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Optical sizing analysis of blasted rock: lessons learned

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ABSTRACT: Optical sizing of blasted rock has been used for about 15 years. Originally thought of as a specification type of measurement tool, it has over the years evolved into a process control tool. Because of the difficulty defining what the size of an irregular fragment is, it is difficult to reconcile different methods of measurement. Screening nominally measures intermediate diameter of particles, whereas optical methods typically measure a statistical average diameter. Because of the need for rapid non-disruptive measurements, optical systems measure particles in-situ while screening systems in essence handle each particle individually. These optical systems are faced with the need to calibrate for partially overlapped pieces, and fines that are too small to resolve in a single image or have fallen in and behind larger fragments.

Given all these issues, optical sizing has enjoyed much greater success as a process control tool, evolved to measuring size distributions of material on conveyor belts, where issues of lighting variability, camera positioning, and sampling biases are easily controlled. As a process control tool it can be used to establish operating norms and to trigger alarms when the measured sizes move outside the measured norms. The typical application for such a system is to control feed sizes to processes such as crushing and grinding.

Once the fragmentation is on a conveyor belt, it has usually passed through a primary crusher and thus is no longer completely indicative of the blasting process. In order to make measurements that reflect original blast sizes, but do not suffer from the issues associated with imaging muck piles, the images must of necessity be made between loading from the muck pile and dumping into the primary crusher. In practice, for many operations, this means that the best measurements can be made by imaging the rock while in transit between the muck pile and the primary crushing station. This includes surface and underground HD (Haul Dump) and LHD (Load Haul Dump) type vehicles which can be imaged as they dump, or prepare to dump, or as they pass through a gate or other restriction. Measurements of this type are much more complex. Systems need to use triggering systems to inform the software when to acquire the image, tracking systems to determine where the material has come from, and software algorithms to determine which part of the images contain rock to be measured and which contain extraneous information.

1. INTRODUCTION

Optical sizing of fragmented and crushed rock arrived with great fanfare about 15 years ago. It was to be fast, cheap, and objective. Before too long more than a few systems were commercially available. A review is given by Franklin et al. (1996). The WipFrag System first proposed in 1987 (Maerz et al. 1987) and commercialized in 1995 (Maerz et al. 1996), was initially used primarily to characterize the size distribution of muck piles (Maerz, 1999).

But it also did not take long before it became apparent that the original goal of measuring gradations for the purposes of determining if fairly precise and narrow specifications were being met was found to be difficult. The reasons for this are twofold.

2. WHAT IS PARTICLE SIZE?

In the first case, the size of an irregular particle of complex shape is hard to define. Rawle (2002) suggests that this is not a stupid question, and furthermore states that it is not possible to describe the size and shape with a single number. He postulates some measures such as the size of a bounding box or the diameter of a sphere/cylinder of equivalent volume to the particle.

Aspect Ratio	Angular fragments	Maximum Size	Rounded fragments	Maximum Size
1:1		0.75"		0.75"
2:1		0.75"		0.86"
3:1		0.83"		0.91"
4:1		0.91"		0.95"
5:1		0.95"		1.00"

Figure 1. Simulation of particles passing through a 19.1 mm (3/4”) screen. This shows that a 25.4 mm (1”) (nominal intermediate diameter) fragment with a flatness (aspect) ratio of 5:1 could pass through a 19.1 mm (3/4”) screen.

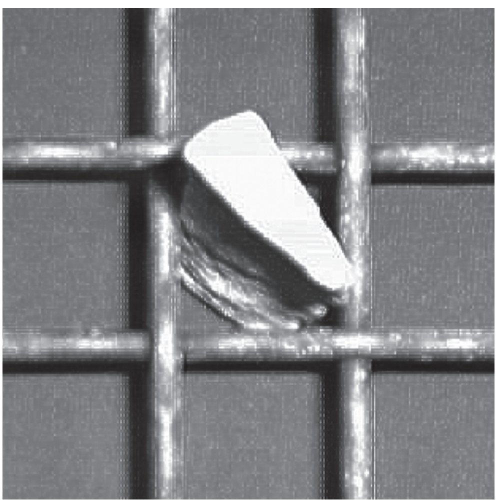

Figure 2. Example of a fragment with an intermediate nominal diameter of 25.4 mm (1”) that, because of flatness, passes through a 19.1 mm (3/4”) sieve.

