Fragmentation Optimization in Aggregate Quarrying in Sri Lanka

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Abstract
Blasting is an essential task in aggregate quarrying industry for rock fragmentation. Rock fragmentation, which is the fragment size distribution of blasted rock material, is used in mining industry as an index to estimate the effect of bench blasting. The extent of rock fragmentation in the blasting process influence the efficiency of all the subsystems such as loading, hauling and crushing in mining operations. To achieve an optimum rock fragmentation a blast with optimized controllable parameters should be designed so that the effects of the uncontrollable parameters could be minimized. Many countries such as Australia, USA, Canada, UK and Russia use Numerical Modelling based software for bench blast simulations, in order to optimize the blasts. However, in Sri Lanka up to now, these methods are not used, and ordinary methods using the experience from previous blasting sequences are practiced. The main objective of this research is to design the most economic blast that will give the optimum fragmentation, using "JKSimBlast – 2DBench" software. To validate the modelling, fragmentations from five blasts were assessed using "Split Desktop" software, and the results obtained were compared with the predictions carried out by JKSimBlast software followed by Kuz-Ram fragmentation model.

Keywords: Blasting, JKSimBlast, Kuz-Ram model, Simulation, Split Desktop

1. Introduction

Rock fragmentation has been the concern of many researchers, because it is considered as the most important aspect of production blasting, since it affects the costs of drilling, blasting and efficiency of all the subsystems such as loading, hauling and crushing in mining operations [1-4]. Today, researchers suggest the "mine to mill" blasting approach that is defined as optimization of the blast design to maximize the overall profitability rather than individual operations [5,6]. Several studies have been conducted on prediction of blast fragmentation. The parameters that determine fragmentation upon blasting can be divided into controllable parameter and uncontrollable parameters [4,5]. For instance, blast design parameters and explosive parameters are controllable parameters, whereas mechanical and physical properties of rock and rock mass structure are uncontrollable parameters [7,8].

Once the blast has been carried out, it is necessary to analyse the results, which gives the directions for successive modifications of the blast parameters for the following blasting rounds. The factors that must be considered to evaluate the results of a blast are: fragmentation, geometry of the muck pile, state of the remaining rock, assessment of the results obtained by blast monitoring systems and environmental problems due to blasting (ground vibration, air – blast overpressure generation, fly rock and dust) [9].

To achieve an optimum rock fragmentation a blast with optimized controllable parameters should be designed so that the effects of the uncontrollable parameters could be minimized [10]. The controllable parameters for optimum fragmentation can be fixed after conducting of trial blasts in a mine and assessment of fragmentation. Quantification of fragmentation refers to the measurement of fragmentation, in order to predict the necessary corrections in the blast design. When these corrections are done to the blast design, the output should be in acceptable fragmentation range. Rock fragmentation obtained as an outcome of blasting operations is said to be optimum, when it contains maximum percentage of fragments in the desired range of size. The desired size usually means the size that is demanded and can be effectively utilized by the consumers for further operations devoid of any processing.

In this research, "JKSimBlast" software has been used to model rock blast [11]. "JKSimBlast" is a suite of powerful modular tools for the simulation and management of blasting data, developed by JK Tech of Brisbane, Australia. 2DBench, 2DRing, 2DFace, JKBMS, 2DView, TimeHEx, Design Importer, StockView and Units are stand-alone modules of JKSimBlast- 2DBench, 2DRing and 2DFace are used for the design and editing of blasts in mining and related applications. The software enables simulation and information management for blasting in mines and related operations. The modular system is introduced for engineers who need to standardize their control of blasting, by integrating all tasks associated with modelling, simulation, analysis and optimization, including the storage and manipulation of models, data and results, within one system [12].

