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ONLINE FRAGMENTATION ANALYSIS FOR GRINDING AND CRUSHING CONTROL

Norbert H. Maerz,
Assistant Professor,
Rock Mechanics and Explosives Research Center,
University of Missouri-Rolla, MO, USA,
(573) 341-6714,
norbert@umr.edu

and

Tom C. Palangio,
Vice President,
WipWare Inc.,
Bonfield, Ont., Canada.
(705) 776-8551,
tom@wipware.com

ABSTRACT

Control of crushing and grinding circuits ideally requires continuous particle size measurements on both in and outgoing streams. Until recently, size distributions could only be obtained by screening methods, which were neither cost effective, frequent enough, nor timely. Input streams are often composed of large fragments, making screening prohibitive.

Optical image processing systems, such as the WipFrag System have been developed to the point that they are an extremely valuable tool to characterize, control, and fine-tune the comminution process. Although accuracy is less than that of screening, measurements are precise enough to detect relatively small changes in size distributions.

INTRODUCTION

To optimize production from crushing and grinding requires measuring and controlling a number of different quantities on the input feed and output product, on a more or less continuous basis. Perhaps the most difficult quantity to measure is that of the fragmentation size distribution. Until recently size distributions could be obtained only by screening techniques. Screening is however time consuming and labor intensive. This translates to high costs and a significant lag time until the results of the analysis are known. Rock materials that come directly from blasting operations often contain large fragments. These are difficult to screen because of their very size, and because of the sheer size of sample required to adequately characterize a representative sample of the material. At the same time, there was no acceptable alternative.

Now however, there are alternatives to screening. One alternative is the use of optical image processing methods that use image analysis to measure size distributions from images taken with video cameras. The WipFrag fragmentation sizing system is an example of such a technology. It has been in widespread use for many years now (Maerz et al., 1987; Maerz et al., 1996; Maerz, 1998). It is being used in the explosives, mining, and materials handling industries for the purpose of evaluating the efficiency of the comminution process, whether by blasting, crushing, grinding, or inadvertently by materials handling processes.

Originally designed primarily to use images of rock piles from "roving cameras" (Figure 1), the experience gained with these types of systems has revealed the accuracy, precision, and errors associated with these systems (Maerz and Zhou, 1999a). By far the most significant source of error is sampling, whether a result of operator error, error obtaining a representative sample, or simply because the variability of the material is just too great for such a simple approach.

As a result it is being recognized that a better way to measure fragmentation is on line, either on a conveyor belt or free falling off the end of a conveyor belt (Figure 2). This has the advantage of discounting a significant amount of sampling bias, getting a larger statistical valid sample, as well as allowing real time process control if necessary. The WipFrag System was designed to meet all these requirements.

To further compensate for systematic sampling errors, workers have for the most part adapted a calibration as a standard (Maerz, and Zhou, 1999b; Barkley and Russell, 1999; Katsabanis, 1999). Others, recognizing that calibration is merely a transformation of measured results, and consequently does not refine the measurement or add precision, prefer not to calibrate and instead correlate measurement results directly to their application without calibration (Simkus and Dance, 1998).

AUTOMATED ON-LINE PROCESSING

Automated on-line processing has a special set of requirements that are not important when using a manual roving camera approach. Material needs to be imaged while moving at high speed. Data is acquired at such a high rate, that real time data reduction needs to be done to prevent an overload of data. For the same reason, manual editing of images is not feasible in real time. Inferior images, such as empty or near empty belts need to be automatically rejected.

At the same time the requirement for a conscientiously planned and executed sampling strategy, required with the roving camera approach, is no longer needed.

Moving images

Capturing moving images of materials moving at high speed requires the use of high speed video cameras with shutter speeds on the order of 1/4000 to 1/10000 sec, to freeze images of material travelling at speeds of several metres per second.

Secondly, because most video cameras use interlaced video, the interlacing must be removed. For typical video cameras such as those using the RS170 standard, (the monochrome version of NTSC), each video frame is constructed by alternately displaying two "fields", one containing the odd numbered lines of the image, the other containing the even numbered lines. Because these two fields, which are subsequently interlaced to form a single frame, are taken 1/60 of a second apart, it is difficult to freeze even images of slow moving material (Figure 3).

The interlace must be removed in software, or alternatively a non-interlaced or progressive-scan camera must be used. Alternatively, more expensive non-interlaced cameras can be used.

Frame averaging

Averaging the analysis results from a number of sequential images is used to remove variability caused both by short-term fluctuations in the nature of the material and system induced variability. These images can be acquired with exacting delays, depending on the speed of the belt, so that successive images cover a section of belt with no overlap and no missing sections. These images can then be analyzed once all have been acquired and stored in memory.