Traditional screening has defined the size of a fragment as the smallest square opening that the particle can pass through. Because the elongated particles can rotate and pass through screens in the direction of their longest axis, we can say that the screening nominally measures the intermediate diameter. Even that is not strictly true, as the particle flatness also dictates which screen a particle will pass through (Figures 1, 2). So what is the particle size? It is unique to and defined by the screening mechanism and cannot be duplicated any other way.

Optical systems measured different aspects of fragment size. The typical optical measurement is one like the diameter of a sphere of equivalent volume, or more precisely the diameter of a circle of equivalent area to the profile of a fragment, as a fragment is typically imaged in 2 dimensions. Small wonder that matching screening results is a challenge.

2.1 Need for rapid non-disruptive measurements

In the second case optical measurements are typically made on assemblages of rock, where there are sampling bias issues: Smaller pieces often are hidden behind larger pieces, some pieces are partially overlapped, and the finer fines are typically too small to be resolved on the images.

Calibrations and extrapolations help match sieving results, but not precisely enough to be able to meet tight size specifications.

2.2 Process control

The real strength of optical systems is, however, in the area of process control. The systems evolved in that direction because of the fundamental fact that optical systems are better at being precise than accurate. That is to say, optical systems turn out to be very good at tracking specific indicators.

The most useful way of using these systems is to track a size parameter, say the D80 value. Empirically the deviation range for that parameter during normal operations is determined, and operational limits are set. During production, if the D80 values consistently stay within that range, the operator knows that the production is within specification. If the D80 value falls outside this range, experience tells the operator that something is wrong, and gives him the opportunity to determine the problem before massive amounts of ‘off-specification’ materials are produced.

3. IMAGING MUCK PILES

The easiest way to measure size distributions of blasted rock is to photograph the shot rock as it lies in the muck pile (Figures 3, 4), using a simple camcorder to image a pile of rock with a scale bar showing in the image. Various studies attest to the success of this approach (Bartley & Trousselle 1998, Chiappetta 1998, Ethier et al. 1999, Barkley & Carter 1999, Palangio & Maerz 1999).

Still, muckpiles are inhomogeneous, natural lighting conditions vary, depending on sun angle and cloud cover, and camera angles can be quite variable. These and other errors were studied and quantified (Maerz & Zhou 1999), (Maerz & Zhou 2001). From these studies the following factors were identified as most important in improving the accuracy of the measurements:

Figure 3. A roving camcorder used to image a muckpile.

Figure 4. Typical image of a muck pile taken with a roving camcorder; there is a scaling device in the foreground of the image.

- Consistent image quality, including uniform and constant lighting
- Fixed scale of observation
- Elimination of sampling biases

Although consistent image quality, lighting, and camera position can be maintained with careful effort; eliminating serious sampling biases when measuring muck piles is difficult because of the segregation in the pile. Significant effort is needed to ensure there are no sampling biases.

4. IMAGING CONVEYOR BELTS

Measurements made on conveyor belts (Figures 5, 6), by their very nature solve most of the above problems. Consistent image quality can be ensured by providing artificial lighting in a controlled environment. Constant scale of observation is guaranteed by fixed mounted cameras. Sampling biases are severely reduced because a) all the material is sequentially paraded before the camera, and b) gravity segregation can be assumed to be constant and calibrated out. Various studies attest to the success of this approach (Elliot et al. 1999, Bouajila et al. 2000, Dance 2001, Maerz 2001).

The only difficulty in conveyor belt applications is that the blast size distribution has already been altered by primary crushing, since in most cases the conveyor systems begin only after the primary crusher. In addition there is typically no indication as to which part of the quarry the material may have originated.

