Improvements in Blast Fragmentation Models Using Digital Image Processing

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ABSTRACT

One of the fundamental requirements for being able to optimise blasting is the ability to predict fragmentation. An accurate blast fragmentation model allows a mine to adjust the fragmentation size for different downstream processes (mill processing versus leach, for instance), and to make real time adjustments in blasting parameters to account for changes in rock mass characteristics (hardness, fracture density, fracture orientation, etc). A number of blast fragmentation models have been developed in the past 40 years such as the Kuz-Ram model (Cunningham, 1983). Fragmentation models have a limited usefulness at the present time because:

1. The input parameters are not the most useful for the engineer to determine and data for these parameters are not available throughout the rock mass.
2. Even if the input parameters are known, the models still do not consistently predict the correct fragmentation. This is because the models capture some but not all of the important rock and blast phenomena.
3. The models do not allow for 'tuning' at a specific mine site.

This paper describes studies that are being conducted to improve blast fragmentation models. The Split image processing software is used for these studies (Kemeny, 1994; Kemeny *et al*, 1999).

INTRODUCTION

The Split software was originally developed at the University of Arizona, and in 1997 the technology was transferred to a newly formed company, Split Engineering. The Split software allows post-blast fragmentation to be determined on a regular basis throughout a mine, by capturing images of fragmented rock in muckpiles, on haul trucks, or from primary crusher feed or product. The resulting size distribution data can then be used to accurately assess the fragmentation associated with different parts of a shot. And in particular, this data can be used to assess and improve the accuracy of fragmentation models (Higgins *et al*, 1999).

Fragmentation models are also being improved by utilising drill-monitoring data. Drill-monitoring data includes raw drilling data such as rotary torque, penetration rate, and pull down pressure, as well as calculated quantities such as drilling specific energy or the Aquila Blastability Index (Peck and Gray, 1995). Because drill-monitoring data is available from every blast hole, it provides data throughout the rock mass to be blasted.

As part of this project fragmentation studies are being conducted at several large open pit mines in Arizona. At these mines Split-Online systems are installed at the primary crushers. On these systems, cameras installed at the truck dumps monitor primary crusher feed and cameras installed at the discharge belts monitor primary crusher product. The primary crusher feed information is then traced back to the original position of this rock on the shot using mining dispatch systems. This information is used to assess post-blast fragmentation and can be correlated with rock mass and blasting information on a hole by hole basis. In addition, the primary crusher feed and product size distributions are used to assess the work index of the fragmented rock. This is important, since blasting can also improve the crushability and grindability of individual fragments of ore due to the introduction of micro-fractures (Nielsen and Malvik, 1999). Finally, on the blast-hole drills, drill monitoring systems are installed. The drill monitoring information is used to assess the pre-blast conditions of the rock mass on a hole-by-hole basis.

THE SPLIT SYSTEM

An effective method to assess fragmentation at the present time is to acquire digital images of rock fragments and to process these images using digital image processing techniques. In the case of post-blast fragmentation, this is the only practical method to estimate fragmentation, since screening is impractical on a large scale. In the case of post-crusher fragmentation, screening is routinely used, but digital image processing allows fragmentation to be assessed on a continuous basis. The development of image processing techniques for the assessment of fragmentation has been in development at the University of Arizona from 1990 through 1997. Since 1997 the development work has continued at Split Engineering, LLC, and professional Split-Online systems have now been installed at over 38 locations worldwide.

The basic steps involved in the Split software are as follows:

1. acquiring digital images, either automatically or manually;
2. pre-processing the images to correct for lighting problems and to screen for unacceptable images;
3. delineate the individual fragments in each image using digital image processing algorithms;
4. apply statistical algorithms to the 2D particle areas in each image to determine 3D particle volumes;
5. statistically correct 3D volumes for overlap and shape and determine histogram of particle volumes;
6. correct particle volume histogram for fines;
7. process multiple images together to get an average distribution (including images taken at different scales); and
8. output data to the screen, hard disk, and network control systems.

Details of these steps are given in Kemeny *et al* (1999) and Kemeny (1994). Figure 1a shows a typical image of primary crusher product and Figure 1b shows the delineation of the individual rock fragments by the Split software.

At typical open pit mining applications, a Split-Online system is installed at the primary crusher, where digital images of both feed and product are continually processed and the results are recorded. The feed cameras are located at the truck dump bays or feed belts, and the product cameras are located above the discharge belts. The resulting size data from the Split system can be imported into a mine-wide database where truck-by-truck averages of the feed and product sizes can be determined.

