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A MODEL STUDY TO MEASURE FRAGMENTATION BY BLASTING

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Abstract: Accurate measurement of blast fragmentation is important in mining and quarrying operations, to monitor blasting and optimize blast design. A new digital photoanalytical method to measure the size of fragments by using FragScan system is presented here. Photographs of the broken rock are digitized, and individual measurement, based on mathematical morphology techniques, achieves, within successive openings on a binary image, a numerical sieving. The method was tested during recent full scale blasting tests in the case of open pit gold mine of Amesmessa (Algeria). It shows great potential as a practical aid to predicting, monitoring, and controlling the quality of the fragmented rock.

Keywords: *FragScan, fragmentation, blasting, rock, explosive*

INTRODUCTION

Fragmentation describes the size distribution of fragments produced by blasting. The ideal design of blast should produce a fragmentation closely matched to that required for a specific application such as for rockfill or armor [riprap] stone, and reduce to a minimum the need for secondary blasting. Improved fragmentation in most applications means smaller fragments, and generally requires more drilling and more explosives, the costs, however, are offset by easier and cheaper loading, hauling, and crushing (Mackenzie, 1966).

Because fragmentation is so closely related to the economics of the mining and quarrying operation, it needs to be measured quickly and accurately. Several methods are used for determining the size distribution of fragments:

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- Boulder counting and visual estimates have been made on the photographs of the muck (Grant and Dutton, 1983). This method is rapid and inexpensive and has been found to have sufficient accuracy for some purposes.
- Sieving has been used extensively in scaled down blasting tests (Bergman et al., 1973; Scott et al., 1996), but is prohibitively slow and expensive for full scale production blasts. Despite its problems, the sieving remainder of the current reference measuring the size distribution of the fragmented rock. Thus, the relevance of the measurement by image analysis will be validated on the basis of the results of sieving.
- Predictions have been made for blasting parameters and rock mass properties, either using measured jointing alone (Van Zyl, 1986), empirical formulae (Gaudin and Meloy, 1962; Cunningham, 1983), or from computer simulations (Harries, 1975; DA Gama, 1984; Cook, et al., 2000; Delille, 2012). These methods, however, do not measure the actual fragmentation.
- Photographic methods have been developed in which some parameter of the size of fragments, such as length or cross sectional area, is measured on the image either manually (Carter, 1977; Aimone and Dowding, 1983) or using an image analyzing computer (Carlsson and Nyberg, 1983). These methods give biased measurements of fragments overlapped by other fragments. This represents a serious sampling error, as discussed below.

As part of a larger investigation to characterize rock fabric, a new method of measuring fragmentation by digital photo analysis has been developed at several (countries/organization) by using their own image analysis systems. This method measures the size of overlapping as well as non-overlapping fragments, and attempts to reconstruct the true size distribution.

This paper describes tests of the method, which were made of muck piles from full-scale blasts at an open pit gold mine owned and operated by ENOR Company located in Tamanrasset (Algeria).

The main justifications for the choice of this measurement method are:

- Reduction of operating costs;
- Continuous control of the fragmentation without interference with the production;
- Gain of execution time.

MEASURING TECHNIQUES

The process of photographing deriving a size distribution from the muck pile can be considered in four stages:

- Photographic sampling following a strategy designed to ensure that the size distributions in the photographs represent the muck pile as a whole;

- Digitization of the photograph by an automatic process involving image enhancement and edge detection;
- Measurement of apparent size of fragments on the photograph;
- Conversion of apparent to real size of fragment distributions.

PHOTOGRAPHIC SAMPLING

The muck piles were clearly heterogeneous with respect to fragment size. A photograph is a record only of a surface of section. The locations and directions of photography must be selected so that when the photographic data are extrapolated to three dimensions, they are representative of the whole muck pile. Three alternatives are possible:

- Photography on the muck pile;
- Photography on the trucks;
- Photography on hopper/belt**.**

PHOTOGRAPHY ON THE MUCK PILE

To photograph the complete muck pile from a camera. Aside from the obvious practical difficulties, this method might give a biased fragmentation measurement, because of the concentration of smaller fragments at the top of the muck pile.

