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Predicting Fragmentation Distribution of Rock Blasting at Eshiem Pit of Aliko Resources Limited, Ghana

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Abstract

This work predicts rock fragmentation distribution and assesses the performance of the Kuz-Ram, Modified Kuz-Ram and Kuznetsov Cunningham Ouchterlony (KCO) models to determine the most accurate prediction model applicable for Aliko Resource Limited (ARL). The performance assessment was done using the Root Mean Square Error and Correlation and Regression Analysis. A general trend of prediction of more fines (<16.00 mm) and boulders (>800.00 mm) was observed for all the three models. The fragmentation results showed that there was a high quantity of fines with insignificant amounts of boulders produced from the blasts. Although all the models had a high correlation coefficient, R (> 95%), the Modified-Kuz-Ram model performed best for the blasts studied. It is therefore recommended for fragmentation prediction and blast optimisation studies of the mine.

Keywords: Modified-Kuz-Ram model; Eshiem; Ghana, Sizes; Fragmentation; Distribution

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1.0 INTRODUCTION

The products of blasting affect all downstream operations of mining such as loading, hauling and processing. Therefore, blasts should be designed to ensure that selected parameters give the desired fragmentation to optimise downstream processes. This may be achieved by using fragmentation prediction models. Several models exist that can be used for fragmentation prediction from primary rock blasting. The cost of drilling and blasting operations greatly contributes to the “high cost trends of the overall mining operations” in open-pit mines. These may be increased up to about 50% due to the presence of boulders which will require secondary blasting [1]. Therefore, optimised rock fragmentation is essential for minimising costs of mining operations. Rock fragmentation in bench blasting is affected by blast conditions such as specific charge, spacing, burden rock heterogeneity and dynamic fracture phenomena [2].

Rock fragmentation analysis, the fragment size distribution of blasted rock material, is used in the mining industry as an index to estimate the effect of bench blasting. Rock fragmentation is a fundamental goal of bench blasting where the most effective blasts can only be achieved through fragmentation optimisation.

The meaning of optimised fragmentation is site-dependent, as there is no single fragment size that is the most cost effective for all mine sites, loading equipment, and processing facilities [3]. This research seeks to predict the size distribution of materials to be blasted using varieties of prediction models. It also assesses the performance of these models to determine the most accurate model that gives the optimum fragmentation distribution.

The objective of this study is to predict the comparative fragmentation distribution of blasted materials using Kuznetsov Cunningham Ouchterlony (KCO) model, Kuz-Ram model, and the Modified Kuz-Ram model to determine the most accurate fragmentation model amongst them.

2.0 METHODOLOGY

The following materials and methods were used to achieve the intended objectives:

i. Field visits and data collection through field measurements of parameters.
ii. Prediction of rock fragmentation distribution using applicable models.
iii. Comparative analysis of model outputs; and
iv. Analysis of fragment images with the WipFrag® software.

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2.1 *Fragmentation Prediction Models*

Various models have been developed over the years that predict the size distribution resulting from a particular primary blast design [4-6]. These models range from purely empirical relations to rigorous numerical models [7]. These approaches fall into two broad categories:

i. Empirical modelling, which infers finer fragmentation from higher energy input; and
ii. Mechanistic modelling, which tracks the physics of detonation and the process of energy transfer in well-defined rock for specific blast layouts, deriving the whole range of blasting results.

The mechanistic approach is intrinsically able to illustrate the effect of individual mechanisms, something beyond purely empirical models. However, it is more difficult to apply daily, as it is limited in scale, requires long run times and suffers from the difficulty of collecting adequate data about the detonation, the rock and the results. It also requires greater or lesser degrees of empiricism, so is not necessarily more accurate. For practical purposes, the empirical models are the ones used for daily blast design.

Some of these models about surface blast include the Bond Index-Ram Model, Kou-Rastan Equation, Energy Block Transition Model, Swedish Detonic Research Foundation Rammler Model, Kuznetsov-Cunningham-Ouchterlony (KCO), Chung and Katsabanis Model, Kuz-Ram Model, Modified Kuz-Ram Model, Crushed Zone Model (CZM), Two-Component Model (TCM), Artificial Neural Networks (ANN) prediction models [8-11]. These models consider a wide range of factors (controllable and uncontrollable) such as geometrical (burden, spacing, hole depth and charge length), explosive (type, amount/quantity and properties) and rock (rock strength, porosity, specific gravity, discontinuity information and groundwater condition) parameters to predict the fragmentation.

Most modelling mistakes arise through the simplistic application or small appreciation of blasting as a sequence generation. A quick assessment of not unusual stumbling blocks is therefore appropriate. These fall widely into the following classes:

i. Parameters not taken into account.
ii. Limited ability to measure fragmentation.
iii. Difficulty in scaling blasting effects.

2.1.1 *The Kuz-Ram model*

The Kuz-Ram Model is made up of three key equations: Kuznetsov's equation, Rosin-Rammler equation and Uniformity equation [12].