4.1 Modifications needed

When imaging a muck pile using a roving camera, there is a lot of manual effort involved, and there is opportunity to delete inappropriate images, use manual editing to better define and resolve individual fragments, and to interpret and act on the data. Moving to conveyor belts, the software has to:

- Have some mechanism to eliminate inappropriate images, such as when the belt is stopped, or empty, or obscured by dust
- Have robust edge detection, as manual editing is not feasible when analysing at up to 5 analyses per second
- Have some real time reporting system, including contingency plans

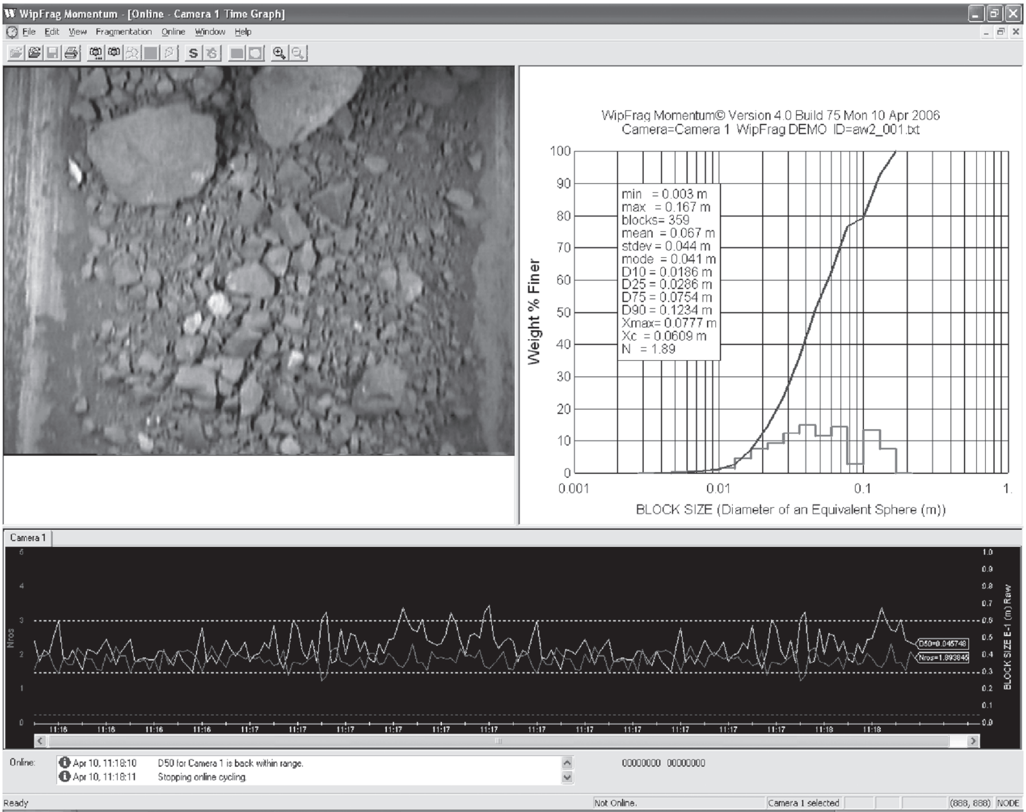

Figure 7. Example WipFrag online output showing image window, current image size distribution, and timeline of D50 and NRos (Rosin-Rammler slope coefficient).

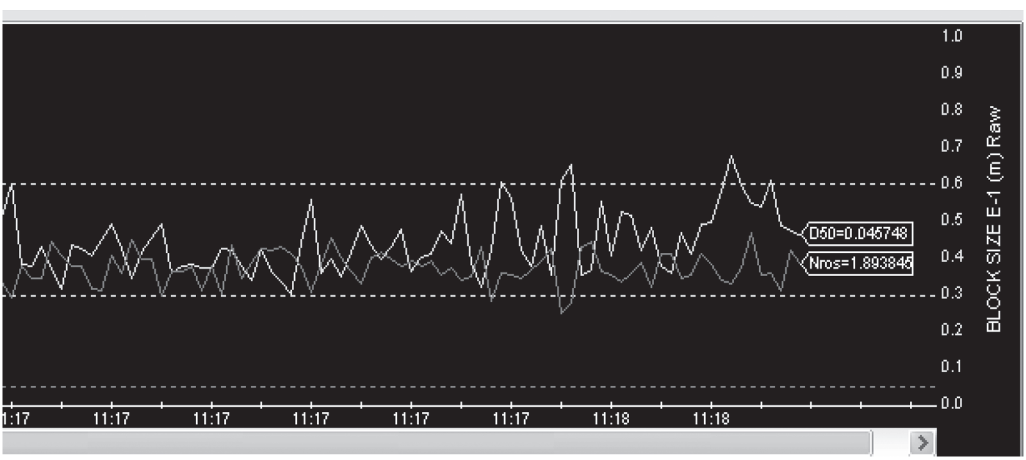

Figure 8. Close up of time graph from Figure 7 showing size limits for D50 parameter in dashed blue lines. When either the upper or lower limit is exceeded, an alarm will sound.

