Limestone Production Optimization by Fragmentation Control – Case Study of Bissel Quarry

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ABSTRACT

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Blasting is one of the most economical production excavation method in hard rock mines. Few studies about blasting fragmentation exist due to lack of reliable fragmentation data. Many researchers have attempted to predict blasting fragmentation using the Kuz-rams model, an empirical fragmentation model suggested by Cunningham. This investigation is to relate the blasting parameters such as the drill hole diameter, the burden, spacing, charge length and explosive weight to the fragmentation size distribution in order to obtain controlled fragmentation blasting.

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This was a clear indication that application of these parameters can be used to solve the issue of large boulders currently experienced at the Bissel Quarry leading to required size reduction and avoiding secondary blasting which is costly in blasting.

Keywords: Blasting, Kuz-rams model, blasting parameters, Presplitting

1. INTRODUCTION

Rock fragmentation design models plays a key role in the evaluation of efficiency and productivity of quarry blasting. Regular assessment of rock fragmentation is needed to control it. If rock fragmentation is not controlled, it can increase production cost and delay the quarrying process due to unnecessary secondary blasting or crushing. Therefore, blasting design should take into account the findings of rock fragmentation assessment to cut down the mining cost and shorten the work time. Drilling and blasting cost in open pit mines represent 15-20% of the total mining cost. Apart from the direct costs, blasting efficiency also influences down the line mining costs.
Firing pattern that provides a pathway for the detonation wave of initiation for the explosive charged in the holes. Several models have been developed for the prediction of fragment size distributions from specific blast designs. Kuz-Ram and adapted the Rosin–Rammler model were chosen for these research work due to the following reasons: Kuz-Ram is the most commonly used models in industrial applications, The data required as input for these models are easier to gather, The adopted Rosin–Rammler model was used to predict the fraction of materials retained on the screen

2. OBJECTIVE

The objective of this research was to define the main blasting parameters values in order to obtain Optimal fragmentation after blasting, improving limestone productivity and improving the stability of the excavated walls at the quarry.

3. OVERVIEW

The Kuznetsov Equation

The amount of breakage that occurs with a known amount of explosive energy can be estimated using the Kuznets's equation. The original question, developed by kuznetsov (1978), was modified by Cunningham (1987) for ANFO base explosive.

$$X_m = AK^{-0.8}Q_E^{0.167}\left(115/S_{ANFO}\right)^{0.633} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where X_m is the mean fragmentation size (cm). A the rock factor (or blastability index) , K the powder factor or specific charge (kg of explosive/m^3 of rock), Q_E the mass of explosive being used (kg), S_{ANFO} the relative weight strength of the explosive relative to ANFO

The blastability index is calculated from an equation originally developed by Lilly (1986). It is used to modify the average fragmentation base on the rock type and blast direction.

$$A=0.06(RMD + JF+ RDI+ HF) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where A is the blastability index

RMD the rock mass description, JF the joint factor, RDI the rock density index, HF the hardness factor

These factors are calculated from geological data such as; in-situ, block size, jointing spacing, joint orientation, and rock specific gravity, young's modulus unconfined compressive strength etc.

Powder factor or specific charge is the mass of the explosive being used (kg) to break a cubic meter volume of rock. $K=Q_E/ V_O$ …………………………………………….. (3)

Where Q_E is the mass of explosive being used (kg),V_0 the rock volume (m^3) broken per blast hole

$$V_O = \text{burden } (B) * \text{spacing } (S) * \text{bench height } (H)$$

The Rosin & Rammler Equation

The size distribution of the material is calculated from the Rosin & Rammler question especially in mineral processing are (Rosin& Rammler 1933)

$$y = 100\left(1 - e^{-(x/x_c)^n}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

Where Y is the percentage of the material less than the size X (%) X diameter of fragment (cm)

X_C the characteristic size (cm) n the Rosin & Rammler exponent e the base of natural logarithm since the kuznetsov formula gives the screen size X_m for which 50% of the material would pass, the characteristic size is calculated from the average size for use in the Rosin & Rammler equation by substituting $X=X_m$ and Y = 0.5 into Equation 4 one find that

$$X_C = \left(\frac{X_m}{0.693^{\frac{1}{n}}} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Average particle size of the material obtained from a blasting operation is not enough information explaining the efficiency of the operation. Uniform particle size distribution is an important parameter that has to be considered.