2.1.1.1 *The Kuznetsov's equation*

The adapted Kuznetsov's Equation (1) is used in estimating the mean fragment size resulting from a blast.

$$X_m = AK^{0.8}Q^{\frac{1}{6}}.\left(\frac{115}{RWS}\right)^{\frac{19}{20}} \tag{1}$$

where, X_m = mean particle size, cm; A = Rock factor (varying between 0.8 and 22, depending on the hardness and structure); K = Powder factor, quantity of explosive (in kg) per cubic metre of the rock; Q = Mass of explosive in the hole, kg; and RWS = Relative Weight Strength of the explosive used (RWS of ANFO = 100); and 115 for Trinitrotoluene (TNT).

2.1.1.2 *Rosin-Rammler equation*

The adapted Rosin-Rammler equation. Rosin-Rammler equation is used for predicting the distribution resulting from the blast. It is given in Equation (2)

$$R_x = exp\left[-0.693\left(\frac{x}{x_m}\right)^n\right] \tag{2}$$

where, R_X is the mass of fraction retained on screen opening x, and n = uniformity index, usually between 0.7 and 2 based on the blast geometry.

2.1.1.3 *The uniformity equation*

$$n = \left(2.2 - \frac{14B}{d}\right)\sqrt{\left(\frac{1+\frac{S}{B}}{2}\right)}\left(1-\frac{W}{S}\right)\left[abs\left(\frac{BCL-CCL}{L}\right)+0.1\right]^{0.1}.\frac{L}{H} \tag{3}$$

where, B is the burden, m; S is the Spacing, m; d is the Hole diameter, mm; W is the Standard deviation of drilling precision, m; L is the Charge length, m; BCL is the Bottom Charge Length, m; CCL is the Column Charge Length, m; H is the Bench Height, m.

The rock factor in Equation (1) is estimated in Equation (4) as:

$$A = 0.06\left(RMD + RDI + HF\right) \tag{4}$$

Where, RMD is the rock mass description; RDI is the density influence; and HF is the hardness factor.

2.1.2 *The Modified Kuz-Ram model*

This is a changed form of the Kuz-Ram Model with a few modifications to the Kuznetsov's equation and the uniformity index. The Rosin-Rammler feature is maintained within the original Kuz-Ram Model. Results in [4] made an adjustment to the Equations (1) and (3). These essential adjustments to the model have been advanced because of transformation of fragmentation by electronic delay detonators (EDs). Both the impact of assigned timing and the impact of timing scatter are accommodated [4]. The new equation set includes adjustments inside the uniformity and suggests fragment size equations, that is Equation (5) as follows.

$$X_{50} = AA_T K^{-0.8} Q^{\frac{1}{6}} \left(\frac{115}{RWS} \right)^{\frac{19}{20}} C(A) \tag{5}$$

where, *‘A_T’* is a newly introduced timing factor; A = 0.06(RMD+ RDI + HF) *C(A). The correction factor *C(A)* would normally be well within the range 0.5 – 2[4] Q = Mass of explosive in blast hole (excluding sub drill) (kg); and K= Technical Powder Factor (excluding sub drill) (kg/m³), and now incorporates the effect of inter-hole delay on fragmentation, *‘C(A)’* a correction factor for the rock factor as in Equation (6) as follows:

$$T_{max} = \frac{15.6}{C_x} B \tag{6}$$

where, T is the inter-hole delay, and Cx is the longitudinal velocity, km/s. The modified uniformity index is expressed in Equation (7) as follows:

$$n = n_s \sqrt{\left(2 - \frac{30B}{d} \right)} \sqrt{\frac{1 + \frac{S}{B}}{2}} \left(1 - \frac{W}{B} \right) \left(\frac{L}{H} \right)^{0.3} C(n) \tag{7}$$

where, n_s is the uniformity factor governed by the scatter ratio, C(n) is the correction factor for the uniformity index as in Equation (8) and (9) as:

$$n_s = 0.206 + \left(\frac{R_s}{4} \right)^{0.8} \tag{8}$$

$$R_s = \frac{T_r}{T_x} \tag{9}$$

where, *R*s is the scatter ratio; Tr is the Range of delay scatter for initiation system, ms; and Tx is the desired delay between holes, ms.

2.1.3 *The KCO Model*

This model is a modified form of the Kuz-Ram model and comprises three equations. The Rosin-Rammler function in the Kuz-Ram model is replaced by the Swebrec function while the uniformity index is replaced by the curve undulation factor.

2.1.3.1 *The Kuznetsov’s equation*

Equation (10) is used in the estimation of the mean fragmentation of the blast:

$$X_{50} = A \left(\frac{1}{q^{0.8}} \right) . Q^{\frac{1}{6}} \left(\frac{115}{S_{ANFO}} \right)^{\frac{19}{30}} \tag{10}$$

where, q is the powder factor, kg/m^3; X_{50} is the mean fragment size, cm; and S_{ANFO} is the relative weight strength of the explosive to ANFO.

2.1.3.2 *Swebrec function*

Equation (11) replaces the Rosin-Rammler equation in the Kuz-Ram- model

$$P(x) = \frac{1}{\left\{ 1 + \left[\frac{In\left(\frac{x_{max}}{x} \right)}{In\left(\frac{x_{max}}{x_{50}} \right)} \right]^b \right\}} \tag{11}$$

where, P(x) is the percentage of material passing sieve size X (%); b is the curve undulation parameter; and Xmax is the maximum *in-situ* block size, cm, or value can be either the spacing or the burden.

