqui *et al.*, 2009). Statistical analyses were conducted in order to compare the results of the two techniques.

According to Badrud (2011), three basic phases are required for the determination of grain size distribution using image analysis method. These are: sampling site selection, imaging and image analysis. The sampling phase involves selection of sites to obtain samples that represent the blasted rock mass while high quality images which can be analysed are prepared at the imaging phase. The last phase determines the size distribution of fragments marked on the image and is measured after drawing the perimeter of fragments on the image. Research is constantly being conducted by mining researchers to improve the blast fragmentation using different models to predict fragmentation efficiency. Some researchers had recognised the link between the levels of accuracy, rapidity and optimality of the empirical models, image analyses and numerical models (Latham *et al.*, 2003). Image analysis method includes: Split Desktop, WipFrag, FragScan, PowerSieve, GoldSize, BLASTFRAG, TUCIPS, IPACS, etc. (Dahlhielm, 1996; Havermann and Vogt, 1996; Maerz *et al.*, 1996; Schleifer and Tessier, 1996; Raina *et al.*, 2002, Sanchidrian *et al.*, 2009; Siddiqui *et al.*, 2009). Thus, the choice of a specific blast fragmentation method to be adopted depends on the needs that

necessitated the analysis (Shehu *et al.*, 2020; Lawal and Kwon, 2020). The image analysis technique is highly advantageous because it has no limitation on the size of samples that can be analysed and does not interrupt the production process. They are usually in the form of computer software or programs and highly affordable (Shehu *et al.*, 2020; Lawal, 2021). However, the inherent errors of the method could be minimised by capturing a large number of high-quality images for analysis. In this study, Split Desktop image analysis software is considered to study the rock fragmentation because of its advantages. It is a user-friendly software (Tavakol and Hosseini, 2017). The results of the software are more accurate and with lesser error.

1.1 Description of the Study Area

The study area is located at Oluyole Local Government, Ibadan, Oyo State, Nigeria. The quarry produces granite aggregates and it is in operation. Fig. 1 shows the Geological Map of Eminent quarry in Ibadan, Oyo State as extracted from the Geological Map of Nigeria, and Fig. 2 depicts the quarry site after the blasting operation. Eminent quarry is located geographically between the latitude $7^{\circ} 10' 0''$ N to $7^{\circ} 20' 0''$ N and longitude $3^{\circ} 50' 0''$ E to $4^{\circ} 00' 0''$ E at 159 m above the sea level.