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A Split-Online system installed at a primary crusher serves four functions. First of all, the crusher feed size provides information on post-blast fragmentation. Secondly, the crusher product size provides information on secondary crusher and ball mill feed size. Thirdly, the feed and product sizes together can be used to estimate the work index, which gives information on the crushability and grindability of the ore. And finally, the feed and product sizes can be used to monitor crusher performance and crusher wear.

Several new technologies are being utilised to trace the crusher feed and product size information back to the original position of the rock on the bench. This is accomplished on a truck-by-truck basis. The technologies utilised include an accurate time/date stamp for the Split data associated with each truckload of ore, mining dispatch systems to trace the trucks back to the bench, and GPS equipped shovels to determine the locations of the material dumped into each truck. Figure 2 shows an example of a bench along with the locations of Split crusher data. The F80 values around each hole are averaged, and this hole-by-hole data is used in the development of fragmentation models, as described in Section 4.

Bond's equation is used to estimate the work index of the material going through the primary crusher (Bond, 1952):

$$W = \frac{P}{T} = 10W_i(P_{80}^{-0.5} - F_{80}^{-0.5})$$

where

W is the work input in kWh/t

W_i is the work index of the ore in kWh/t

P_{80} is the 80 per cent passing size of the product

F_{80} is the 80 per cent passing size of the feed

T is the throughput of new feed in t/h

P is the power draw in kW

Bond's equation can be rearranged to estimate the work index:

$$W_i = \frac{P}{10T(P_{80}^{-0.5} - F_{80}^{-0.5})}$$

Thus by knowing the feed and product sizes and the power draw and throughput, the work index for the material passing through the crusher can be estimated.

DRILL MONITORING DATA

One of the factors that has limited the usefulness of blast fragmentation models is the lack of information on the *in situ* characteristics of the rock mass. This information includes rock strength, RQD, fracture spacing, and fracture orientation. In most mining environments these parameters will be highly variable even within a single shot, and the traditional methods for obtaining this information, diamond drill core and geologic mapping, cannot collect the quantity of information necessary for fragmentation models. A new approach to obtaining at least some of the rock mass properties is the use of drill monitoring data. This information is available prior to blasting and throughout the rock mass to be blasted. Typical parameters recorded by a drill monitoring system include depth (ft), penetration rate (ft/hr), pull-down force (lbs), rotary speed (rpm), bit air pressure (psi), rotary current (amps) and rotary torque (lb-ft).

Drilling parameters have been used in a number of studies to estimate rock drillability or blastability (Protodyakonov, 1962; Peshalov, 1973; Miller, 1972; Schmidt, 1972; and Rabia, 1980). The most common approach to predicting drillability and blastability is the concept of specific energy. Teale (1965) defines specific energy as the work done per unit volume of rock excavated.

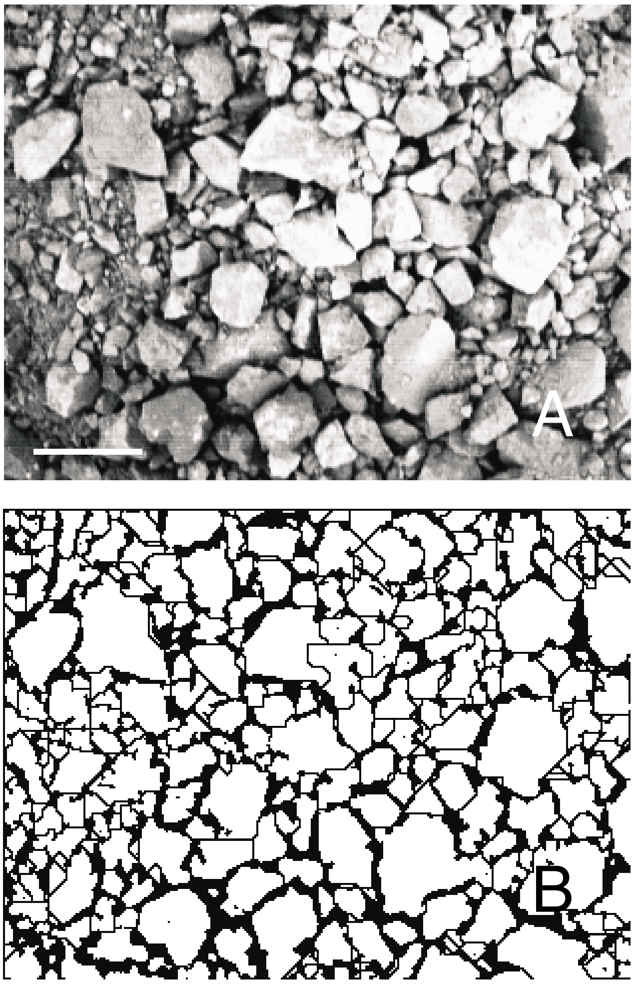


FIG 1 - a) Image of primary crusher product. b) Delineated image using the Split software. Scale in the image is six inches.