2.1.3.3 *Curve undulation parameter*

Equation (12) characterizes the fragmentation distribution. It depends on Cunningham’s uniformity index (Equation 3) and the mean fragment size.

$$b = \left[2.In2.In\left(\frac{x_{max}}{x_{50}} \right) \right] .n \tag{12}$$

where, b is the curve undulation parameter; X_{50} is the 50% passing size (same as in Kuz-Ram model) (cm); X_{max} is the maximum in situ block size; and n is the uniformity index (same as in Kuz-Ram model).

2.2 Comparative Analysis of Model Outputs

The comparative analysis in this study was done using the root mean square error (RMSE) and correlation coefficient. The root mean square error is frequently used to measure the differences between values predicted by models and the values observed. The root mean square error (RMSE) is a measure of accuracy, to compare forecasting errors of different models for a particular data and not between datasets, as it is scale-dependent. The correlation and regression analysis provide information on the strength and direction of the linear relationship between two variables, and a linear regression analysis estimates parameters in a linear equation that can be used to predict values of one variable based on the other. The strength can range from absolute value 1 to 0, the stronger the relationship the closer the value is to 1.

The effect of each error on RMSE is proportional to the size of the squared error; thus, larger errors have a disproportionately large effect on the root mean square error (RMSE). Equations (13) and (14) are the equations for root mean square error and correlation coefficient respectively.

$$RSME = \sqrt{\frac{\sum_{i=1}^{n} (\hat{y} - y)^2}{n}} \qquad (13)$$

where, $\hat{y}_i$ is the predicted values; y_i is the actual value; and n is the number of predictions.

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_1 - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2 \sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \qquad (14)$$

Where:

$\bar{X}$ is the mean of variable X values and $\bar{Y}$ is the mean of variable Y values

2.3 Collection of Data

Collection of data for the study was done between 29th June 2021, and 1st July 2021 at Aliko Resource Limited (A-Zone Eshiem). Primary data in the form of muck pile pictures were taken for analysis, and secondary information from drill and blast images were obtained from the drill and blast phase of the mine.

The information obtained for the studies included geometric, explosive, and rock parameters of the mine. The geometric blast parameters are presented in Table 1 while the explosive parameters are shown in Table 2. The bulk explosive used on the mine is Riomex 8000 (20% Ammonium Nitrate Porous Prills, ANPP, and 80% emulsion). The average density is 1.2 g/cm^3 (1 200 kg/m^3) and the average velocity of detonation (VOD) is 4 900 m/s. The relative weight energy of Riomex 8000 is 83%. Rock characteristics records for A-Zone Eshiem were acquired from the Geotechnical Department of the mine. A summary of the Geometric data for the pit is provided in Table 1. Table 2 summarises the explosive parameters of A-Zone Eshiem pit and Table 3 represents the rock records obtained at the pit.

Table 1: Summary of Geometric Parameters at A-Zone Eshiem Pit

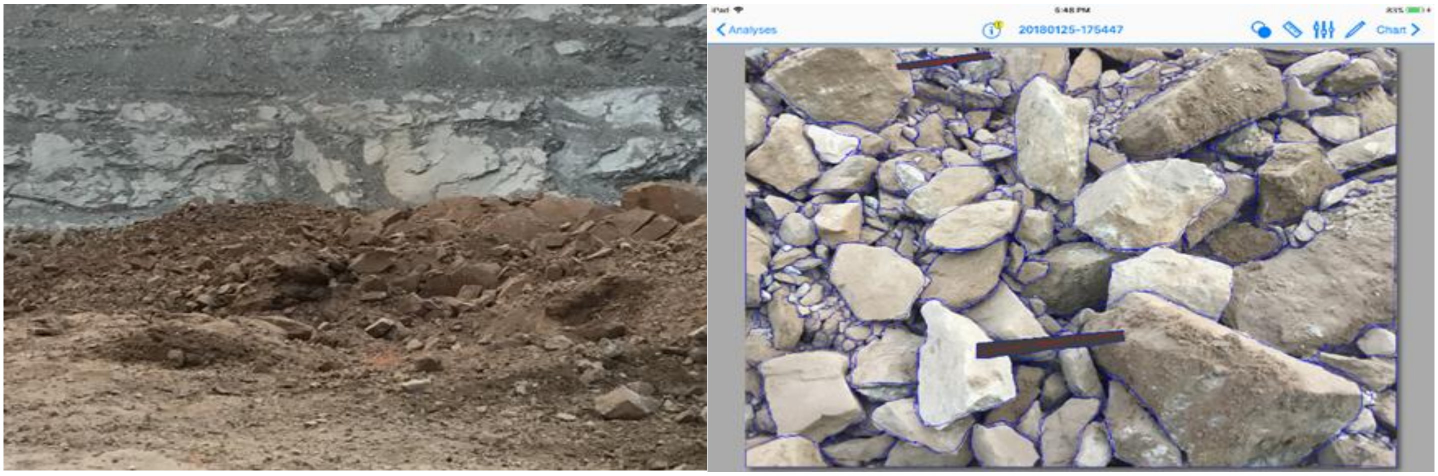
Parameters	**Shot 1**	**Shot 2**	**Shot 3**	**Shot 4**
Spacing(m)	3.5	3.6	3.5	3.8
Burden(m)	3.0	3.1	3.0	3.2
Hole Diameter(mm)	115	115	115	115
Bench Height(m)	6	6	6	6
Stemming Height(m)	2.8	2.8	2.8	2.8

