Enhancing Productivity in Opencast Mines – A Quantified Approach

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Abstract – Productivity improvement is a difficult task. For this both managers and work force must be persuaded somehow that they have a common interest in increasing output per head. The consistent necessity to improve the utilization of costly HEMM and the Productivity of the project calls for a systematic study of the economic factors influencing it. Among the factors affecting the performance of shovels and dumpers, blasting occupies an important position. Blasting operations play a vital role in this respect. Rock fragmentation by blasting may be considered as the most important parameter in the production cycle, especially in medium to hard formations as the cost effectiveness of other operations like excavation, transportation, and further size reduction, is going to be affected significantly by the blast results. The design of the blasts should therefore be made to compliment the loading and transporting equipment. In this paper, an approach is made to evaluate the cycle time of loading equipment of as objective function for work study i.e., To quantify the size of rock fragment to know the job efficiency to produce output.

Key Words: Rock Fragmentation; Image Analysis; Rock Blasting.

1. INTRODUCTION

Profitability in opencast mine is controlled primarily by the blasting because it affects other operations such as loading, crushing, haulage, and milling. In large opencast mine blasting is critical operation which requires more attention to improve the blasting technique to get the desirable outputs. Better fragmentation, optimum throw and good muckpile profile is the desirable outputs of the blasting whereas backbreak, ground vibration, fly rock, noise pollution etc. are undesirable features. They indicate unscientific and improper blasting (Thote, et. al, 1999). The word ‘fragmentation’ means anything ‘the limit of breaking ‘to’ the percentage of passing, above or below a certain size. Cunningham, (1996) defined fragmentation as the economically significant size range of a definite volume of broken rock. Further, economically significant fraction can usually be classified as oversize, fines, and mid-range: (1) Oversize: The bounders’ size above which secondary breaking is necessary before further handling. In opencast mines it is defined as greater than 1000 mm; (2) Fines: The particle size below which product can either not be sold or which becomes difficult to handle due to flow or other properties; and (3) Mid-range: Those sizes which have significant, but not terminal importance of handling and the ability to achieve premium pricing. The market value of these fractions, and their impact on the production rate are illustrated in Fig – 1 (Thote, et. al, 1999).

Fig - 1 – Effect of Particle Size on Product Value and Production Rate (Cunningham, 1996).
Figure. 1 shows the fragment size increasing from left to right. The value of the fines is zero below a certain range, while larger fragments can be sold at low prices, and mid-range product achieves premium pricing.

Optimum fragmentation means: (1) Improved efficiency of shovel loading; (2) Minimum cost of loading and, transportation; and (3) Degree of fragmentation – finally affects fill factors of buckets, dumper body. The degree of fragmentation affects the economy of the mining process. The properties of fragmentation such as size and shape are very important information for the optimization of the production. Fragmentation mainly depends on: (a) Strength of explosives; (b) Specific charge; and (c) Hole spacing. For a desired degree of fragmentation, the number of oversize fragments produced decreases with decreased burden, which calls for small hole drilling and larger specific drilling. In multi shot blasting, interaction between shots causes better fragmentation. Short or millisecond delay blasting- better fragmentation is achieved (Karmakar, 2014).

Liu and Tran (1996) revealed that the results of fragmentation determined by three different image analysis systems were not the same. In India mostly WipFrag and Fragalyst are used for analysis of fragmentation. To compare the output from both the software an experiment was done by Sudhakar et al. (2003) where they compared the output of fragmentation analysis by three methods, namely WipFrag, Fragalyst and manual.

In this light, the present research paper evaluates the influence of cycle time of loading equipment of as objective function for work study i.e., To quantify the size of rock fragment size and its distribution in the blasted muck piles to get the job efficiency to produce output by image processing and analysis technique.

2. MECHAMISM OF ROCK FRAGMENTATION BY BLASTING

When an explosive is detonated in a rock mass the emitting energy is consumed in two ways: (a) For breaking and moving the rock; and (b) Dissipated as heat, vibrations, noise and flyrock. Investigations indicated that only 25% of the total explosive energy is consumed for breaking and moving the rock with which a mine operator is really concerned with. The breakage process can be divided into three stages (Karmakar, 2014):

(1) State-1: When an explosive is detonated the gases produced in a hole generate high pressure, which shatters the rock in the area adjacent to the blast hole. The outgoing shock waves, which are compressive in nature and are called P waves, produce tangential tensile stresses which are responsible for creating micro and macro cracks and fades away with distance.