More specifically 2DBench which is the open cut blast simulation module of JKSimBlast is used in this study. It allows the user to lay out a blast model which is consisted of blast holes, decks, downhole and surface delays and connections, and then to run a detonation simulation [12]. Basic analyses of volume, tonnage, powder factor, component and total costs can be calculated for the blast simulation. In the study, an existing bench blast is optimized by changing spacing, burden, stemming height, explosive height, drilling pattern and downhole delay [13].

2. Methodology

2.1 Site Visit

The first step of the project was to select a site to optimize a bench blast. A quarry belongs to Metal Mix Pvt Ltd, located at Galpatha, Kalutara, Sri Lanka was selected to execute the blasting experiments related to this research. The quarry is a well-established one, having an "IML-A" category mining license. The quarry is situated in the southern section of the large rock outcrop located within the Trigstand Estate at Galpatha in Kalutara district.

Geologically, the area belongs to the Highland Complex of Sri Lanka. The rocks encountered in and around the area on regional scale are Charnockites, Charnockites biotite gneiss, hornblende biotite gneiss and garnet Sillimanite biotite gneiss. [14] The main rock in the quarry is generally light greasy grey in colour and medium grained Charnockites Biotite gneiss. These rocks are widely encountered in the quarry. During the field visits, important information about the blasting parameters such as space, burden, bench height, diameter of the drill hole, bench level, floor level, under drilling, hole dip, number of rows per blast, number of holes per row, stem height, explosive height, explosive type, number of cartridge per hole were collected. Also, rock samples were collected at different locations within the quarry, in order to carry out rock testing to determine the rock properties such as, tensile strength, compressive strength, and specific gravity.

2.2 Rock Testing

Rock samples were subjected to uniaxial compressive strength test (UCS), Brazilian disk test, and specific gravity test to determine uniaxial compressive strength, tensile strength and specific gravity respectively. Following are the average values derived for each of test done. Rock testing results:

- Uniaxial Compressive Strength (UCS) = 25.82 MPa
- Specific Gravity (SG) = 2.63
- Tensile Strength = 4.81 MPa

2.3 Blasting Simulations for Existing Blast

Blast simulation was done using JKSimBlast software for the blast design being practiced on site, and based on the average physical property values from the rock testing results.
The blasting parameters for the typical blasts of the quarry which have been used over the years are given in Table 1.

Table 1: Blasting parameters used by the quarry over the years

Parameter	Value
Burden (m)	1.2
Spacing (m)	1.6
Diameter (mm)	38
Bench height (m)	3.6
Bench level (m)	3.6
Floor level (m)	0
Under drilling (m)	0
Hole dip (degrees)	90
Rows	3
Holes per row	1st row-8 2nd row-7 3rd row-5
Stem height (m)	1st row-1.75 2nd row-1.25 3rd row-1.5
Explosive height (m)	1st row-1.85 2nd row-2.35 3rd row-2.10

Other than the above information, the explosive type was selected as "**ANFO**" (Mixture of Ammonium Nitrate and Diesel-94.5% & 5.5% w/w % respectively), number of cartridges as one, and the blast pattern as "staggered" for analysis of the blast design used by the mine site by means of "JKSimBlast" software. Furthermore, Kuz-Ram model was used to predict the fragmentation.

2.4 Blasting Simulations for the Optimized Blast

Hundreds of blasting simulations were done by changing blasting parameters, and among them a few were selected to conduct test blasts and validate the results. During these simulations, following parameters were mainly changed.

- Spacing - from 1.4 m to 2.0 m
- Burden - from 1.0 m to 1.6 m
- Stemming height - from 1.0 m to 1.75 m
- Explosive height - from 1.85 m to 2.6 m
- Drilling pattern –square pattern and staggered pattern
- Downhole delay – from delay No 0 to No 9

Following parameters were mainly considered when evaluating the forecast results of blast simulations to select the most suitable blast design.