Table 2: Summary of Explosive Parameters of A-Zone Eshiem Pit

Parameter	**Shot 1**	**Shot 2**	**Shot 3**	**Shot 4**
Volume blasted per hole (m^3/hole)	63	66.96	63	72.96
Powder Factor(kg/m^3)	0.60	0.57	0.72	0.65
Charged length(m)	4.0	4.0	4.0	4.0
Average Quantity per hole (kg/hole)	54	55	54	56

Table 3: Rock Parameters at A-Zone Eshiem Pit

Parameters	**A-Zone Eshiem**
Uniaxial Compressive Strength (MPa)	48.9
Bulk density (tonnes/m^3)	1.40
General Rock description	Moderately strong
Rock factor	5.0



(a) Image Acquisition (b). Scale Setting and Automatic Delineation

Figure 1: Image Analysis Procedure in WipFrag® Software

Before any drilling operation, marking-out was the first activity to be done. The marking-out was done using a tape measure and a spray maker to mark-out all the spacing and burdening of 3.5 m and 3 m respectively. Drill rigs were used for drilling. Blast holes were drilled to a depth of 6 m depth and a subdrill of 0.8 m with diameter of 115 mm in staggered pattern. Holes that exceeded designated requirements were backfilled with drill cuttings, the booster was then primed and lowered carefully into the hole. The booster used was pentolite 250 g. The holes were then charged with Riomex 8000.

Rock chippings were used to stem the charged hole to a depth of 6 m. The stemming enhances fragmentation and rock displacement by reducing premature venting of high-pressure explosion gases to the atmosphere and it also produces better- fragmented rocks. Tie-in was then done with 500 ms down-hole delay, 25 ms surface delay and 42 ms inter-hole delay. After that, they made sure that the demarcated area and the pit were made free from workers and equipment before the blast was initiated. NONEL was the initiation system used. Images of muckpile were taken using a digital camera of high resolution. Photographs were captured to cover the entire excavation history of each blast. The images were fed into the WipFrag® software and analysed using the image analysis technique as shown in Figure 1.

The results were compared to know the model with better prediction. Fragments less or equal to 17 mm were considered as fine, and fragments 800 mm in diameter are considered as boulders at the mine, taking into consideration the size of the gape of the crusher. Ms Excel was used for the prediction and also used to determine the Root Mean Square Error to analyse the performance of the model.

3.0 RESULTS AND DISCUSSIONS

3.1 Fragmentation Analysis

The mean sizes of the actual blast were analysed by the WipFrag® software. Table 4 summarizes the mean sizes of the actual blast.

The top sizes passing for all the blasts were less than the size of the gape which is 800 mm, which means no boulders were produced from any of the blasts. Fig. 2 represents fragmentation analysis of blast 1.

Table 4: Mean Sizes of the Actual Blasts

Blast	**Mean Sizes (mm)**
1	128.84
2	153.41
3	163.85
4	184.70

3.2 Fragmentation Prediction

This section summarises the fragmentation prediction results using KCO, Kuz-Ram and Modified Kuz-Ram models.

For blast 1 the actual quantity of fines produced was 1.67% and it was obtained from table 5, Fragments less or equal to 17 mm are considered as fines. The Kuz-Ram predicted 10.46%, KCO predicted 18.59% and the modified Kuz-Ram predicted 9.29% fines to be produced from blast 1 and it was obtained from Table 5 sizes less or equal to 17 mm are considered as fines, so it was calculated by summing up all the fragment sizes that are below 17 mm. There were no boulders produced from any of the blasts since at a gape size of 800 mm of the crusher, there were no fragment sizes greater than 800 mm. There was a 100% passing of the materials. At 800 mm, KCO predicted 96.52% passing, Kuz-Ram predicted 97.43% passing and Modified Kuz-Ram predicted 97.92%. Table 5 summarises the results obtained from the prediction with the models.