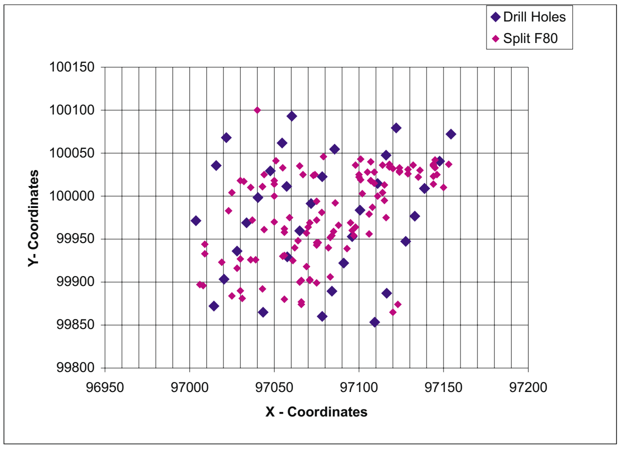


FIG 2 - A blasting shot showing the locations of drill holes and also F80 fragmentation size information. The F80 information is from a Split-online system installed at the primary crusher.

Consider the following drilling parameters: penetration rate (PR, in/min), torque (T, lb-in), rotational speed (N, rev/min), cross section area of drill hole (A, in^2), and pulldown force (F, lb). The work done per minute is given by W = F PR + 2 π N

T. The volume of material excavated in a minute is given by V = A PR. The specific energy SE is then given by:

$$SE = \frac{w}{v} = \frac{F\ PR + 2\pi\ NT}{A\ PR} = \frac{F}{A} + \frac{2\pi\ NT}{A\ PR}$$

Specific energy can be thought of as having two components, one due to the pulldown force and another due to the torque. Previous studies have shown that the component of specific energy from the pulldown force is very small compared to that from torque, typically less than five per cent (Teale, 1965; Schivley, 1994; Karanam and Misra, 1998). For all practical purposes, the first term in the equation above is negligible and can be dropped out, leading to the equation below.

$$SE = \frac{2\pi\ NT}{A\ PR}$$

Typical variations of specific energy with depth are shown in Figure 3 for three adjacent drill holes. This data was acquired during a normal mine production blasthole drilling operation at an open pit mine in Arizona.

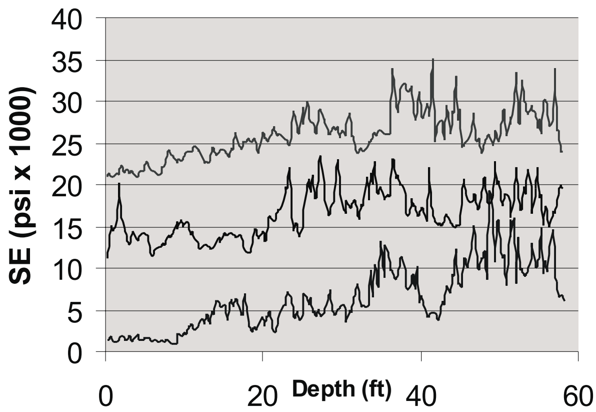


FIG 3 - Drill specific energy (SE) versus depth for three adjacent blast holes. The top and middle curves are offset by 20 000 and 10 000 psi, respectively, for better clarity.

From Figure 3 it can be seen that the specific energy has a gentle upward trend with depth. This is expected due to:

- increasing rock hardness with depth due to confining pressure; and
- drilling through and below the damage zone created from the previous blast.

For the purpose of correlating specific energy with blast fragmentation, a single specific energy value was obtained for each hole by averaging all the interval specific energies of each hole.

In addition to the gradual upward trends, the curves in Figure 3 show sudden changes at specific depths due to lithologic changes or fractures. Some of these changes occur at similar depths in adjacent holes. Current studies are being conducted to identify the nature and properties of the discontinuities based on drill monitoring data such as the data shown in Figure 3.