The adapted Rosin–Rammler equation

$$R_m = \exp\left[-0693 - \left(\frac{x}{x_m} \right)^n \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where R_m =mass fraction retained on screen opening – boulders, X =screen opening; n=uniformity index, usually between 0.7 and 2.The uniformity coefficient is calculated by Cunningham (1987), established the applicable uniformity taking into consideration the impact of such factors as: blast geometry, hole diameter, burden, spacing, hole lengths and drilling accuracy. The exponent n for the Rosin % Rammler equation is estimated as follows

$$n = \left(2.2 - 14\frac{B}{D} \right) \left[\frac{1 + \frac{S}{B}}{2} \right] \left(1 - \frac{W}{B} \right) \left(\frac{L}{H} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where B is the blasting burden (m) S, the blast hole spacing (m) W, the standard deviation of drilling accuracy (m) D, the blast hole diameter (mm) L, the total charge length (m) H, the bench height (m).

4. DATA COLLECTION

Data for the research work were obtained from the Bissel quarry of the East African Portland Cement Company Limited (EAPCC). They were acquired through field measurements and extraction from the geological files and documents from the mine. The data include the geometric blast design and explosive data of the lasts studied and rock parameters of the pits where the study was conducted.

Table 4.1: Rock and Explosive Parameters at Bissel Quarry

Parameter	Value
Bulk density (tonnes/m3)	2.51
Volume of blasted rock per drill hole (m3)	165
Nature of Blasted face	Highly rugged
Average quantity per hole (kg/hole)	57
Powder factor (kg/m3)	0.3 varies
Loading density (kg/m)	9.5
Average charge length (m)	7.0
Stemming (m)	4.0
Base charge height (m)	1.0
Column charge height (m)	6.0
(S)Relative weight strength of explosives (ANFO)	100
Fly rock factor	1 for normal blasting

Table 4.3: Geometric Blast Parameters

Parameter	Value
Spacing (m)	3.0
Bench height (m)	10.0
Burden (m)	3.0
Average hole depth (m)	11.0
Hole diameter (mm)	150.0
Average final stemming height (m)	4.0
Drilling deviation(m)	0.015
Average sub drill length (m)	1.0
Blasting pattern	rectangular

5. RESULTS AND DISCUSSION

Rock fragmentation prediction using collected data

After the data were gathered, the geometric, explosive and rock parameters were used for the prediction of the fragmentation output for each of the blasts considered. The prediction was done using the Kuz-Ram and adapted the Rosin–Rammler model using excel Calculator model.

Volume of boulder produced per hole =volume of rock blasted per hole x % of boulders produced

165x0.1625=26.81m³, Tonnage of large boulders= volume of total boulders x bulk density

26.81x2.51=57.65 tonnes per hole

Total tonnage of boulders per round of blast=Tonnage of large boulders x number of holes

57.65x20=1152.94tonnes per round.

The results of the model calculator are shown in fig 5.1, 5.2 with the parameters in red representing the calculated values while the rest are the values entered to the calculator to generate the desired parameters based from Kuz ram and Rosin Rammler empirical models.

Design parameters calculations

Burden (B) a) Using Scott and cocker, 1996 formula, $B = 19.7 \times d^{0.79} = 19.7\times 0.150^{0.79} = 4.4m$

Where; d = diameter of blast hole in meters

a. Also according to Wesley L. Bender burden should be 24 to 36 times of the explosive diameter. Hence, B = (24+36) x 0.150/2 = 4.3m: approximately 4m.

From the above calculations, the influence of the blasthole diameter on determining the burden size can be noted. From research, it has been noted that the increase in the blasthole diameter will result to increase in the burden size. This can translate to an increase in blasting related problems like fly rocks, vibration and fragmentation hence the need to analyze the blast well for effective production.

Spacing (E)

From the mathematical model used to calculate burden, we have obtained a burden of 3m

According to Wesley L. Bender, Spacing **= (1.0 to 2.0)** times the burden,

Therefore 1.0x 4m =4m

Stemming (h_o)

According to Wesley L. Bender, h_o = 0.3×Bench height = 0.3×12 (sub drill included) =3.6m

Sub drilling (u)

Konya and Walter, 1990 defined sub drill as, u=0.3×burden =0.3×4 =1.2 m

Explosive charge length (l)

l = Blast hole length +sub drill– stemming length (Konya and Walter, 1990).

= 10m – 3.3m+1.2m = 7.9mapproximate 8 m

Q_E the mass of explosive being used (kg)

$$Q_E = \text{volume x density}$$

$$QE = \pi r^2 h \text{ x } 840kg/m^3$$

$$= \pi(\frac{150}{1000x2})^2 \text{x8m x 840kg/m}^3$$

$$= 118.8kg$$

Prediction of blast fragments using defined blast design parameters

By using the developed excel model to predict the mean fragment, the uniformity index and fraction of material retained as boulders. From the parameters calculated using other researchers' empirical formulas it was observed that their application in prediction of the mean fragment yielded a mean of 28.35cm with a lower percentage material retained of 0.649%. This is a great improvement compared to the parameters already in use at the quarry.