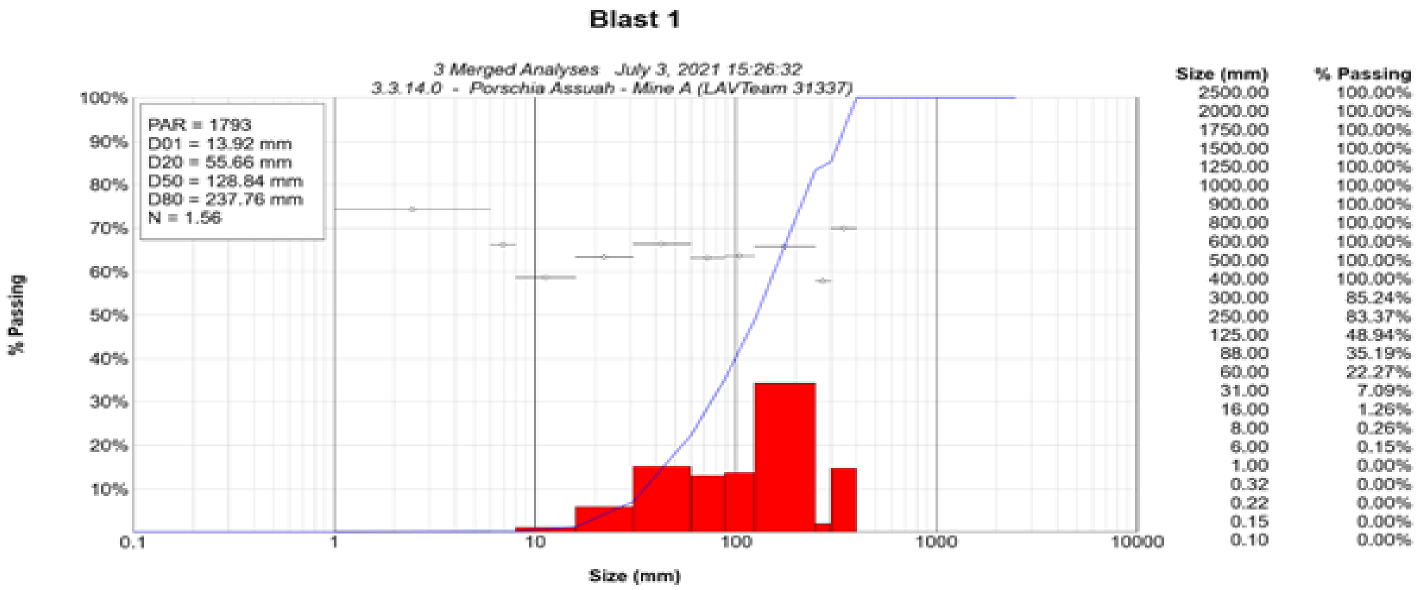


Figure 2: Fragmentation Analysis of Blast 1

Table 5: Summary of Results from the Prediction Models for Blast 1

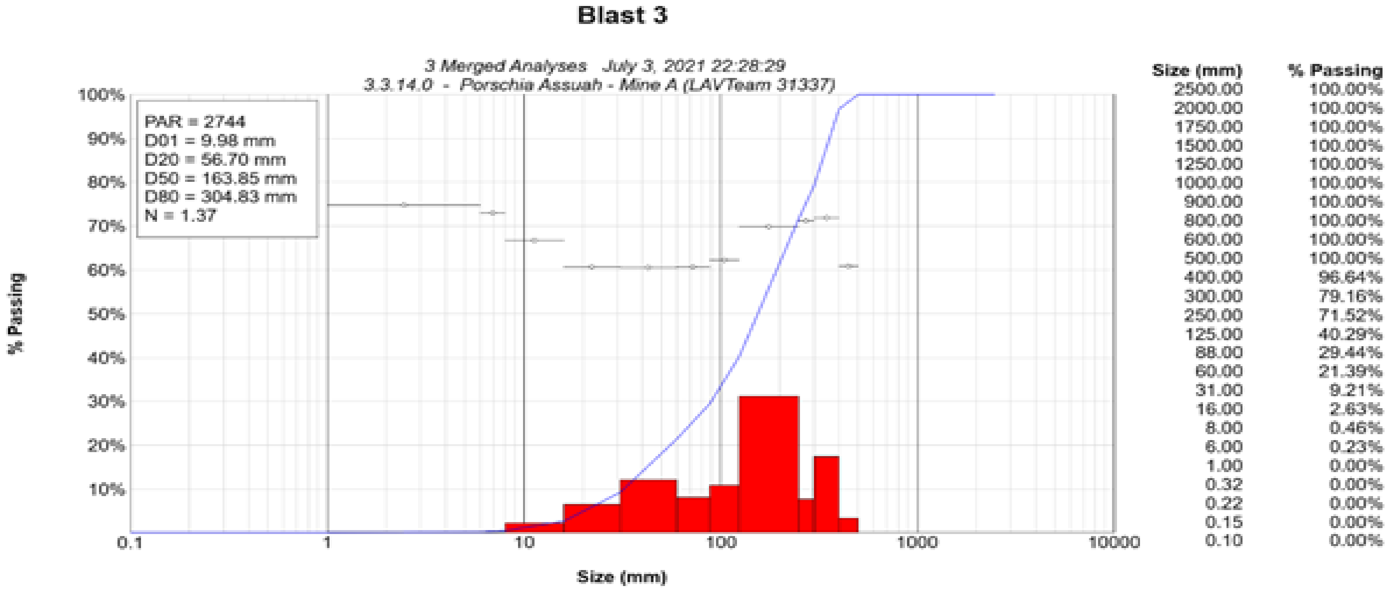
Size (mm)	%PASSING	KCO	KUZ-RAM	MODI-KUZ-RAM
2500	100.00	100.00	100.00	100.00
2000	100.00	99.98	99.99	100.00
1750	100.00	99.92	99.98	99.99
1500	100.00	99.77	99.92	99.96
1250	100.00	99.38	99.73	99.83
1000	100.00	98.39	99.04	99.30
900	100.00	97.63	98.43	98.79
800	100.00	96.52	97.43	97.92
600	100.00	92.28	93.22	94.00
500	100.00	88.31	89.07	89.96
400	100.00	82.07	82.51	83.37
300	85.24	72.14	72.24	72.85
250	83.37	65.16	65.16	65.52
125	48.94	39.54	39.49	38.94
88	35.19	29.49	29.18	28.41
60	22.27	21.22	20.47	19.62
31	7.09	12.15	10.68	9.96
16	1.26	7.12	5.42	4.91
8	0.26	4.37	2.62	2.31
6	0.15	3.60	1.93	1.68
1	0.00	1.25	0.29	0.23
0.32	0.00	0.71	0.08	0.07
0.22	0.00	0.60	0.06	0.04
0.15	0.00	0.51	0.04	0.03
0.1	0.00	0.43	0.02	0.02