- Volume of rock
- Tonnage
- Powder factor
- Percentage passing through jaw crusher (< 0.5 m without secondary breakage)
- Ground vibration
- Airblast over pressure
- Cost

To obtain a cost-effective blast, secondary breakage cost should be minimized. Due to this reason, blast designs which gives higher percentage of fragmented rocks passing jaw crusher (lower percentage of boulders (> 0.5 m)) were selected to conduct test blasts and validate the results. Table 2 shows the parameters got for optimized blast design, after running simulations.

Table 2: Input blasting parameters of the optimized rock blast

Parameter	Value
Burden (m)	1.1
Spacing (m)	1.7
Diameter (mm)	38
Bench height (m)	3.6
Bench level (m)	3.6
Floor level (m)	0
Under drilling (m)	0
Hole dip (degrees)	90
Rows	3
Holes per row	1st row-8 2nd row-7 3rd row-5
Stem height (m)	1st row-1.75 2nd row-1.00 3rd row-1.25
Explosive height (m)	1st row-1.85 2nd row-2.60 3rd row-2.35

Other than above mentioned parameters, "Water gel" was used as primary explosive (one carriage per hole), ANFO as secondary explosive (Total of 43 kg per blast) and staggered drilling pattern. Also, the following downhole delay pattern shown in Figure 1 was selected by running several drilling pattern simulations using JKSimBlast software.

Table 3: Used delay numbers and their delay time in milliseconds(ms)

Delay number	Delay time(ms)
0	0
1	25
2	50
3	75
4	100
5	125
6	150
7	175
8	200
9	225

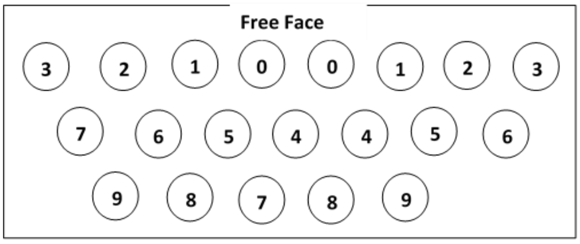

Figure 1- Delay pattern (Not to scale)

2.5 Actual Fragmentation Analysis

Five test blasts were done at the quarry site by changing blasting parameters in accordance with the simulations done by means of the software. Ground vibration and air blast over pressure were measured using a "Micromate" instrument. In order to analyse the fragmentation of the muck file, every blast was photographed. The photographs were analysed by means of "Split Desktop" software, in order to compare the predicted fragmentation with the actual fragmentation [15]. In this case, more than fifty photographs were taken for each and every blast and among them around fifteen photographs were subjected to fragmentation analysis, using the split desktop software. While capturing the photographs, two scales (2 Spheres with a diameter of 24 cm) were used to identify or scale down the fragments and boulders of the resulted muck pile.

Figure 2- Image of a muck -file

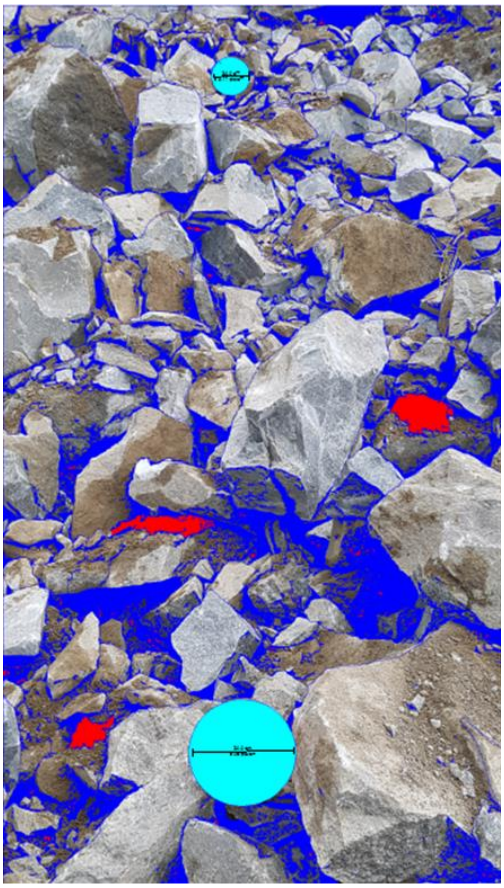

Figure 3- Fragmentation analysis using "Split Desktop" software

3. Results

Table 4 shows the results from simulation of the blast pattern being practiced on the mine site.