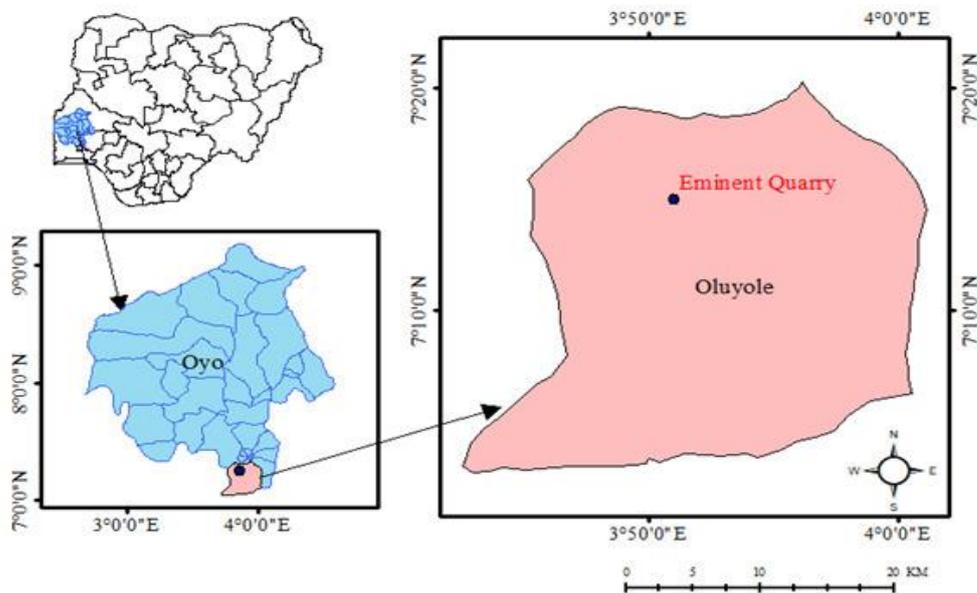


Fig. 1 Map of Study Area



Fig. 2 Eminent Quarry Site after Blasting

2 Resources and Methods Used

In conducting this research, five blast operations at Eminent Quarry were studied and the resulting fragmentation was evaluated using the Split Desktop analysis and the Kuz-Ram empirical model. Split Desktop is designed for analysis of digital images retrieved from the digital camera and for determining the rock fragmentation gradation distribution. To capture accurate images, it is recommended that the horizontal axis of the camera should be at right angle to the surface of the blasted muckpile. In the field, deviation from this standard is utmost unavoidable. The images of muckpile at Eminent quarry were captured from the view point exactly in front of the muckpile with the horizontal axis of the camera at some varied angles from 90° to the face of the muckpile. The images of muckpiles captured were thereafter uploaded into computer for the Split-Desktop analysis. Split Desktop analysis involves five phases for each image captured. In the first phase, the image is scaled. Secondly, it is dedicated to segmentation of rock fragments in each image. Thirdly, it gives permission for editing the desired rock fragments to ensuring precision of results. While the fourth phase involves the analysis of rock fragments marked in the image, and in the final stage, the fifth phase, the size distribution results are displayed in the form of diagrams (Bobo, 2010).

At Eminent quarry, the bench of the mine has height of 10 m with the same holes diameter of 76 mm; while the sub-drill is assumed to be 1 m. In the blast design, ANFO and emulsion type of explosives were used. The powder factor used is 0.25 kg/tons and the delay between 2 consecutive detonators is 25 milliseconds.

According to Kuznetsov (1973), Kuz-Ram model is an empirical relationship that evaluates blast fragmentation by incorporating blast design parameters such as explosive characteristics, quantity of explosive used, blast geometry and rock factor. It measures fragmentation by estimating the 50% passing block size of a muckpile known as mean size (X_{50}). The two results from Split Desktop and Kuz-ram model were compared using statistical analyses. The Kuz-Ram model has three key equations; the Kuznetsovs Equation, Rosin-Rammler Equation and the Uniformity index as shown in Equations 1- 3 (Shehu *et al.*, 2020; Lawal 2021).

$$X_{50} = A \times Pf^{-0.8} \times Q^{\frac{1}{6}} \times \left[\frac{115}{RWS} \right]^{\frac{19}{30}} \quad (1)$$

where X_{50} is the mean particle size of muckpile (cm), A is the rock factor, P_f is the powder factor (kg/m³), Q is the mass of explosive in the blast hole (kg) and

RWS is the weight strength of explosive relative to ANFO.

According to Hustrulid (1999), the rock factor (A) of the model was selected to be 10 as shown in Table 1. The Rosin-Rammler distribution (Rosin and Rammler, 1933) was used to evaluate the proportion of muckpile passing through a specific screen size as given in Equation (2).

Table 1 Rock Factor Based on Structural Conditions

Rock mass condition	Rock factor A
Very soft	3
Soft	5
Medium soft	7
Rigid	10
Rigid and homogeneous	13

(Source: Hustrulid, 1999)

$$R(X) = 1 - e^{-\left(\frac{X}{X_c}\right)^n} \quad (2)$$

where $R(X)$ is the % passing through a screen opening of size X , X is screen size (cm), X_c is the characteristic size (cm), and n is the uniformity index.

According to Cunningham (1987), the uniformity index (n) was calculated by employing the effects of blast geometry as shown in Equation (3).

$$n = \left[2.2 - \frac{14B}{d} \right] \left[\frac{1}{2} + \frac{S}{2B} \right]^{0.5} \left[1 - \frac{w}{B} \right] \times \left[\frac{L}{H} \right] P \quad (3)$$

where n is the uniformity index of the Kuz-Ram model; B is burden (m); S is spacing (m); d is the hole diameter (mm); w is the standard deviation of drilling precision (m); L is the charge length (m); H is the bench height (m); and P is the factor of staggered drilling pattern.