Size (mm)	% Passing
2500.00	100.00%
2000.00	100.00%
1750.00	100.00%
1500.00	100.00%
1250.00	100.00%
1000.00	100.00%
900.00	100.00%
800.00	100.00%
600.00	100.00%
500.00	100.00%
400.00	100.00%
300.00	94.58%
250.00	85.41%
125.00	49.52%
88.00	33.09%
60.00	22.3%
31.00	10.11%
16.00	3.6%
8.00	1.21%
6.00	0.73%
1.00	0.00%
0.32	0.00%
0.22	0.00%
0.15	0.00%
0.10	0.00%

Figure 2: Fragmentation Analysis of Blast 2

Table 6: Results from The Prediction Models for Blast 2

Size (mm)	%PASSING	KCO	KUZ-RAM	MODI-KUZ-RAM
2500	100.00	99.98	100.00	100.00
2000	100.00	99.91	100.00	100.00
1750	100.00	99.81	100.00	100.00
1500	100.00	99.61	100.00	100.00
1250	100.00	99.21	100.00	100.00
1000	100.00	98.34	100.00	100.00
900	100.00	97.74	100.00	100.00
800	100.00	96.88	100.00	100.00
600	100.00	93.90	99.99	100.00
500	100.00	90.90	99.96	99.40
400	100.00	86.36	98.51	97.54
300	94.58	78.84	88.53	91.30
250	85.41	73.26	81.89	84.66
125	49.52	49.79	50.04	49.64
88	33.09	38.92	35.58	33.80
60	22.3	29.10	23.45	21.08
31	10.11	17.30	10.71	8.68
16	3.6	10.38	4.68	3.42
8	1.21	6.26	1.93	1.27
6	0.73	5.13	1.33	0.84
1	0.00	1.71	0.13	0.06
0.32	0.00	0.94	0.03	0.01
0.22	0.00	0.78	0.02	0.01
0.15	0.00	0.66	0.01	0.00
0.1	0.00	0.55	0.01	0.00



Size (mm)	% Passing
2500.00	100.00%
2000.00	100.00%
1750.00	100.00%
1500.00	100.00%
1250.00	100.00%
1000.00	100.00%
900.00	100.00%
800.00	100.00%
600.00	100.00%
500.00	100.00%
400.00	96.64%
300.00	79.16%
250.00	71.52%
125.00	40.29%
88.00	29.44%
60.00	21.39%
31.00	9.21%
16.00	2.63%
8.00	0.46%
6.00	0.23%
1.00	0.00%
0.32	0.00%
0.22	0.00%
0.15	0.00%
0.10	0.00%

Figure 3: Fragmentation Analysis of Blast 3

Table 7: Results from the Prediction Models from Blast 3

SIZE (mm)	%PASSING	KCO	KUZ-RAM	MODI KUZ-RAM
2500	100.00	99.97	100.00	100.00
2000	100.00	99.86	99.99	100.00
1750	100.00	99.72	99.98	99.99
1500	100.00	99.45	99.92	99.96
1250	100.00	98.89	99.73	99.83
1000	100.00	97.67	99.04	99.30
900	100.00	96.83	98.43	98.79
800	100.00	95.63	97.43	97.92
600	100.00	91.32	93.22	94.00
500	100.00	87.42	89.07	89.96
400	96.61	81.37	82.51	83.37
300	79.16	71.77	72.24	72.85
250	71.52	64.97	65.16	65.52
125	40.29	39.48	39.49	38.94
88	29.44	29.25	29.18	28.41
60	21.39	20.78	20.47	19.62
31	9.2	11.54	10.68	9.96
16	2.63	6.60	5.42	4.91
8	0.46	3.83	2.62	2.31
6	0.23	3.10	1.93	1.68
1	0.00	0.97	0.29	0.23
0.32	0.00	0.52	0.08	0.07
0.22	0.00	0.43	0.06	0.04
0.15	0.00	0.36	0.04	0.03
0.1	0.00	0.29	0.02	0.02

The Modified Kuz-Ram predicted closest to the actual results.