Table 4: Average forecasting parameters from the existing blast design

Parameter	Value
Volume (m^3)	138.24
Tonnage (tons)	363.571
Powder Factor (Kg/m^3)	0.274
Percentage rejected by grizzly feeder % (< 0.01 m)	1.166
Percentage passing through Jaw Crusher % (< 0.5 m)	54.884

Table 5: Average forecasting parameters for the optimized blast design

Parameter	Value
Volume (m^3)	134.64
Tonnage (tons)	354.103
Powder factor (Kg/m^3)	0.302
Percentage rejected by grizzly feeder % (< 0.01 m)	0.824
Percentage passing through Jaw Crusher % (< 0.5 m)	57.674

4. Discussion

The aim of his research is to optimize an existing bench blast by changing various blasting parameters using the "JKSimBlast - 2DBench "software. During this study, following parameters were mainly considered.

- Spacing
- Burden
- Stemming height
- Explosive height
- Drilling pattern
- Downhole delay

After running number of simulations through the software, a several optimized situations (trial blasts) were selected and executed on site for the verification of their reliability.

4.1 Evaluation of Model Performance

To evaluate the performance of the simulations don by JKSimBlast software several test blasts were carried out at Galpatha quarry site, and comparisons were made between the predicted fragmentation (using "JKSimBlast" software) and the actual (measured) fragmentation (using "Split Desktop" software) [15,16]. Two indices, coefficient of determination (R^2) Eqn. (1) and root mean square error (RMSE) Eqn. (2) were used to carry out the performance analysis [2].

$$\mathbf{R^2} = \left[\frac{\sum_{i=1}^{n}(x_{i\,pred} - \bar{x}_{i\,pred})(x_{i\,meas} - \bar{x}_{i\,meas})}{\sqrt{\sum_{i=1}^{n}(x_{i\,pred} - \bar{x}_{i\,pred})^2 \sum_{i=1}^{n}(x_{i\,meas} - \bar{x}_{i\,meas})^2}}\right] \quad (1)$$

$$\mathbf{RMSE(x)} = \sqrt{\frac{\sum_{i=1}^{n}(x_{i\,meas} - x_{i\,pred})^2}{n}} \quad (2)$$

Where,

Xi meas	i^{th} measured element
Xi pred	i^{th} predicted element
n	number of data sets

For existing/ traditionally used blast

- R^2 = 0.9922
- RMSE = 6.08

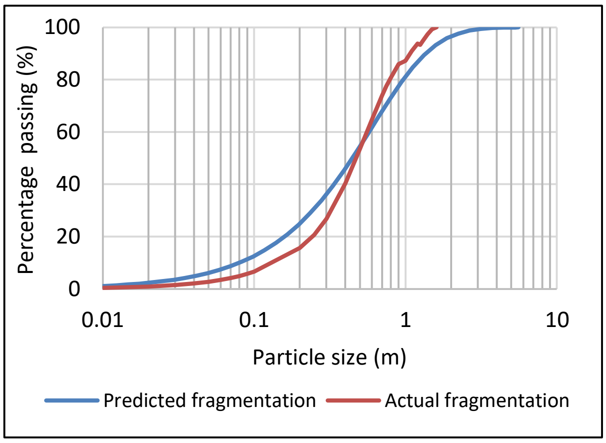

Figure 4-Comparison of fragmentation in existing blast (Cumulative percentage passing)