To photograph a vertical cut through the length of the muck pile. This could have delayed mucking, and thereby reduced the production rate. Furthermore, excavation of a vertical face might have introduced further errors because of the collapse of the excavation and the plucking of larger fragments.

To correctly estimate the size of the fragments, photographic sampling must be perpendicular to the average plane of the fragments (Fig. 1. b).

This method was used in the tests, mainly by use of a second loader because it allowed sampling without delaying the other operations of production.

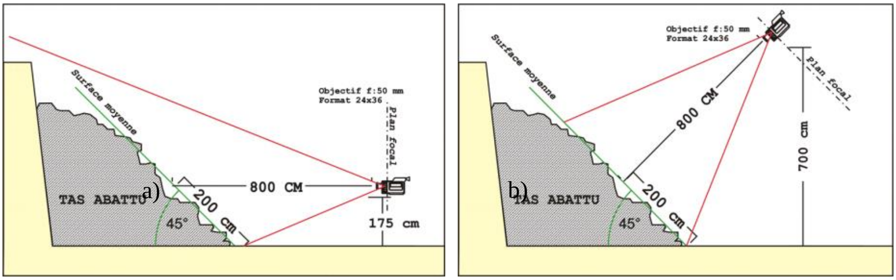

Fig. 1. The problem of parallax in the photographic sampling (Tessier, 2008)
a) Parallax error (b) Parallax well controlled

Globally, it is necessary to choose between a “muck pile” system, cheap and flexible, providing poor results, and a “truck” or “belt” system, providing good results, but at high costs.

A good way to see things would be to use the “muck pile” system for preliminary study, whereas other systems would be used for industrial implementation (Schleifer and Tessier, 2000).

PHOTOGRAPHY DEVELOPED

Regular intervals along the muck pile were fixed randomly. At each point, a muck pile sample was photographed for analysis. This allowed measurement of front to back variations.

While removing some biases. This method of sampling introduced others:

- A perspective error caused by the closely fragments appearing larger than the fragments further away.
- The largest size appeared to have a tendency to be thrown to the forward fringes of the pile, and the smallest to cover the upper surface. Sizes appeared to increase progressively from the back to the front of the pile, and lateral variations may also have been present.

To minimize the perspective error, photographs were taken at a suitable distance so that:

- Firstly, all fragments have the opportunity to appear in full as part of an image;
- And secondly, the images will be perfectly adapted to the digital analysis developed.

DEFINING AND DIGITIZING FRAGMENTS OUTLINES

Two methods of digitization, manual tracing (vector), and automatic scanning (raster) methods were available (Franklin and Morse, 1986). “Profiles” of fragments, defined as the outlines of completely or partially overlapped fragments, were stored in digital form as the vertices of polygons.

With the manual method, each photograph took two to three hours to digitize. In more recent studies the authors have made increasing use of the much faster automatic image analysis alternative. Techniques of image enhancement and edge detection are being developed to improve the recognition of fragments from the computer.

For this work, the automatic scanning method was used, in which photographs of the muck piles were automatically digitized.

The image processing operates on a digitized image of fragments. This image consists of a matrix of pixel, each pixel having a grey-level value ranging from 0 (black) to 255 (white) (Schleifer and Tessier, 1996).

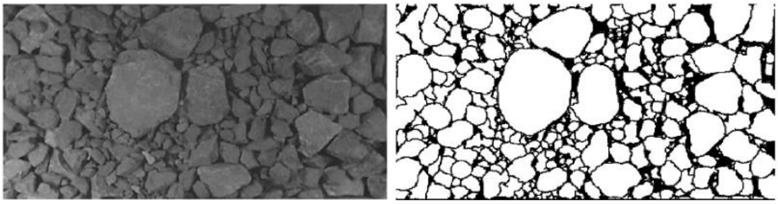

Fig. 2. Broken rock (left), digital image of fragment profiles (right)

In order to improve efficiency, we have opted to extract information on a binary image. For this reason, the first step is a conversion of a grey-level image into a binary image (Schleifer and Tessier, 1996).