Figure 5.1: shows blast hole parameters currently in use at Bissel quarry. It can be seen that the mean fragment produced from the quarry blast were 45.15 cm, the percentage of material retained on the crusher were 16.25%. This percentage is equivalent to 1,152.94 tonnes per round of 20 blast holes. The crusher gape of the quarry is 80cm. It means that 16.25% of the blasted limestone were larger in size than the crusher gape. This is an indication of the presence of large boulders observed currently at the quarry.

Figure 5.2 show the blast hole parameters prediction defined for use at Bissel quarry. From the parameters calculated using other researchers' empirical formulas it was observed that their application in prediction of the mean fragment and material retained yielded a mean of 28.35cm with a lower percentage material retained of 0.649%. This is a great improvement compared to the current parameters in use at the quarry. This implies that the ore will be highly fragmented with good top size which is less size than the crushers gape and hence an insignificant boulders would be produced per blast.

In order to achieve the best possible profile for the final excavated wall presplitting technique this research recommended its use in Limestone mines. This involves the drilling of closely spaced holes at the planned excavation perimeter which are lightly loaded with explosive in order to generate an appropriate borehole pressure

6. CONCLUSION

Kuz Ram and Rosin Rammler being empirical models, which infers finer fragmentation from higher energy input, it is more about guidance rather than accuracy. The results obtained remain a starting point to give an overview of what is expected of an adjustment to a preexisting blast design. It can therefore act as a datum for evaluating different designs, investigating the effect of changing certain variables and predicting the size distribution to be produced by the design.

Furthermore, the simplicity of the model and the relative ease of gathering the data required to serve as feed to the model remains a major advantage of the model and putting it on the forefront of fragmentation prediction models. A general overview of results from various designs can also be examined using this simple model. The most important function of Kuz–Ram is to guide the blasting engineer in thinking through the effect of various parameters when attempting to improve blasting effects.

By using the developed excel model calculator which adopted both Kuz ram and Rosin Rammler models, the larger boulders being produced at the Limestone quarry can be significantly reduced. The model calculator is effective and the values can be adjusted to suit the desired bench height requirement of even other Limestone quarries.

Presplitting was suggested in order to obtain a better profile after each blast. The advantage of this method over others is that it can employ the same diameter hole used for production drilling.

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APPEDIX

	A	B	C	D	E	F	G
4	**BISSIL LOW CARBONATE LIMESTONE BLAST DESIGN**						
5	**A** the rock factor (or blastability index)						9
6	**V** volume of blasted rock, m cubic						165
7	**K** Powder factor						0.34545
8	**Qe** Mass of explosive charge per hole, per kg						57
9	**E** Relative weight strength of explosive (ANFO = 100)						100
10	**U** sub drill						0.9
11	**B** Burden(m)						3
12	**D** Hole Diameter (mm)						150
13	**W** Standard deviation (m)						0.15
14	**S** Spacing						3
15	**Lc** Column Charge Length						6
16	**Lb** Bottom Charge Length (m)						1
17	**L** Total Charge Length (m)						7
18	**H** Bench Height (m)						10
19	**Xm** Mean fragmentation size (cm)						45.1458
20	**X** Crusher gape(cm)						80
21	**N** Uniformity index						1.68515
22	**Xo** Characteristic size						56.1215
23	**Rx** The fraction of rock retained on the screen						0.16245
24	**Øx** Distribution function						0.83755
25	**ho** Stemming(m)						4

Sheet1 Sheet2 Sheet3

Figure 5.1: Blast Hole Parameters Currently in Use at Bissel

1	**BISSIL LOW CARBONATE LIMESTONE BLAST DESIGN**	
2		
3		
4		
5	**A** the rock factor (or blastability index)	9
6	**V** volume of blasted rock, m cubic	165
7	**K** Powder factor	0.72
8	**Qe** Mass of explosive charge per hole, per kg	118.8
9	**E** Relative weight strength of explosive (ANFO = 100)	100
10	**U** sub drill	1.2
11	**B** Burden(m)	4
12	**D** Hole Diameter (mm)	150
13	**W** Standard deviation (m)	0.15
14	**S** Spacing	4
15	**Lc** Column Charge Length	7.2
16	**Lb** Bottom Charge Length (m)	1
17	**L** Total Charge Length (m)	8.2
18	**H** Bench Height (m)	10
19	**Xm** Mean fragmentation size (cm)	28.3544
20	**X** Crusher gape(cm)	80
21	**N** Uniformity index	1.91234
22	**Xo** Characteristic size	34.3483
23	**Rx** The fraction of rock retained on the screen	0.00649
24	**Øx** Distrion function	0.99351
25	**ho** Stemming(m)	3

Figure 5.2: Blast Hole Parameters Prediction for Use at Bissel Quarry.