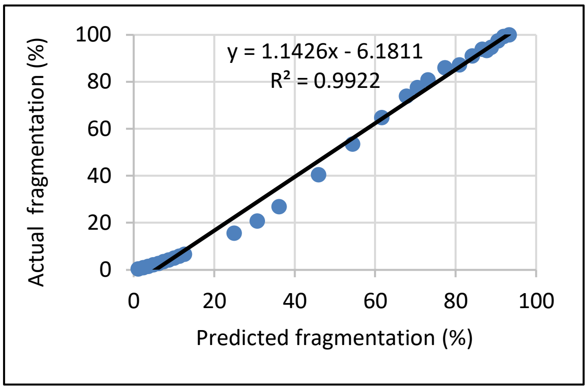

Figure 5-Comparison between the measured and predicted fragmentation in existing blast

For optimized blast by this research

- R^2= 0.9978
- RMSE = 4.88

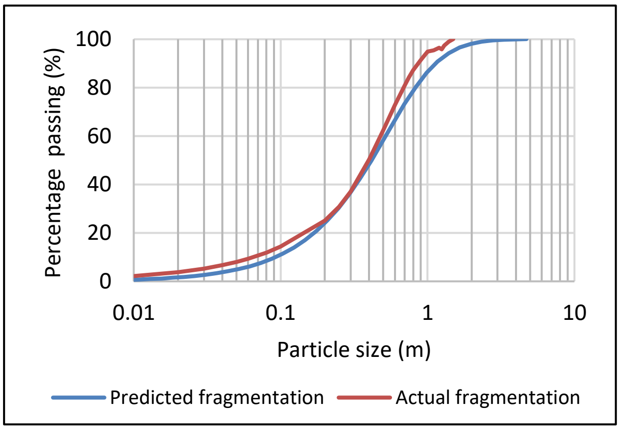

Figure 6- Rock fragmentation in the optimized blast (Cumulative percentage passing vs. particle size)

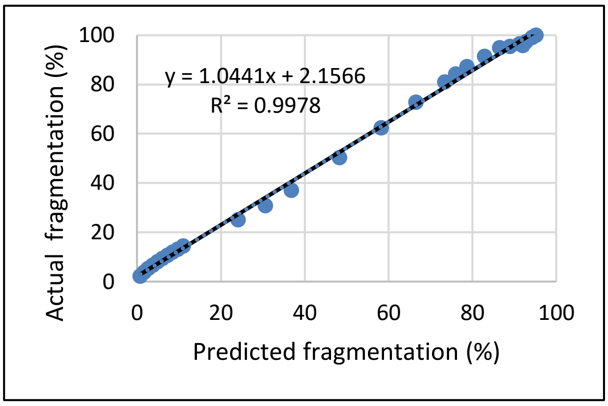

Figure 7- Comparison between the measured and predicted fragmentation in optimized blast

5. Conclusions

As per the research findings of this study, following recommendations can be made to optimize the bench blasting on this site:

- Use burden as 1.1m and spacing as 1.7m in the blast.
- Use following stem and explosive heights as shown in Table 6.

Table 6: Stemming and explosive heights

Stemming height (m)	1st raw-1.75 2nd raw-1.0 3rd raw-1.25
Explosive height (m)	1st raw-1.85 2nd raw-2.6 3rd raw-2.35

- Use one carriage for one drill hole.
- Use Staggered drilling pattern in drilling.
- Use the delay pattern shown in Figure 1.

Acknowledgements

The authors wish to extend their sincere gratitude to Metal Mix (pvt) ltd for giving the opportunity to execute this research and a special thanks go to Eng. M.D. Wimal (General Manager of the Metal Mix (pvt) ltd, Eng. Anushka De Silva, Quarry Manager, Eng. B.U Kankanamage, former Quarry Engineer, and all the working crew of the Metal Mix (pvt) ltd, Galpatha quarry site. We would like to thank all academic and technical staff members of the Department of Earth Resources Engineering.

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