The uniformity exponent of the Rosin-Rammler distribution is estimated as a function of the blast design parameters. The characteristic size (X_c) of the Rosin-Rammler distribution (Equation 2) was obtained using Equation (4).

$$X_c = \frac{X_{50}}{(0.693)^{\frac{1}{n}}} \quad (4)$$

3 Results and Discussion

A total number of five blasted muckpiles were analysed. The blast design parameters for the five blast operations are shown in Table 2 with the burden thickness of 2 m and spacing of blast holes of 2 m. The particle size distribution analyses of the

muckpile obtained from the five different blasts A to E using Split Desktop model are shown in Fig. 3. The maximum allowable size of the fragment that the primary crusher can handle is 100cm. The results of the Split Desktop processing of the blasted rock fragments are recorded in all the five blasts. The Split Desktop analyses show a very closely related particle size distribution for the five blasts with similar uniformity index of 1.7217.

Table 2 Blast Design Parameters

S/N	Parameter	Value
1	Burden (m)	2
2	Spacing (m)	2
3	Bench height (m)	10
4	Hole diameter (mm)	76
5	Stemming (m)	1
6	Sub-drill (m)	0.4
7	Powder factor (kg/tons)	0.25
8	Quantity of Explosive per meter	ANFO = 3.75 kg
9	Explosive type	Ammonium nitrate and Bulk emulsion
10	Delay time/interval	25 ms

The % passing from the Split Desktop image analysis for the five blast operations are shown in Table 3, the average values of F_{80} and F_{90} are 90.96 cm and 98.24 cm respectively.

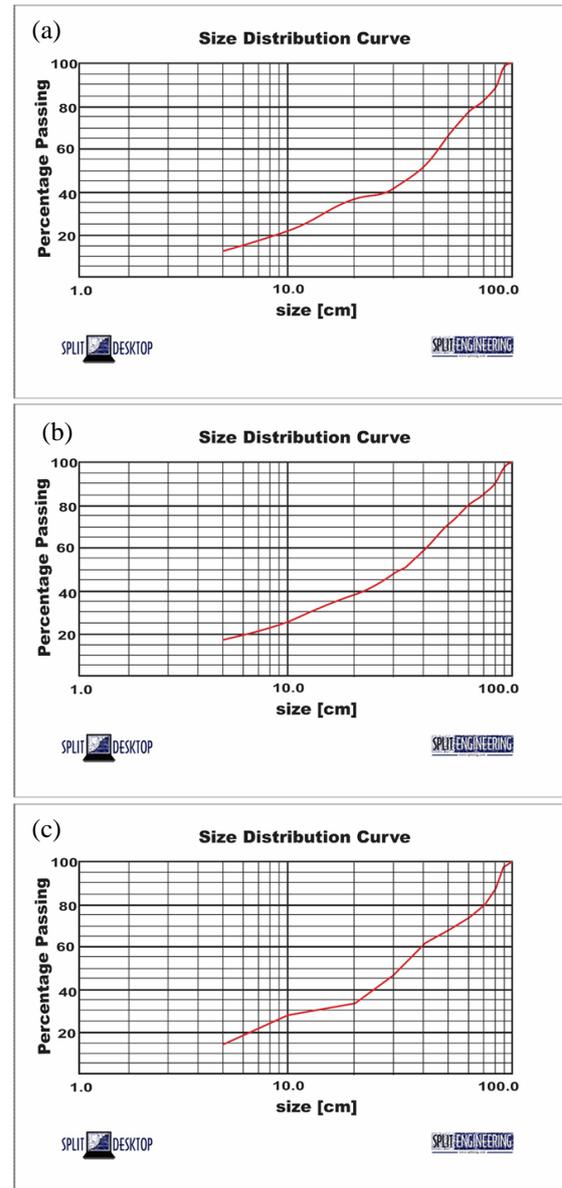
Table 3 Values of % passing obtained from Image Analysis of the five muckpiles

Muckpile	A	B	C	D	E
F_5	13.8	18.6	14.8	17.6	19.2
F_{10}	21.4	25.7	28.2	23.7	28.4
F_{20}	36.9	39.2	34.8	40.2	39.7
F_{30}	42.2	48.1	46.9	50.6	51.0
F_{40}	53.5	59.3	61.3	66.4	62.8
F_{50}	68.4	71.8	68.5	78.2	75.3
F_{60}	78.9	80.3	74.9	83.6	84.6
F_{70}	83.1	85.8	80.5	87.3	89.1
F_{80}	89.8	90.1	86.7	94.8	93.4
F_{90}	99.7	98.2	96.4	99.3	97.6
F_{100}	100	100	100	100	100