THE DEVELOPMENT OF FRAGMENTATION MODELS

An approach has been developed for the optimisation of blasting and the development of accurate blast fragmentation models. As described in the previous sections, recent technologies have allowed important pre and post-blast information to be obtained on a hole-by-hole basis. This includes the Split size information and the drilling specific energy (SE). In addition, the explosive energy per ton of rock (kcal/t) can also be estimated on a hole-by-hole basis. At the present time the focus of the modelling is on the following five quantities that can be obtained on a hole-by-hole basis:

1. SE (drilling energy),
2. kcal/t (explosive energy per volume),
3. F80 (post-blast 80 per cent passing size),
4. P80 (post primary crush 80 per cent passing size), and
5. Wi (work index).

These quantities take into account the *in situ* characteristics of the rock mass, the blasting parameters and the resulting fragmentation size and strength. One approach to analysing this data is to determine parameters needed for existing fragmentation models from the obtained information. For example, the uniaxial compressive strength can be estimated from the drilling specific energy. The approach taken here, however, is to develop fragmentation models that take as their input (and output) the specific quantities given above.

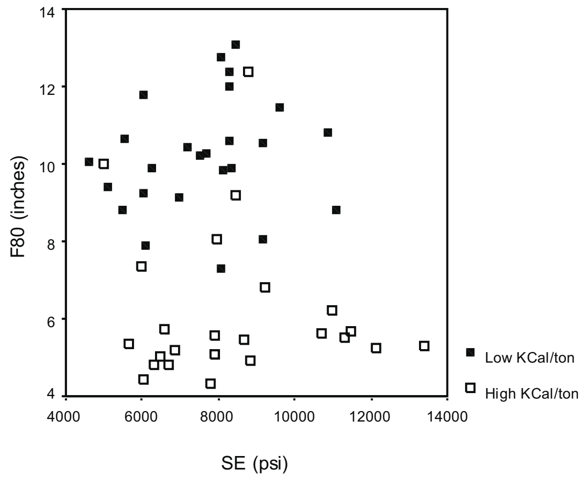
Using data from standard and experimental blasts at a mine in Arizona, statistical relationships between SE, F80, P80, Wi, and kcal/t are being investigated. Some sample results from several shots at a mine in Arizona are given below. Figures 4a and 4b present results from two blasts, a high-energy blast (average 250 kcal/t) and a low energy blast (average 150 kcal/t). Each of the points in the figures represents the data from an individual blast hole. The filled squares are data points from the low energy blast, and the unfilled squares are data points from the high-energy blast.

Figure 4a is a plot of F80 as a function of drilling SE. The F80 is representative of the post-blast fragmentation and SE is representative of the strength of the pre-blast rock mass. First of all, on average Figure 4a shows a significant decrease in fragment size with increasing blasting energy. Secondly, the figure shows that for the low energy blast the fragmentation size is somewhat sensitive to the hardness of the *in situ* rock (SE), but for the high energy blast a correlation between F80 and SE is not evident. Figure 4b is a plot of F80 as a function of explosive energy per ton. This plot clearly separates the high and low-energy shots into two groups, with the high energy shot showing a significant reduction in F80 on average. It is worth noting that Figure 4b shows the large variation in hole-to-hole blasting energy for each of the shots.

Overall, the main conclusions from Figures 4a and 4b involve the large decrease in F80 with increasing explosive energy. More subtle conclusions about specific relationships on a hole-by-hole basis between SE, F80 and KCal/ton are difficult to make at the present time due to the small sample size and the large scatter in the data. Much of the scatter is probably due to heterogeneities in the rock mass properties. Some of the scatter may also be due to errors, such as the error in estimating the exact location of the bucket when it digs and the error in assigning this ore to a specific drill hole due to throw and mixing. As more data is collected at the mine and the overall sample size becomes much bigger, statistically significant relationships should become apparent, and these relationships will form the basis for a mine-specific fragmentation model.

CONCLUSIONS AND FUTURE WORK

This paper presented an approach for developing accurate models to predict the fragmentation due to blasting. The approach makes use of drill monitoring data to provide information on the *in situ* rock mass, Split image processing software for assessing