4.1.1 Inappropriate image elimination

On conveyor belts with a continuous stream of material, timing of the imaging process can be left up to the software. When the software is ready for the next image, it can trigger an acquisition knowing that any image it takes should be adequate. The condition of empty or stopped belts can be signalled to the software using TTL (Transistor-Transistor Logic) signals, or using OPC (OLE for Process Control).

For empty belts or belts obscured by dust, software image filters can be used that 'recognize' inappropriate images by their spectral characteristics.

4.1.2 Reporting system

Many varieties of reporting systems are available. Data can be written to disk files including database files, that can be accessed later or in real time by control systems. Data can be sent thought RS232 protocols such as MODBUS, or communicate to mine control system through OPC. Simpler outputs consist of a 4-20 mA current loop and TTL I/O triggers that can set off alarms when pre-determined conditions are encountered (Figures 7, 8).

5. IMAGING TIPPING TRUCKS

Because of the two issues with measurements made on conveyor belts, the fact that the distribution has typically already been altered by primary crushing and so is not a primary measure of blasting, and the ambiguity about the source of the material where mucking is taking place in multiple locations, another mode of operation was needed.

Since all material in a typical operation passes through the primary crusher bottleneck, that turns out to be the most effective place for imaging the fragmentation. Using the feed bin or crusher hopper (Figure 9) is difficult, as it is intermittently full and empty, then half full, etc. In addition there is still no indication for the source of the material.

Imaging the material in the back of trucks as it is being transported is a better solution. Figure 10 shows a Load Haul (LH) truck on its way to the primary crusher. A better solution is imaging the material as is being dumped into the crusher (Figure 11, because multiple images of the material can be acquired as the tipping process proceeds. This process was first described by Maerz & Palangio (2004), Palangio et al. (2005) and Eloranta et al. (2007).

Figure 9. Fragmentation in primary feed bin.

Figure 10. Image of fragmentation in bucket of LH (Load Haul vehicle.

5.1 Modifications needed

When imaging, there are new issues that have to be dealt with. There is not always material present (in the backs of trucks), and when it is, it is not exactly in the same place every time. Images show truck boxes, and complex noisy backgrounds. The software needs to execute many complex functions in order to obtain a suitable image for analysis such as:

- 'Sense' the presence of a sample
- 'Wake up' from a dormant state
- 'Identify' the vehicle and origin of material
- 'Determine' whether or not the bucket is full or empty
- 'Image' the bucket

Figure 11. Sequence of truck tipping images.

- ‘Discard’ any parts of the image that do not show rock material
- ‘Analyze’ the image with an advanced fragmentation analysis system
- ‘Collect’ the information in a comprehensive database
- ‘Share’ the information over a network
- ‘Sleep’ if no further activity is detected

These complex functions required a significant expansion of sensory capabilities, breakthrough development of system logic and the tight integration of tracking technology with analysis results.

5.2 Triggering system

The software contains a 3-fold triggering system, and triggers can be prioritized in any combination and order. One of the triggers is the tracking system described below. It is a non-precise trigger, telling the system that a truck is in proximity, but does not distinguish between a truck that is just approaching the dumping area or one that is in the process of dumping. A second trigger is a hardware trigger that uses an ultrasonic or microwave path that is interrupted by either the truck moving in position, the box of the truck tipping up, or the drop of rock off the end of the truck. The third trigger is a software or ‘pixel’ trigger, which interprets a predetermined part of the scene and triggers if that part of the image contains information that is representative of rock fragments.

5.3 Tracking system

An active RFID type tracking system is integrated into the truck tipping measurement system. In addition to identifying the truck, the tag can dynamically store data, such as weight or source of the material.