(2) State-2: When the shock or P wave reaches a free face, they are reflected as a tension wave called S waves, which travels backwards towards the blast hole. It is well-known that a rock is weakest in tension and therefore, these reflected waves cause breaking of the rock mass. The extent of breakage depends on the dynamic or propagation properties of the rock structure. The point at which the magnitude of tensile stresses becomes just equal or less than the tensile strength of the rock masses the cracking stops; and

(3) State-3: In this stage, which follows stage-2 the rock mass moves forward under the influence of high-pressure gases. The cracks already formed increase in magnitude because of pneumatic wedging and reflected tensile waves.

2.1 FACTORS AFFECTING ROCK FRAGMENTATION

Rock fragmentation refers to the post blast size distribution of the rock mass and basically depends on two variables; Rock Mass Properties – that cannot be controlled and Blast Design Parameters – which can be controlled. Optimum fragmentation helps to: (1) Minimise oversize boulders (less secondary breaking); (2) Minimise ultra-fine production; (3) Fragmentation enough to ensure efficient digging and loading; and (4) Muckpiles loose enough for fast cycle times and full buckets. In principle the front row is probably the most critical portion of a blast. When the front row burden moves out adequately there is an excellent chance that the remainder of a round will succeed. Good forward movement of the blast is only possible with an adequately charges front row and a good free face to act on. For this reason, shovel clean-up of a free face is encouraged in order to obtain an improved wall for the front row of a later blast to work on (Karmakar, 2014).
Delays are used to divide the blast energy into smaller ‘packets’ in order to reduce ground vibrations and noise and reduce the backwall damage which can result. For the crater to be produced, and for the material to start forward movement, there is a lapse time necessary. If subsequent delay periods are prior to this laps time occurring, then the shot starts to become choked. The pit floor conditions fall off, the muck pile is tighter than is desirable, and an inadequate delay interval can result in an increase in flyrock. The majority of blast designs delay and tie-in the blast in such a manner that blast movement is in the direction of the previous shot. That is the design principle, but catering is not only heavily influenced by the blast hole position.

Rock type and rock structure affect the outcome of the blast. Production schedule demands large quantities of rock to be broken at a time because of the simple fact that each round of blast leads to downtime of machinery and unproductive safety precautions. Thus, a blast may be if practicable at a time and within the constraints of the available facilities. Time its width, the (stationary rock on both sides of the blast area has a constraining i.e., drag) effect on forward rock movement. For this reason, the length of the blast should be at least 1.5 times and preferable more than 3 times the width of the blasts. The factors that influence the rock fragmentation can be summarized as follows (Pal Roy, 2005):

1) Rock conditions
   a) Tensile strength of rock - Tensile strength > 15 MPa has tended to give a rough fragmentation whereas < 6 MPa is supposed to give fine fragmentation.
   b) Young’s Modulus of the rock – For the rock with same tensile strength a coarser fragmentation is expected at a lower value of Young's Modulus than at a higher one.

2) Specific drilling and charging
   a) Increase of specific drilling and specific charge gives a finer fragmentation.
   b) To maintain a certain fragmentation, it is therefore usual to increase the specific charge when increasing the hole diameter.

3) Drilling Pattern
   Staggered pattern gives lower characteristic fragment size compared to the square pattern for the same powder factor, because of the better distribution of explosives in the rock mass. Staggered pattern gives more uniform distribution.

4) The firing patterns
   Influences the effective spacing to burden ratio at the time of detonation.

5) Delay timing
   a) Short delay intervals (<25 ms) between holes in a row reduce fragmentation but improve displacement.
   b) Longer delay intervals (> 100 ms) are required between rows to maximize displacement.
   c) The delay between rows should be at least 2 to 3 times the delay between holes in a row.

6) Bench stiffness - Equal to the Bench height divided by burden. The value of: (a) <<2 indicates stiff and poor fragmentation; (b) 2 – 3.5 indicates good fragmentation; and (c) >> 3.5 indicates excellent fragmentation.

7) Initiation system - A non-electric initiation system with shock tubes is more effective than the detonating fuse as it largely assists in arresting the disruption of stemming column. This feature enhances the proper utilization of available explosive energy in the hole.

8) The type of explosive – To achieve optimal fragmentation an explosive adapted to the natural rock condition be chosen.