Fig. 4 shows the size distribution curve of the blast design obtained from the Kuz-Ram model while Figs. 5-9 compare the Kuz-Ram curve with the five results obtained from Split Desktop. The particle size distribution obtained from the Kuz-Ram model deviates from that of the Split Desktop model despite showing similar trend. The Kuz-Ram model shows that all the fragments of the muckpile are less than 100cm benchmark.

Also, the five analyses from the Split Desktop indicate an allowable range of boulders. The five independent results from the Split desktop model are

very close as shown in Fig. 10 and thereby reflecting the same design method. The small difference can be attributed to variation in rock mass structural features (Gheibie *et al.*, 2009, Akbari *et al.*, 2015). Table 4 shows the percentage passing obtained from the Kuz-Ram experiential model analyses of the blasted rock. The details of the percentage passing obtained from the Kuz-Ram experiential model and Split Desktop analyses of the blasted rocks are shown and compared in Table 5. The salient characterisation features of the analyses are also shown in Table 6.



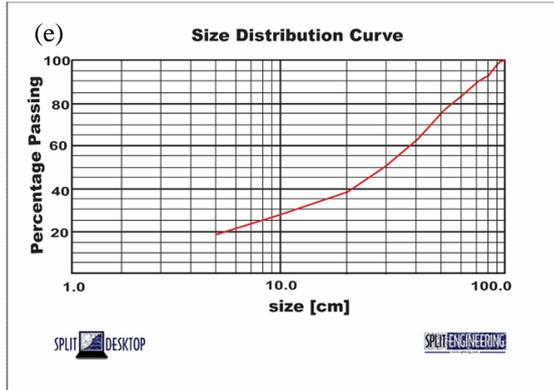
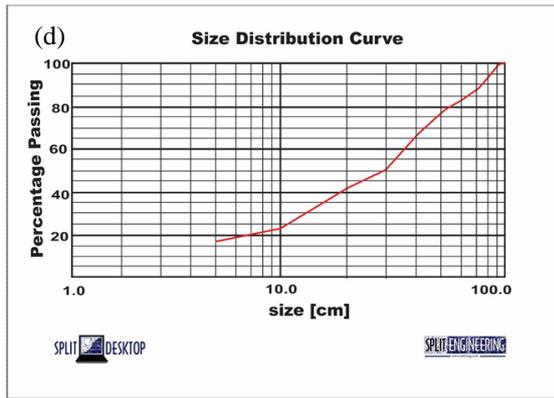