Figure 12. A Haul Dump (HD) truck with an RFID tag.

Figure 13. Imaging at a truck dumping station at Municipal Quarry in Bedford, Nova Scotia, Canada.

A single active RFID tag reader/writer is located in close proximity to the camera unit and lighting, and an optional tag writer can be put in he area where mucking is taking place, to identify the source of the material. On the truck is a tag (Figure 12) which has a battery life of 10 years.

The tagging system also complements the triggering system. Since the tagging system can only identify a truck within a range of a few meters it can override false triggers when a valid truck is not present. This will reduce the chances of false triggers from service vehicles.

5.4 Vehicle positioning

On a conveyer belt, the rock to be measured is always at the same place with respect to the camera. For muck pile sampling, image position is done by an operator. However when measuring rock in moving images (in an automated system) a problem that comes up is that the vehicle is not always in the same position. Consequently there is a possibility that any given image is not centered over the vehicle, which will result in some error.

The solution is to capture the image at a point where the vehicle always passes a fixed point, or alternatively force the vehicle to drive into that position. In the case of truck tipping, a good location is the tipping station, since the truck is typically in the same position, and it is not moving at that point (Figure 13). For underground haulage, a good location is in narrow passes where the conveyance vehicle is naturally channelled into a narrow lane (Figure 14).

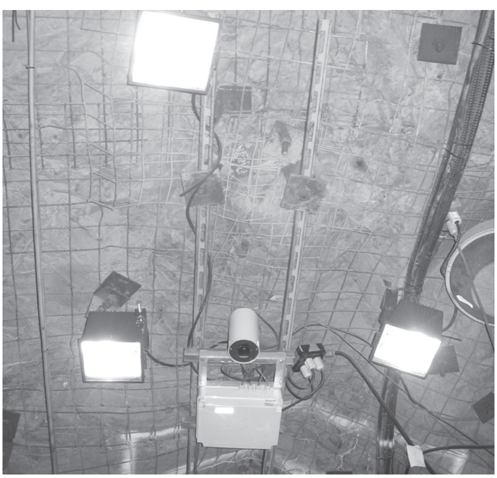

Figure 14. Imaging LHD vehicles as they pass through a narrow passage at an INCO mine in Sudbury Canada. Image shows lighting, camera enclosure, and nearby RFID tag reader.

5.5 Removing extraneous features from the images

An intelligent image exclusion zone feature (a way of distinguishing between rock, and objects such as the edges of the container) was required to ensure that only the rock material in the bucket or truck bed part of the image is analyzed instead of other items such as the vehicle, ground or background. This is because the edge detection algorithm will attempt to force edges onto everything on the image, including those of foreign materials.

5.6 Environmental conditions

Dust, fog, rain, snow and particulates can be an issue if they obstruct the image or the triggering mechanism. Infrared lighting in underground applications will eliminate much of the dust problem; however, surface applications usually have more difficulty with this issue. Software image filters are used which require certain image quality criteria to be met prior to image analysis, this filter will discard any non-suitable images from a 'set' taken from a tipping event, for example when a HD type vehicle approaches the crusher to dump, the system will take a preset number if images (usually 3-5) during the dumping process, prior to analysis it will audit each image to determine if the image characteristics are suitable for an analysis. If it is, the image is analyzed, if it is not, the image is discarded, as for example when the dust from dumping starts to obscure the image.

Variable daylight conditions serve to confuse the image analysis sequence. Light intensity variations, sun angles, superstructure shadows, and differences between natural and artificial lighting all serve to create small differences in the analysis results. Solutions range from shielding the material from direct sunlight or operating at night only to accepting the errors.

6. CONCLUSIONS

Fifteen years of experience has shown that optical fragmentation systems are better suited for process control than specification, being more precise than accurate. Fifteen years of experience has shown that to measure the size distribution produced by blasting is best done in transit on haul trucks, after being removed from the muck pile, and before entering the primary crusher.

Technological advances have provided all the hardware and software elements to accomplish this work. These include external and internal triggering mechanisms, RFID identification tags for tracking, and software filters to determine if images are valid and appropriate.

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