9) Among the property of explosive which may influence the fragmentation there are for instance –
   a) Gas volume
   b) Detonation Velocity
   c) Density

10) Environment consideration because of the useful energy released by the explosive is dependent on factors-
   a) Properties of explosives,
   b) Confinement of the explosive
   c) Hole diameter, etc.
2.2 DEGREE OF FRAGMENTATION OF BLASTED MATERIAL

Quantitative determination of fragmentation size is an effective tool for the evaluation of efficiency and performance of the blasting. The muckpile characteristics like, homogeneity, maximum, minimum and average fragment size etc. can precisely be known from the particle size determination. Better size distribution of fragment has the following influences on the productivity: (1) Operating capacity of loading is raised; (2) Dumper cycle times are reduced because of less waiting periods and loading time; and (3) Increase in bucket fill factor decreases cycle time of the excavator. The blasted material, in practice should not only be adequately fragmented but also be displaced into a muckpile which should complement the digging and the haulage equipment (Harries, 1987).

![Fill factor of Bucket as a function of Relative Block Size](image)

**Fig. 2** – Fill factor of Bucket as a function of Relative Block Size (m).

The situation like improper fragmentation causes many problems. Eg., Because of improper fragmentation, huge boulders are generated which requires secondary blasting. Next, because of poor blasting, toe problems are encountered which requires additional cost for eliminating the toe by drilling and blasting. Further, the loading efficiency of the excavating equipment like a shovel, is reduced and as a result shovel output becomes very less, thus creating less production (Sahoo, 1999).

2.3 FRAGMENTATION AND DISPLACEMENT

One of the most challenging tasks related to the blasting operation is the prediction of fragmentation. This assumes special significance in field operations where cost control is a priority. Many indicators are in practice to assess the fragmentation, like mean fragment size, specific surface area, granulometry, shovel performance, crusher performance, photographic analysis, high speed photography, digital image analysis etc. Most of these methods have some or the other inherent disadvantages. However, shovel loading performance is most probably the best practical solution to assess fragmentation. This is because it is related to both fragmentation and muckpile profile (Sastry & Singh, 1999).

The power consumed by the shovel while loading is another indicator, in addition to the time cycle. Problems like oversize, poor toe and difficult digging conditions encountered by the shovel are directly reflected in the evaluation. In fact, some studies were conducted by one of the authors to assess the performance of explosives in an opencast coal mine. The power consumed by shovels was systematically recorded and correlated with the fragmentation (Raju and Sastry, 1993). This technique was observed to yield good results.
The size of the broken fragments and profile of the displaced muck should be compatible with the machinery deployed. Fig. 3 shows three types of muckpile profiles. Small mines operating with front end loaders require muckpile shown in fig. 3a which is safe for the operation of equipment and the operator. However, it is not suitable to shovel-dumper combination as the spread area is excessive. Muckpile shown in fig. 3b is dangerous to operate with, and profile shown in Fig. 3c is best suited to shovel operating as the clean-up area is a minimum and the profile of the muck is also safer. Blast design should therefore aim at not only to meet the fragmentation requirements of machines, but also to increase the productivity of equipment by minimizing the clean-up area to some extent. It should address the specific requirements of the loading machinery (Sastry & Singh, 1999).
Fig – 3 – Muckpile Profile Shapes (Sastry & Singh, 1999).

2.4 DESIRABLE FRAGMENT SIZE (Karmakar, 2014).

For maintaining continuity of flow at the crusher there must be a planned relationship between the characteristics of the deposit, the rock pile fragmentation that is intended, the bucket size of the loading equipment and the feed aperture in the primary crusher. The table below gives a rough idea of the designed fragmentation for various shovel capacity and crusher size.

<table>
<thead>
<tr>
<th>Fragmentation (m)</th>
<th>Shovel Capacity (m³)</th>
<th>Jaw Crusher size (cm)</th>
<th>Gyratory crusher size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.46</td>
<td>0.8</td>
<td>91x61</td>
<td>51</td>
</tr>
<tr>
<td>0.61</td>
<td>1.1</td>
<td>107x81</td>
<td>76</td>
</tr>
<tr>
<td>0.76</td>
<td>1.5</td>
<td>122x102</td>
<td>91</td>
</tr>
<tr>
<td>0.91</td>
<td>1.9</td>
<td>152x122</td>
<td>107</td>
</tr>
<tr>
<td>1.07</td>
<td>2.7</td>
<td>183x142</td>
<td>122</td>
</tr>
<tr>
<td>1.22</td>
<td>34</td>
<td>213x163</td>
<td>138</td>
</tr>
</tbody>
</table>

Langefor’s Equation for Estimation of Fragment Size (Karmakar, 2014).