With the resulting binary image, it is necessary to outline the fragments using the contours. Instead of trying to isolate fragments by recomposing the available incomplete contours, requiring a morphological marker on the original grey-level image, we have preferred to bound the portion of fragments with circular structuring elements, in fact dodecagonal elements because of the discrete image structure (Schleifer and Tessier, 1996).

MEASUREMENT OF FRAGMENT AREAS AND DIAMETERS

The area of each polygon (profile) was measured using the standard mensuration formula (Nyberg et al., 1982; Maerz et al., 1987). Areas are difficult to visualize, so fragment sizes were expressed in the FragScan system as the diameters of equivalent (equal-area) circles (D_C) (Fig. 3).

The term (equivalent circle), proposed by (Heywood, 1947) can correspond to two different definitions:

- The circle has the same area as the particle;
- The circle has the same perimeter as the particle.

From the viewpoint of image analysis, it is easier to calculate the area of the fragment that its perimeter. Therefore, the size of the fragment is often taken as the diameter of the circle having the same area (Out al, 2006). (Fig. 3).

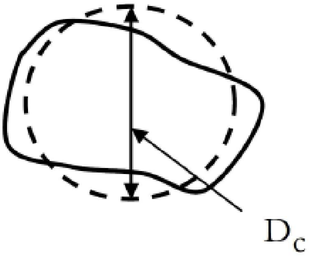

Fig. 3. Circle-equivalent diameter of the equal-area

DETERMINATION OF TRUE FRAGMENT SIZE DISTRIBUTION

This stage of analysis required converting the measured distribution of diameters (D_c) into a “true distribution”; the one that would be obtained if the particles were spread without overlaps. Fragment size must now be expressed three-dimensionally in terms of the diameter of an equivalent sphere (D_s), one with a volume equal to that of the particle. This allows easy conversion to fragment weight or mass, as measured by sieving. Quarry and mine operations are much more concerned with weight than with numbers of fragments, particularly when considering small-sized particles.

A somewhat similar problem has studied and solved by stereologists in the fields of biology, metallography, and petrography: that of obtaining true particle size distributions from apparent ones observed in microscopic thin or polished sections (Underwood, 1970; Weibel, 1980). In these cases, the (D_c) of a particle sliced at random is only some fraction of a diameter through its centroid. “Unfolding functions”, derived on the basis of geometric probabilities, are used to convert from (D_c) to (D_s) distributions. When however, some of these unfolding functions were obviously in error.

In the process of FragScan, the volume particle size is calculated based on the model of spheres (Schleifer, 2001).

With the information about partial contours, the reasoning is based on the notion of class. The area of the class obtained after two successive openings (of sizes μ_{i-1} and μ_i) is assumed to represent the projection of (n_i) spheres of diameter (d_i) representing the class size (Outal, 2006).

$$d_i = \frac{\mu_{i-1} + \mu_i}{2} \tag{1}$$

$$S_i = S_{\mu_i} - S_{\mu_{i-1}} \tag{2}$$

The volume of the class [μ_{i-1}; μ_i] is given by:

$$V_i = n_i \frac{4}{3}\pi\left(\frac{d_i}{2}\right)^3 \tag{3}$$

Corrections are used according to segregation and grouping problems (Chavez et al., 1996) as well as errors due to manipulation of subcontours. Adjustments are then carried out of, in the case of spread distributions for taking particular account of the fines incorrectly detected by image analysis.

Different models are used for the adjustment of particle size distributions (Allen, 1981; Ouchterlony, 2005). The two best-known models, and widely employed in the case of the particle size data for image analysis, are those of Gates-Gaudin-Schuhmann, and Rosin-Rammler-Bennet.