Fig. 3 Cumulative Grain Size Curves of Image Analysis of Blasts A- E

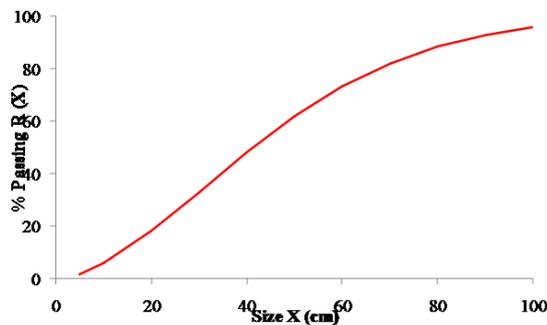


Fig. 4 Kuz-Ram Size Distribution Curve for Blast Design

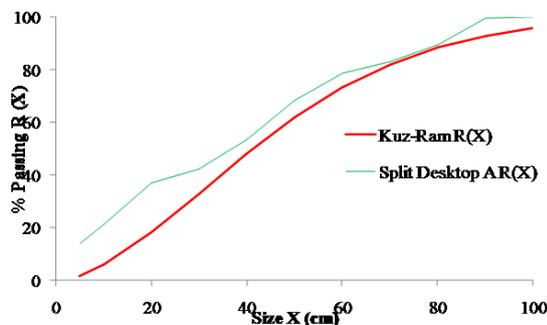


Fig. 5 Kuz-Ram versus Split Desktop Size Distribution Curves for Blast A

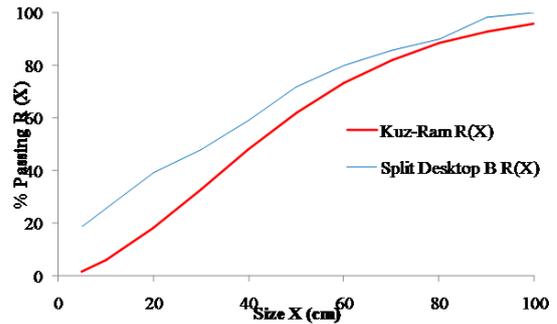


Fig. 6 Kuz-Ram versus Split Desktop Size Distribution Curves for Blast B

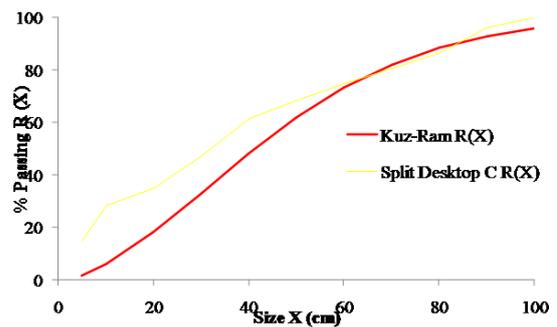


Fig. 7 Kuz-Ram versus Split Desktop Size Distribution Curves for Blast C

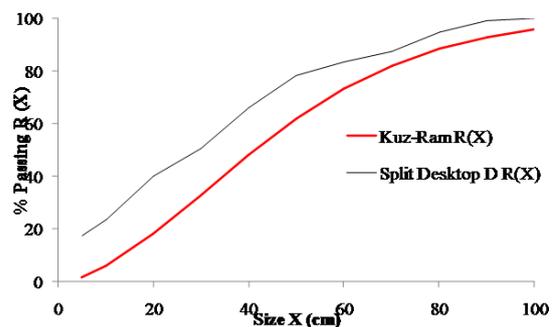


Fig. 8 Kuz-Ram versus Split Desktop Size Distribution Curves for Blast D

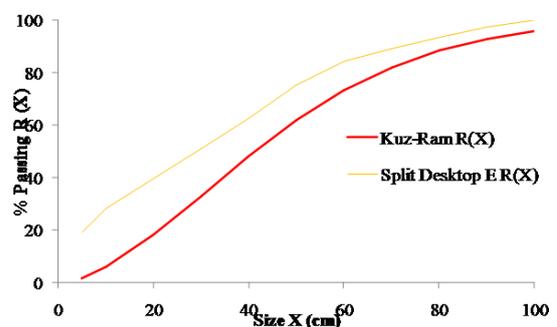


Fig. 9 Kuz-Ram versus Split Desktop Size Distribution Curves for Blast E

Table 4 Results of the Kuz-Ram Experiential Model

Size (cm)	F ₅	F ₁₀	F ₂₀	F ₃₀	F ₄₀	F ₅₀	F ₆₀	F ₇₀	F ₈₀	F ₉₀	F ₁₀₀
% Passing	1.81	5.86	18.05	32.97	48.13	61.86	73.27	82.10	88.52	92.95	95.84

Table 5 The Basic Percentage Passing for Kuz-Ram and Split Desktop Analyses of the Blasted Muckpiles

Size X (cm)	Kuz-Ram (%)	Split Desktop blast A (%)	Split Desktop blast B (%)	Split Desktop blast C (%)	Split Desktop blast D (%)	Split Desktop blast E (%)
100	95.84	100	100	100	100	100
90	92.95	99.7	98.2	96.4	99.3	97.6
80	88.52	89.8	90.1	86.7	94.8	93.4
70	82.10	83.1	85.8	80.5	87.3	89.1
60	73.27	78.9	80.3	74.9	83.6	84.6
50	61.86	68.4	71.8	68.5	78.2	75.3
40	48.13	53.5	59.3	61.3	66.4	62.8
30	32.97	42.2	48.1	46.9	50.6	51.0
20	18.05	36.9	39.2	34.8	40.2	39.7
10	5.86	21.4	25.7	28.2	23.7	28.4
5	1.81	13.8	18.6	14.8	17.6	19.2