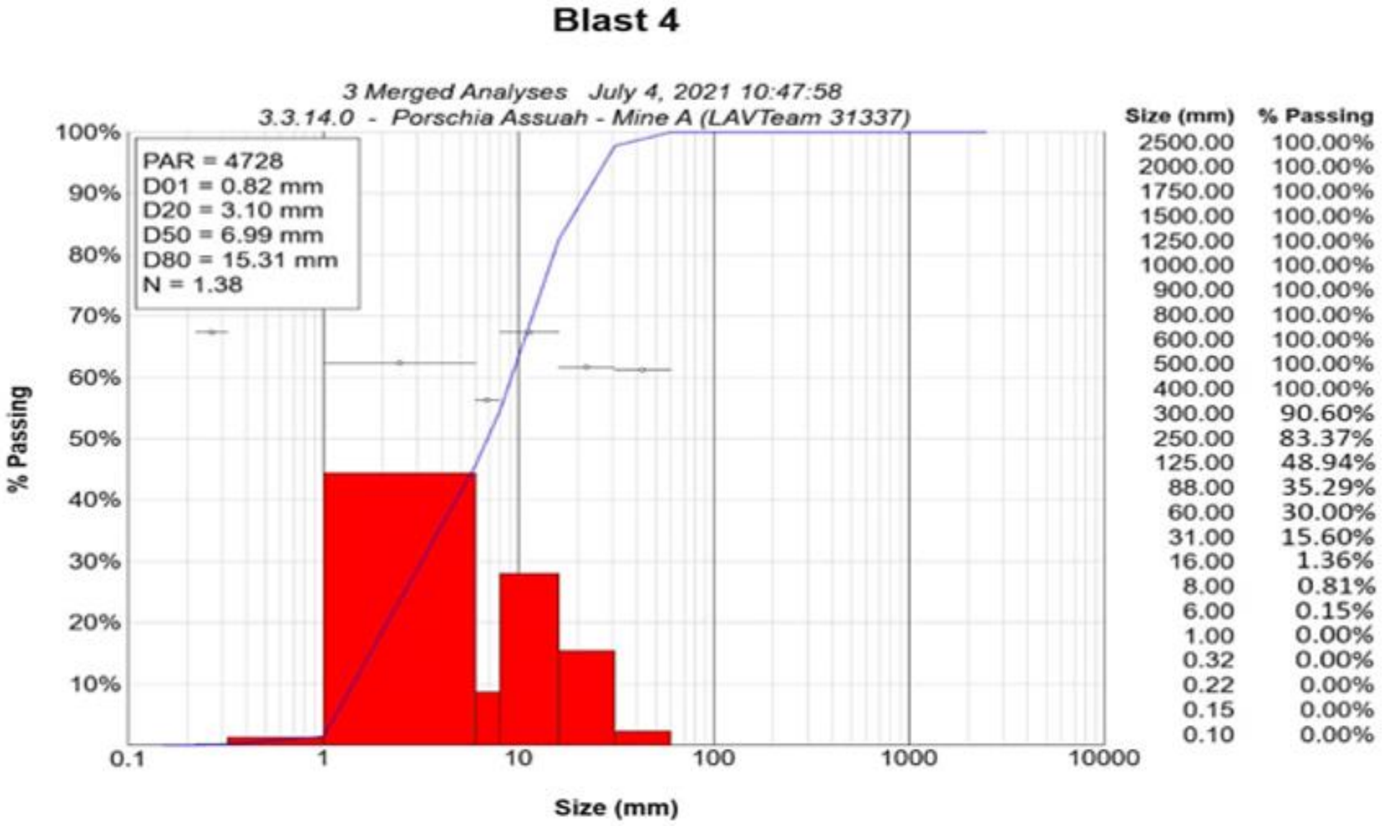
Fig. 2 shows the fragmentation analysis of blast 2. For blast 2, the actual quantity of fines produced was 5.54% and it was obtained from in Table 6. Fragments less or equal to 17 mm are considered as fines, so it was calculated by summing up all fragments sizes below 17 mm. The Kuz-Ram predicted 8.14%, KCO predicted 26.41% and the modified Kuz-Ram predicted 5.612% to be produced from blast 2. There were no boulders produced from any of the blasts since at a gape size of 800 mm of the crusher, there were no fragment sizes greater than 800 mm. There was a 100% passing of the materials. At 800 mm, KCO predicted 96.88% passing, Kuz-Ram predicted 100% passing and Modified Kuz-Ram predicted 100%.

Blast 3

For blast 3 the actual quantity of fines produced was 3.32%. The Kuz-Ram predicted 10.46%, KCO predicted 16.1% and the modified Kuz-Ram predicted 9.29% fines to be produced from blast 3 and it was obtained from table 4.6, Fragments less or equal to 17 mm are considered as fines, so it was calculated by summing up all the fragment sizes below 17 mm. There were no boulders produced from any of the blasts since at a gape size of 800 mm of the crusher, there were no fragment sizes greater than 800 mm there was a 100% passing of the materials. At 800 mm, KCO predicted 95.63% passing, Kuz-Ram predicted 97.43% passing and Modified Kuz-ram predicted 97.92%. Table 6 summarises the results obtained from the prediction with the models for Blast 3.