Largest Boulder Size \( L_1 = (B^2)^{1/3}/2 \); for \( B = 0.5 \text{m} \).

Rub Stove, has given following relation:

\[
L_{av} = 60 / \{(1/L_n) X Q_s X (300 + H) / (100 + d)\}
\]

where,

- \( L_{av} \) = Average Lump Size (cm), \( L_n \) = Average Dimension of Natural Block (m), \( H \) = Bench Height (m),
- \( Q_s \) = CF (kg/m³), and \( d \) = Hole Diameter (mm).

Distance of Flying Fragment : \( D_f = B_{ST} / B = 155.2 (D_f)^{1.37} \)

where,

- \( B_{ST} \) = Length of Stemming Column (m), \( B \) = Effective Burden (m).

For shovel
The formula is: \[ A = 0.8 \times (C_d)^{1/3} \]
where,

- \( A \) = Fragment Size
- \( C_d \) = Dipper Capacity of Shovel (in m³).

Hole spacing has a bearing on optimum fragmentation. The formulate used for better fragmentation is \( E = (1.0 - 1.3) \times V \).

Lange for and kihlstrom recommends, \( E_c = 1.3V \).

where,

- \( E \) = Spacing and \( V \) = burden

The above formulate are guidelines which can be used to reach a better fragmentation after trial blasting.

3. PREDICTION OF FRAGMENTATION

3.1 ROCK FRAGMENT ASSESSMENT METHODS (Pal Roy, 2005)

1) Sieving or Screening - Rock fragments are screened through sieves of different mesh numbers for different fragment sizes for evaluation of size distribution of particles or fragmentation.
2) Oversize boulder count method - Manual counting of the oversize boulders in the muck pile which cannot be handled by the shovel is done. It gives an over-size index with respect to the total in-situ rock mass blasted.
3) Explosive consumption in secondary blasting - An index regarding the consumption of explosives in secondary blasting by either pop shooting or plaster shooting is determined. This index is then used for comparing the degree of fragmentation of a group of blasts.
4) Shovel loading rate method - Assumes that faster the mucking the better the fragmentation. The loading rate of shovel for a muck pile is considered.
5) Bridging delays at the crusher method - Delay in bridging at the crusher mainly due to oversize boulders is observed. This attribute in determining the number of oversize boulders in the muck pile.
6) Visual analysis method - The post-blast muck is viewed immediately after blasting and a subjective assessment is made.
7) Photographic or manual analysis method - Delineation of fragments of the photographs of muck pile is carried out manually to determine the number of fragments using a graph paper.
8) Conventional and high-speed photogrammetric method - This method is more reliable and accurate than the photographic method. It can provide three dimensional measurements and thereby helps in the calculation of fragmentation volume.
9) High speed photography or image analysis method - The image analysis software uses the technique of analysis of digital images of the blasted rock with granulometry system to predict the grain size distribution in the muck pile. For eg. IPACS, TUCIPS, FRAGSCAN, SPLIT, Fragalyst, WipFrag.

3.2 HOW TO QUANTIFY THE FRAGMENTATION

The results of a production blast may be described in terms of the fragmentation and the properties of the fragmented rock. The fragmentation may be described in terms of a fragment size distribution and the shape and angle or roundness of the fragments, i.e. basically geometrical data. A complete description of the former is the cumulative size distribution or CDF. The CDF is the ‘fraction of mass \( P \) passing a screen with a given mesh size \( x \). \( P(x) \) then varies between 0 - 1 or 0 - 100%.

- \( X_{50} \) = A measure of the average fragmentation, i.e. mesh size through which half of the muckpile (\( P = 0.5 \) or 50 %) passes. \( X_{50} \) is a central production measure. To use the mean fragment size, often designated by \( k_{50} \), \( k_{50} \) is a figure which represents the screen size through which 50% of the loosened rock would pass if screened.
- \( X_N \) = Other percentage related block size numbers in use. \( N = 20, 30, 75, 80, 90 \) etc.
- \( P_0 \) = Percentage of fragments larger than a typical size \( X_0 \). \( P_0 \) is related e.g. for the handling of big blocks by trucks or the size of blocks that the primary crusher cannot swallow.
- \( P_F \) = Percentage of fine material smaller than a typical size \( X_F \).
3.3 CALCULATION OF FRAGMENTATION - THE KUZ-RAM MODEL