The FragScan system, based on the Swebrec© function for adjustment to predicting fines.

$$P(x) = \frac{1}{1 + \left[\ln\left(\frac{x_{\max}}{x}\right) \Big/ \ln\left(\frac{x_{\max}}{x_{50}}\right) \right]^{b}} \tag{4}$$

Where: x_{max} – maximum estimate size of passing;
x_{50} – median or size of 50 % passing;
b – curve-undulation parameter.

CASE STUDY

OBJECTIVES

The purpose of the full scale blasting tests at open pit gold mine of Amesmessa was to evaluate the relative performance of explosives in the rock of this particular open pit, and at the same time to evaluate the way of measuring performance, by the use of digital photoanalysis to measure fragmentation.

In this paper, we show in detail the results obtained for three blasts.

DESCRIPTION OF THE SITE

Gold deposit Amesmessa is located in the extreme south Algeria, in the south-west part of the Hoggar massif (Ahggar). The center coordinates are (2°29') east longitude and (20°59') of latitude (Fig. 4 and 5).

Fig. 4. Geographic situation of the open pit gold mine

A variable geological profile such as that shown in (Fig. 5), reflecting different rock materials can have a significant effect on open pit operation. The purpose was to select the rock to be blasted, and measure their fragmentation.

A Caterpillar excavator handles face loading with a $6m^3$ bucket loading into the company's fleet of three Caterpillar trucks which have 30t of capacity. The hopper's capacity is $30\ m^3$ and the opening of the primary crusher is (900x600 mm).

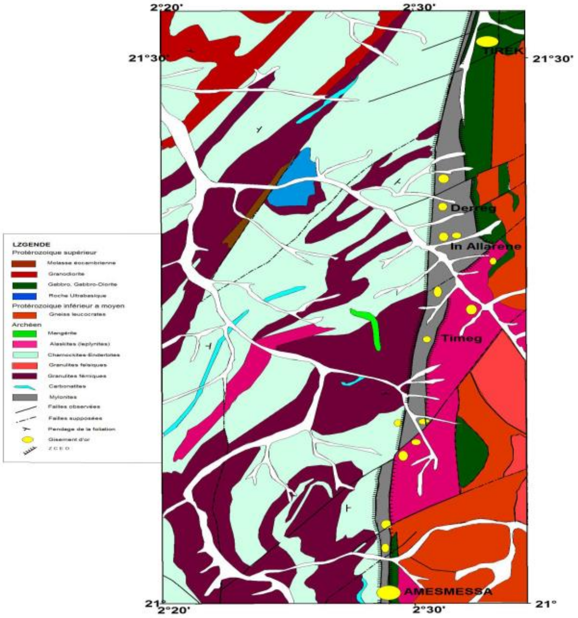

Fig. 5. Geological map locating the gold deposits
of the Tirek- Amesmessa region (ENOR, 1999)

GEOLOGICAL AND MINING CONDITIONS

The mineralized corps of the Amesmessa deposit is represented either by thin quartz veins (0.2 m to 2 m, rarely up to 3 m) and a fort dip varies between (55°÷60°) to (75°÷85°) west, whether by bérésitised areas. The contacts of mineralized corps are very tectonised. They are often made by friction argile. The pit of contact areas reaches (0,1÷10) m. Far contacts, rock cleavage decrease abruptly thereafter are weakly altered rocks. These rocks are sometimes cut by diagonal cracks. The stability of the roof and wall rock is very good. The foisonnement coefficient is about 1.6 (ENOR, 1999).

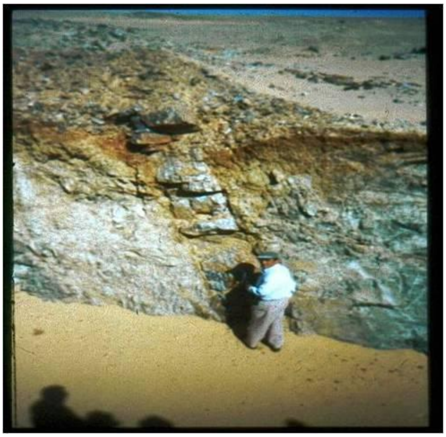

Fig. 6. Morphology of Corps deposit of Amesmessa (ORGM, 1995)