Predicting fragment sizes for blast 3, the Modified Kuz-Ram predicted closest to the actual results. Fig. 4 is a graph of the predicted results from the Models for Blast 4.

For blast 4 the actual quantity of fines produced was 1.82%% and it was obtained from Table 8, Fragments less or equal to 17 mm are considered as fine. The Kuz-Ram predicted 6.54%, KCO predicted 19.28% and the modified Kuz-Ram predicted 4.41% fines to be produced from blast 3 and it was obtained from Table 8, fragments less or equal to 17 mm are considered as fines so it was calculated by summing up the fragment sizes that are below 17 mm. There were no boulders produced from any of the blasts since at a gape size of 800 mm of the crusher, there were no fragment sizes greater than 800 mm there was a 100% passing of the materials. At 800 mm, KCO predicted 96.45% passing, Kuz-Ram predicted 98.80% passing and Modified Kuz-ram predicted 99.96%.



PAR = 4728
D01 = 0.82 mm
D20 = 3.10 mm
D50 = 6.99 mm
D80 = 15.31 mm
N = 1.38

Size (mm)	% Passing
2500.00	100.00%
2000.00	100.00%
1750.00	100.00%
1500.00	100.00%
1250.00	100.00%
1000.00	100.00%
900.00	100.00%
800.00	100.00%
600.00	100.00%
500.00	100.00%
400.00	100.00%
300.00	90.60%
250.00	83.37%
125.00	48.94%
88.00	35.29%
60.00	30.00%
31.00	15.60%
16.00	1.36%
8.00	0.81%
6.00	0.15%
1.00	0.00%
0.32	0.00%
0.22	0.00%
0.15	0.00%
0.10	0.00%

Figure 4: Fragmentation Analysis of Blast 4

Table 8: Results from The Prediction Models for Blast 4

Size (mm)	%PASSING	KCO	KUZ-RAM	MODI-KUZ-RAM
2500	100.00	99.98	100.00	100.00
2000	100.00	99.90	100.00	100.00
1750	100.00	99.80	100.00	100.00
1500	100.00	99.59	100.00	100.00
1250	100.00	99.14	100.00	100.00
1000	100.00	98.15	99.98	100.00
900	100.00	97.45	99.93	99.99
800	100.00	96.45	98.80	99.96
600	100.00	92.80	98.61	99.46
500	100.00	89.43	96.57	98.19
400	100.00	84.11	91.98	94.51
300	90.6	75.41	82.37	85.22
250	83.37	69.08	74.57	76.96
125	48.94	43.97	42.66	41.57
88	35.29	33.23	29.70	27.60
60	30	24.04	19.28	16.92
31	15.6	13.65	8.68	6.87
16	1.36	7.92	3.77	2.69
8	0.31	4.66	1.55	0.99
6	0.15	3.78	1.07	0.66
1	0.00	1.21	0.10	0.05
0.32	0.00	0.65	0.02	0.01
0.22	0.00	0.54	0.01	0.01
0.15	0.00	0.45	0.01	0.00
0.1	0.00	0.37	0.01	0.00

Table 8: Estimated RMSE Result of the Models at Cut 3 Pit

Blast	KCO	KUZ-RAM	MODI KUZ-RAM	BEST PREDICTOR
Blast 1	7.03	6.78	6.5	Modified Kuz-Ram
Blast 2	6.16	1.82	0.95	
Blast 3	5.07	4.39	4.06	
Blast 4	6.37	4.31	4.05	

Table 10: Summary of Correlation and Regression Analysis Results

BLAST NO	KCO	KUZ-RAM	MODI KUZ-RAM	BEST PREDICTOR
Blast 1	98.32	98.44	98.53	Modified Kuz-Ram
Blast 2	99.24	99.36	99.45	
Blast 3	98.72	99.87	99.96	
Blast 4	98.36	99.93	99.94	

3.3 Models Performance

Root Mean Square Error Analysis was done for the results and in all cases, the Modified Kuz-Ram had the lowest deviation from the actual results. Table 8 depicts the estimated results from RMSE. Correlation and Regression Analyses were also done to show the strength of the relationship between the predicted values and the actual values. And in all cases, the Modified Kuz-Ram showed the strongest relationship with the actual values. Table 10 summarises the results obtained from correlation and regression analysis.

The Modified Kuz-Ram Model can be used for fragmentation prediction and blast optimization at Eshiem pit of Aliko Resources Limited, Ghana corroborating with some results obtained in [12] for similar mining and technical conditions

The results of the predictions from all the models had a stronger correlation, they should be taken into consideration when designing blast for the mine with sufficient knowledge of the rock characteristics.

4.0 CONCLUSIONS

From the results and analysis, the conclusions made were:

i. All the models predicted very well and close to the mean size passing of the actual blast. The Modified Kuz-Ram predicted best with the lowest Root Mean Square Error(RMSE) values ranging between 0.95 and 6.5 whilst the worst estimator, KCO, produced RMSE values between 5.07 and 7.03.
ii. An insignificant quantity of boulders was predicted.
iii. The validation trial results with Correlation and Regression revealed a strong relationship between the predicted values and the actual values. In all cases, the Modified Kuz-Ram showed the strongest relationship with the actual values between 99.45 and 99.96.

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