Table 6 Characterisation Features of the Analyses

	X ₅₀ (cm)	X _c (cm)	n
Kuz-Ram	41.28	51.08	1.7217
Split Desktop of blast A	39.5	48.87	1.7217
Split Desktop of blast B	32.1	39.72	1.7217
Split Desktop of blast C	32.7	40.46	1.7217
Split Desktop of blast D	29.5	36.50	1.7217
Split Desktop of blast E	29.8	36.87	1.7217

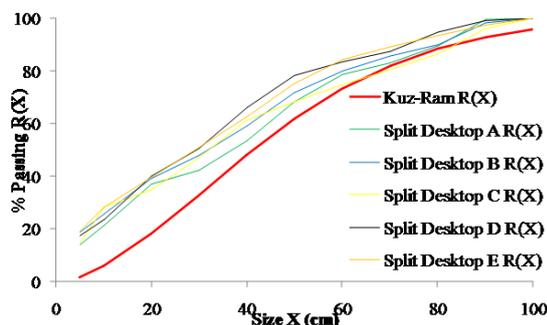


Fig. 10 Kuz-Ram versus Split Desktop Size Distribution Curves for Blasts A, B, C, D and E

The efficiency of fragmentation is given by the fragmentation indicator (FI) by comparing the produced fragments with the estimated ideal size obtained from the Kuz-Ram model (Shehu *et al.*, 2020). If the FI value is less than 1, it implies that

the average fragment size obtained is larger than the ideal size and when the FI value is greater than or equal to 1, it shows a highly efficient fragmentation with average fragment size less than or equal to the ideal size. According to Shehu *et al.* (2020), fragmentation indicator (FI) for assessing the quality of blast fragmentation is as expressed in Equation (5).

$$FI = \frac{X_{kr}}{X_{bm}} \quad (5)$$

where *FI* is fragmentation indicator, *X_{kr}* is expected ideal mean size of the blasted material from Kuz-Ram model (cm) and *X_{bm}* is mean size of blasted muck pile from particle distribution analysis (cm).

Table 7 shows the fragmentation indication values for the five blasted muckpiles. The blast event values varied from 1.045 to 1.399. From the principle of fragmentation indication, all the blast events A-E displayed very efficient fragmentation. However, the blast event D recorded the highest FI value of 1.399 and thereby considered as the most efficient fragmentation.

Table 7 Fragmentation Indicators for the Blasted Rock

S/N	Blast Events	X _{kr} (cm)	X _{bm} (cm)	FI
1	Blast A	41.28	39.5	1.045
2	Blast B	41.28	32.1	1.286
3	Blast C	41.28	32.7	1.262
4	Blast D	41.28	29.5	1.399
5	Blast E	41.28	29.8	1.385

4 Conclusion

This research was carried out to examine and compare particle size distribution of blast-induced fragmentation of Eminent granite quarry using the Kuz-Ram empirical model and the Split Desktop digital image analysis software. Five different blasts of similar blast design were analysed. From the analysis, the results of the Split Desktop show close relationship with one another. However, the minor differences could be attributed to human errors and structural geological features especially the discontinuity characteristics of the rock mass. Other factors that can cause the variations are the structural properties of rock mass such as the compressive strength, groundwater condition, joint aperture and joint infillings. The Split Desktop analyses how that different rock masses subjected to similar blast design will produce varied degrees of fragmentation as a result of inherent resistances of the rock mass during blasting. The average values of F_{80} and F_{90} obtained from the Split Desktop image analysis were 90.96 cm and 98.24 cm respectively. These average values of F_{80} and F_{90} percentage passing of the muckpiles are considered suitable for the quarry operation as a result of the values closeness to the allowable value of 100cm of the crusher. The particle size distribution predicted from the Kuz-Ram model shows significant variations from that of the Split Desktop and thus, do not reflect the true values obtained. The Kuz-Ram model underestimates the coarseness of the fragmentation and the mean fragment size predicted is smaller than the correct values in the five blast events studied. The results show that the model is very useful in the preliminary evaluation of blast design.

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