NATURE OF THE TEST BLASTS

Blasting is carried out only for (quartz). The hole pattern is 3.6 × 3.2 m and a typical bench for (quartz) is nearly 6 m high. The visual result of the fragmentation is shown in (Fig.7). Three separate blasts designated (A 2015, B 2015 and C 2015) were made, with the following database:

Table 1. Blasting parameters

Parameters	Size/description
Borehole diameter	102 mm
Bench height	6 m
Borehole Inclination	0°
Deposit	bancs multi direction
Hydrogeology	No water
Priming	punctual, hole
Primary explosive	Marmanit (III) Ø80 mm
Secondary explosive	Anfomil
Hole length	7 m
Burden	3.6 m
Spacing	3.2 m
Stemming length	2.68 m
Marmanit per hole	5 kg
Anfomil per hole	28.57 kg
Specific charge	0.47 kg/m^3

Fig. 7. Visual result of the fragmentation (Amesmessa Blast A 2015)

RESULTS

Table 2. Sieving carachtersic of blast (A 2015) determined by FragScan

Sieve size (mm)	Volume/Sieve (m^3)	Percentage (%)	Cumulative volume (m^3)
80	0,067656426	0,377947126	0,067656426
100	0,01729164	0,4745429	0,08494806
125	0,0248059	0,61311539	0,10975397
160	0,03436055	0,80506275	0,14411452
200	0,01915498	0,91206768	0,1632695
250	0,00784433	0,95588823	0,17111383
315	0,00789646	1	0,17901029
400 and > 400	0	1	0,17901029

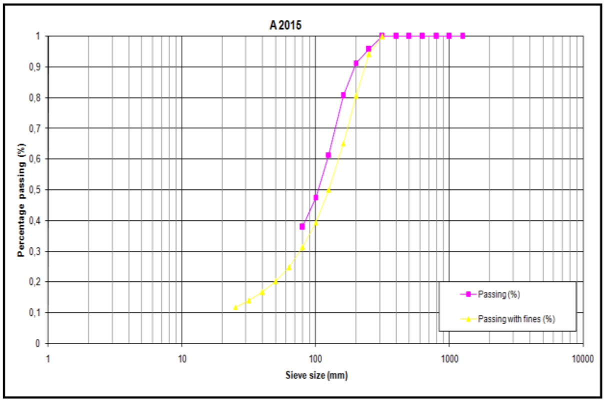

Fig. 8. Fragment size distribution for blast (A 2015)
Curve fit parameters (Table 2): x_{50} = 125 mm, x_{max} = 315 mm and b = 2

Table 3. Sieving carachtersic of blast (B 2015) determined by FragScan

Sieve size (mm)	Volume/Sieve (m^3)	Percentage (%)	Cumulative volume (m^3)
80	0,06288157	0,426997704	0,06288157
100	0,01411918	0,52287409	0,07700075
125	0,01641741	0,6343566	0,09341816
160	0,01992516	0,76965853	0,11334332
200	0,01692355	0,884578	0,13026687
250	0,01699755	1	0,14726442
315 and > 315	0	1	0,14726442

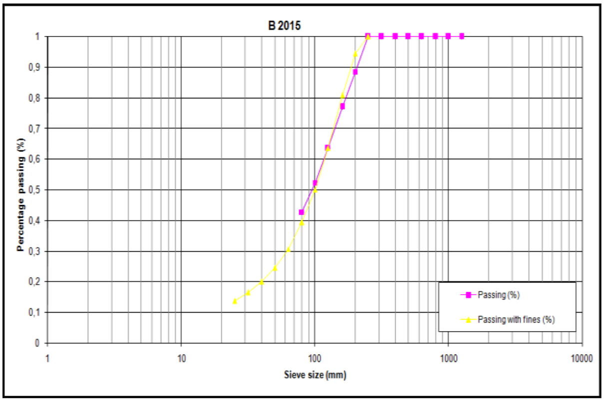

Fig. 9. Fragment size distribution for blast (B 2015).
Curve fit parameters (Table 3): x_{50} = 100 mm, x_{max} = 250 mm and b = 2