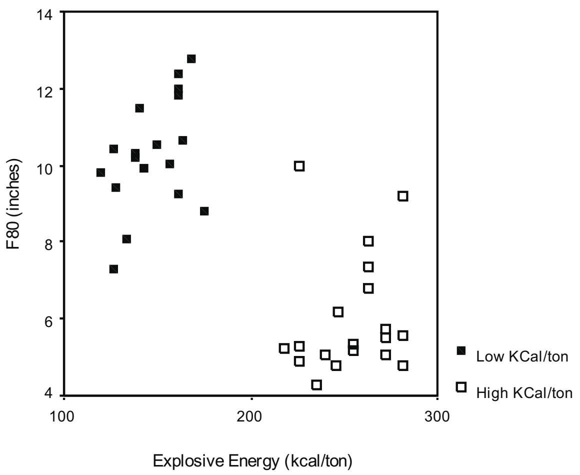


FIG 4 - a) Drilling specific energy (SE) versus primary crusher F80. Results from two blasts, a high-energy blast (average 250 kcal/t, unfilled squares) and a low energy blast (average 150 kcal/t, filled squares). b) Explosive Energy (kcal/ton) versus primary crusher F80. Each of the points in the figures represents the data from an individual blast hole.

post-blast fragmentation and the crushability and grindability of the ore, and the explosive energy per unit volume of rock. These three types of data are collected and analysed on a hole-by-hole basis, giving 50 or more data points for each blast. These data points form the basis for a statistical correlation between *in situ* conditions, blasting parameters, and the resulting fragmentation size and strength. At a specific mine, the database is continually updated as mining progresses, resulting in an evolving and increasingly accurate model with time. Neural networks or other learning algorithms are well suited for handling this evolving fragmentation model, and these types of models will be investigated in the future. Some sample results from a mine in Arizona have been presented. Even with the small data set shown, these results show the potential usefulness of being able to analyse data on a hole-by-hole basis.

This work is ongoing, and several additional aspects may be investigated in the future. Most importantly, data from the mines using this technique is continually being collected, resulting in improved correlations with time. Also, in addition to the F80 and P80 size information, additional size information can be used in the statistical analysis, including the F20, P20, F50 and P50. Additional blasting information could be utilised in the future, including the explosive geometry, particle velocity and detonation timing. Additional information about the rock mass could also be collected, including digital images of rock faces for determining detailed fracture information. Finally, laboratory tests are being planned to investigate changes in mechanical properties that occur due to changes in *in situ* and blasting conditions.

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REFERENCES

Bond, F C, 1952. The third theory of comminution, *Transactions AIME*, 193, 484.

Cunningham, C V B, 1987. Fragmentation estimation and the Kuz-Ram model – Four years on, in *Proceedings Fragblast '87*, Keystone, Colorado, pp 475-487.

Higgins, M, Seppala, V, Kemeny, J, BoBo, T and Girdner, K, 1999. Integrated software tools and methodology for optimization of blast fragmentation, Proceedings of the International Society of Explosive Engineers annual meeting, Nashville, TN.

Karanam, U M R and Misra, B. *Principles of Rock Drilling*, pp 111 – 144 (A A Balkema).

Kemeny, J, 1994. A practical technique for determining the size distribution of blasted benches, waste dumps and heap-leach sites, *Mining Engineering*, 46(11):1281-1284.

Kemeny, J, Girdner, K, BoBo, T and Norton, B, 1999. Improvements for fragmentation measurement by digital imaging: accurate estimation of fines, in *Proceedings FragBlast 6*, (South African Institute of Mining and Metallurgy: Johannesburg).

Miller, M. Normalization of specific energy, *Int J Rock Mech Min Sci*, pp 661-663.

Nielsen, K and Malvik, T, 1999. Grindability enhancement by blast-induced microcracks, *Powder Technology*, 105:52-56.

Peck, J and Gray, J, 1995. Total Mining Systems (TMS): the basis for open-pit automation, *CIM Bulletin*, 88(993):38-44.

Peshalov, Y A. Resistance of rocks to breaking by impact loads due to drilling, *Soviet Mining Science*, Vol 9, pp 97-100.

Protodyakonov, M M, 1962. Mechanical properties and drillability of rocks, in *Proceedings Fifth Symposium on Rock Mechanics*, pp 103-118.

Rabia, H and Brook, W, 1980. An empirical equations for drilling performance prediction, in *Proceedings 21st US Symposium on Rock Mechanics*, pp 103-111.

Schivley, G P. Predicting rotary drill performance, 20th Annual Conference on Explosive and Blasting Techniques.

Schmidt, R L, 1972. Drillability studies – Percussive drilling in the field. USBM RI 7684.

Teale, R, 1965. The concept of specific energy in rock drilling, *Int J Rock Mech Min Sci*, pp 57-73.

Tunstall, A and Bearman, R, 1997. Influence of fragmentation on crushing performance, *Mining Engineering*, Vol 49, pp 65-70.

Wills, B A, 1997. *Mineral Processing Technology*, Sixth Edition (Butterworth-Heinemann: Oxford).