There are three key equations (Konya, 1995):

The adapted Kuznetsov equation

\[ x_m = A^K \times Q^{1/6} \times (115/RWS)^{19/20} \]  
\[ x_m = \text{Mean Particle Size, cm.} \]
\[ A = \text{Rock Factor.} \]
\[ A = 0.06 \times (\text{RMD + JF + RDI + HF}) \]
\[ \text{RMD} = \text{Rock Mass Description,} \]
\[ \text{JF} = \text{Joint Factor,} \]
\[ \text{RDI} = \text{Rock Density Influence,} \]
\[ \text{HF} = \text{Hardness Factor,} \]
\[ K = \text{Powder Factor,} \]
\[ Q = \text{Mass of Explosive in the hole, kg.} \]
\[ \text{RWS} = \text{Weight Strength Relative to ANFO.} \]

The adapted Rosin-Rammler equation

\[ R_x = \exp \left[-0.693 \times \left(\frac{x}{x_m}\right)^n\right] \]  
\[ R_x = \text{Mass Fraction Retained on Screen Opening x.} \]
\[ n = \text{Uniformity Index.} \]

The uniformity equation

\[ n = \left(2.2 - 14B/d\right) \sqrt{1+S/B}/2 \times (1 - W/B) \times (\text{abs}(\text{BCL-CLL}/L) + 0.1)^{0.1} \times L/H \]  
\[ B = \text{Burden, m;} \]
\[ S = \text{Spacing, m;} \]
\[ d = \text{Hole Diameter, mm.} \]
\[ W = \text{Standard Deviation of Drilling Precision, m.} \]
\[ L = \text{Charge Length, m;} \]
\[ \text{BCL} = \text{Bottom Charge Length, m;} \]
\[ \text{CLL} = \text{Column Charge Length, m;} \]
\[ H = \text{Bench Height, m.} \]

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Fig 4 – Typical Fragmentation Curve.
3.4 EFFECTS OF BLASTING PARAMETERS ON “n”

It would normally be desired to have uniform fragmentation in a blast, avoiding both excessive fines and boulders. If this is to be obtained, high values of “n” are preferred. The blasting pattern parameters used to determine “n” change as follows:

1. The value for “n” increases as the burden/hole diameter decreases.
2. The value for “n” increases as the drilling accuracy increases.
3. The value for “n” increases as the charge length/bench height increases.
4. The value for “n” increases as the spacing/burden increases.
5. The value for “n” increases with the use of a staggered pattern rather than a square pattern.

3.5 LIMITATIONS OF THE KUZ-RAM MODEL

1. The S/B ratio applies only to the drilling function, not the timing. Therefore, spacing is always considered along the row where burden considers the distance between rows, which parallel the face. The layout on this blast can never be such that the spacing to burden ratio is greater than two.
2. It is assumed that reasonable timing sequences are used which will enhance or maintain fragmentation.
3. The explosive should yield energy close to its RWS for the diameters that are being used on the job.
4. Jointing and bedding, especially in the case of loose jointing, which is more closely spaced than the drill pattern, can affect the size distributions. Maximum sizes could be controlled by geologic features rather than the explosive energy released from the blasting process.

4. RESEARCH METHODOLOGY

Rustan (1998) emphasised the use of image analysis techniques with suitable software for quick, precise, and almost inexpensive quantification of fragmentation. Besides the image capturing, the field procedure involved recording of total cycle time for the 14m³ hydraulic shovels excavating the muck piles in order to investigate the influence of fragmentation on the diggability of the shovels. Pal Roy and Mondal (1999) mentioned that the diggability of the excavator is related to the degree of fragmentation.

Singh et al. (1999), has conducted a series of trial blasts in an Indian iron ore mine to report the influence of fragmentation on the performance of shovels. Marton and Crookes (2000) reported the reduction in productivity of the face excavators due to improper fragmentation. Digitization of fragmentation was first introduced by Grannes in 1986 and consequently refined and modified by Cunningham (1986), Stagg (1987), Maerz et al. (1988), Former and Kemeny (1991), Maerz and Franklin (1996) and Chung and Ludwig (1996).