Table 4. Sieving carachtersic of blast (C 2015) determined by FragScan

Sieve size (mm)	Volume/Sieve (m^3)	Percentage (%)	Cumulative volume (m^3)
80	0,336677571	0,246370734	0,336677571
100	0,11501549	0,33053569	0,45169307
125	0,14994401	0,4402603	0,60163707
160	0,23347482	0,6111103	0,83511189
200	0,21579326	0,76902145	1,05090516
250	0,13726105	0,86946505	1,1881662
315	0,09636631	0,93998307	1,28453251
400	0,08201604	1	1,36654856
500 and > 500	0	1	1,36654856

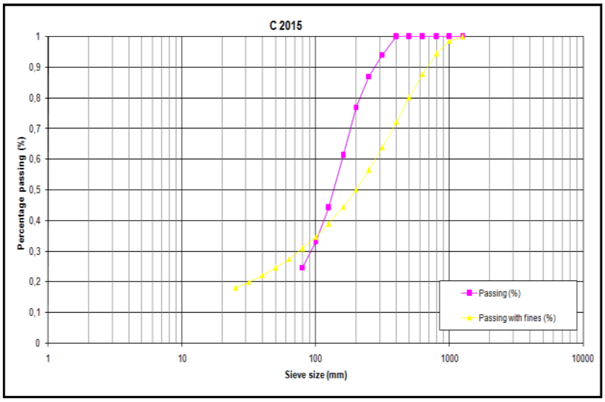

Fig. 10. Fragment size distribution for blast (C 2015).
Curve fit parameters (Table 4): x_{50} = 200 mm, x_{max} = 1250 mm and b = 2

CONCLUSION

There are considerably economics incentives to determine quantitative relationships to enable the design of efficient blasting operations.

The results obtained for the blasts (A2015, B2015 and C2015) shown in Figs (8, 9 and 10) are typical. Their shape of the distribution function, and particularly the form of its upper part (large size), does not influence the loading carried out by an excavator of (6 m^3, for capacity) and crushing operation (900×600 mm, opening for the primary crusher installed), energy consumption and equipment wear. Adequate blasting can give fragments that are too optimum for the crusher to handle. In some operations, oversized fragments must be laboriously broken with a drop ball or secondary blasting. In any case, a small proportion of such fragments on either a number or weight basis can have a substantial effect on the economics of mining.

Therefore the form of the distribution function, that has for the extreme sieve size (400 mm) (Table 4 and Fig 10), is particularly important to the operator, because in mining we consider for upper block size more than fines. A measure of the form of the upper tail of the distribution function has the potential to give accurate estimates of the fractions, and might therefore be useful for assessing the adequacy of the fragmentation.

The test blasts demonstrated a link between rock size before and after blasting. Rock which was initially more closely jointed tended to finish up in smaller fragments.

Despite being at an advanced stage in the development of methods, the photoanalytical technique compares favorably with conventional methods of measuring fragmentation, like sieving, which is simply not economically feasible for large sizes such as riprap or armorstone. Even for smaller sizes, such as routine blast fragmentation, the costs in time and effort are prohibitive. Using the comprehensive photographic record, stored digitally, analysis can be carried out without disrupting production, and results can be re-analyzed at a later date if necessary.

Solving of actual production problems need to conduct advanced applications, and in that way Fragscan system leads to higher profits (optimisation of blasting parameters, selection of industrial équipment). Method of sampling and digitization based on the FragScan system has been tested. This method has been concerned for correcting the apparent size distribution to give a true volumetric or weight distribution of the broken rock. It showed a performance for measuring of the fragmentation by blasting with explosives.

The photoanalysis technique will, however, become much more efficient, and a really useful and practical tool, with replacement of the vector by the raster (automatic) method of digitization, and with further development of formula, testing it for scale effects, different size distribution and fragment shapes.

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