To evaluate the fragmentation, image analysis techniques were deployed as it is a good and practical alternative to quantify the fragment size and its distribution in the blasted muck piles (Kandibotla et al., 1999). Digital image processing using different software and hardware is the latest fragmentation tool. It has replaced the conventional methods like visual analysis, Photographic, Photogrammetry, and boulder count and sieve analysis technique. The conventional methods possess inherent problems. Digital image processing method comprises of image capturing of muck pile, scaling, and image, filtering the image, segmentation of images, binary image manipulation, measurement, and stereo metric interpretation.

Evaluation of fragmentation results for Bauxite Mine-A was done by using image processing and analysis technique for quantification of the fragment size and its distribution in the blasted muck piles. Further, the influence of the firing patterns was investigated on the total cycle time of 2.7m³ hydraulic shovels excavating the blasted muck piles. The field captured photographs were processed and analyzed by image analysis software; FragScan. The system is based upon a digitizing tablet whose image superimposed over that of video input or still photographs. Features within the image seen by the camera can be selected by tracing around them using handheld cursor. Flowchart of working operation is indicated in Fig. 5.
**Fig – 5** – Flow Chart of Size Distribution Working Operation (Thote, et. al, 1999).
5. RESULTS – FIELD WORK AT OPENCAST BAUXITE MINE - A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
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<td>-</td>
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<td>4</td>
<td>5</td>
<td>4</td>
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<td>50</td>
<td>45</td>
<td>60</td>
<td>55</td>
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<tr>
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<td>102</td>
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<td>Firing sequence</td>
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<td>&quot;V&quot; pattern</td>
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<td>Sub-grade drill</td>
<td>m</td>
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<td>Specific gravity of explosive</td>
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<td>Length of explosive charge</td>
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<tr>
<td>Weight of explosive charge</td>
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<td>17</td>
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<tr>
<td>Total explosive weight</td>
<td>kg</td>
<td>6682.5</td>
<td>6069</td>
<td>7862.5</td>
<td>7078.5</td>
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<td>Total blasted rock</td>
<td>m³</td>
<td>6187.5</td>
<td>5619.40</td>
<td>7560</td>
<td>6806.25</td>
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<tr>
<td>Powder factor</td>
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<td>1.08</td>
<td>1.04</td>
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<td>Maximum Long Dimension</td>
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<td>Mean Long Dimension</td>
<td>m</td>
<td>82.8</td>
<td>57.65</td>
<td>110.5</td>
<td>108.75</td>
</tr>
<tr>
<td>Optimum fragment size</td>
<td>cm</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Mean fragment size</td>
<td>cm</td>
<td>25.99</td>
<td>29.55</td>
<td>26.44</td>
<td>25.99</td>
</tr>
<tr>
<td>Total cycle time of the shovel</td>
<td>sec</td>
<td>28</td>
<td>35</td>
<td>30</td>
<td>28</td>
</tr>
</tbody>
</table>

Production of loading machines is governed by the bucket capacity, cycle time, fill factor and swell factors, which, in turn, are influenced by the operating muckpiles and fragmentation resulting from the blasts. Similarly, transportation and crushing (in case of hard ores/minerals) are highly dependent on the fragmentation achieved. The size distribution of fragments provided by the primary blast, therefore, influences the effective performance of other operations of any of the following ways:

1. Higher drilling and blasting costs, improving fragmentation.
2. Better fragmentation improving productivity of excavating machines.
3. Increased operating capacity of dumpers or other transporting equipment due to reduced loading times.
4. Decreased secondary blasting, resulting in less down time of equipment; and
5. Energy savings in crushing stage due to better fragmentation.
6. CONCLUSIONS

1. Blasting can have a considerable effect on subsequent mining and ore handling operations the variability of the rock cannot be controlled, but most of the other variables can be controlled by the mine.
2. The degree of fragmentation in the blasted muck piles affects the digging as well as unloading segment time of the operational cycle of the excavators.
3. The effect in assessing blasting especially if the fragment size distribution must be measured is considerable. A systematic change of variable is virtually impossible on an operating mine and would be a costly and time-consuming exercise.
4. The only other possible alternative is to use an assessment of blasting to calibrate a computer simulation of blasting. An attempt can now be made to use a model to optimize blasting. There may however be difficulties in realizing the expected benefits which could lost among another uncontrolled variable.
5. While a considerable amount of ingenuity has gone into the modelling of blasting this does not mean that all the pertinent variables have been considered. There is also no guarantee that a calculated change can be seen in practice.
6. As a rough guide a change in maximum fragment size of 10 mm is visible to the naked eye. A change which could have a significant economic effect, and not be immediately obvious and could be ignored.

REFERENCES


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