Alternatively, the images to be averaged can be sequentially imaged and analyzed, resulting in image delays on the order of 3 to 5 seconds, depending on the processing speed of the computer and the complexity of the image. Finally, the delays can be set at any greater interval.

Multiple cameras

Automated systems usually involve imaging from multiple cameras on multiple lines or on different parts of the same line. Consequently there is a requirement for sequencing and timing of the cameras.

Timing for each camera is set in two ways. Timing can be set between the acquisition of sequential images that are used for frame averaging; and, timing can be set between sequential analyses.

Separate configurations need to be stored and invoked for each camera. This is because lighting conditions, the geometry of imaging, and the nature of the material being imaged may be different.

Inappropriate images

Using manual imaging, images that are inappropriate for analysis are discarded or simply not acquired. In an automated mode, the decision to accept or reject an image is considerably more difficult.

Examples of inappropriate images are images where the belt is stopped, or empty, or partially loaded. Processing can be halted, by monitoring a TTL I/O ((Transister-Transister Logic Input/Output) input signal, generated electronically based on the speed of a belt motor, or the weight determined by a belt scale.

Another option is to use image filters that measure the characteristics of the image, and apply user input limits on a particular characteristic to determine if the image is appropriate. This can be used to reject empty or near empty belt conditions, as well as conditions like dust, fog, or steam obscured images.

Continuous reporting

Data presentation requirements for continuous on-line monitoring again are different than those for manual methods. Because of the large amount of data being generated, graphs showing the size distribution of each analysis are not useful. It is better to track one or several parameters throughout the course of the analysis, so that each analysis can be portrayed as a single data point on a time based chart (Figure 4).

The data used to generate this strip chart, in its various configurations is also saved on the computer as a continuous log file.

External communications

The biggest advantage of an on-line system is that it can generate measurement results in real time. Consequently it is useful to be able to send that information to control systems, so that they can act on information, such as adjusting belt feeds, mixtures, crusher setting, or shut down the system before a greater deal of material is produced that is out of specification. External communication can be done in several ways, depending on the application and the nature of the control system.

Digital TTL I/O. In the case of a rudimentary control system, or where process control is not highly automated, the fragmentation sizing software can be used to determine out of specification conditions by comparing any characteristic size measured on an image or series of images to a user supplied alarm threshold. The software then generates a TTL I/O output signal that electronically triggers an alarm, allowing the operator to stop production, or make adjustments to control systems.

Analog 4-20 mA current loop. Where control systems are more sophisticated, and are capable of proportional responses, but have limited programmability, a proportional signal is more appropriate. A 4-20 mA current loop output can be used to generate a current in proportion to a specified size passing, (e.g. D_{80}, defined as the size which 80% by weight of the sample is finer and 20% coarser). Thus the control system can possess its own knowledge of appropriate size ranges, and make decisions based on the degree of deviation from the norm. Current loops are largely unaffected by long transmission lines, and consequently can be transmitted over great distances.

Digital RS232. Where control systems are fully automated, and have advanced decision-making capability, it is more appropriate to send as much data as possible to the control system, including the information required to reconstruct the measured size distributions. This is best accomplished by using RS232 outputs to transmit a stream of digital encoded data. RS422 or digital current loop outputs can be used to transmit the same digital data over much greater distances than RS232.

ON-LINE EXPERIENCE IN THE MINING INDUSTRY

Material Services Quarry, Chicago

In a small investigation, a clear minus 5/8" crusher run product was measured in a stock pile, on a moving conveyor belt, and falling off the end of the conveyor belt (Figure 5). Size distributions from each of the analyses were compared to each other and to the specification, and found to be in close agreement. The measurement that was closest to the actual specification was from the images falling off the end of the conveyor belt. This has been attributed simply to the fact that in these images, the fines were more visible.

INCO Underground mining operations, Copper Cliff, Ontario, Canada

INCO mines uses on-line time-lapse video photography at drawpoints to characterize the fragmentation of their ore (Preston Lidkea, 1996). Images are transmitted to surface by broadband coaxial cable, fiber optic cables, or wireless transmission.

At INCO's Coleman mine, a large study using WipFrag resulted in a 40% pattern expansion, twice as good fragmentation, and considerable reduction of oversize (Palangio et al., 1995).

Highland Valley Copper, Logan Lake, B. C., Canada, grinding mill performance

Highland Valley Copper is using on-line monitoring of ore size, and combining it with ore hardness tracking to predict SAG (Semi-autogenous grinding) mill performance (Simkus and Dance, 1998). Figure 6 shows a typical image, and Figure 7 shows the correlation between the actual SAG mill throughput and the throughput predicted by the model that was developed based on feed size as measured by WipFrag and feed hardness. Highland Valley Copper is claiming a 10% increase in mill productivity as a result of controlling feeds based on size and hardness.

Brunswick Mining, Bathurst, N. B., Canada, autogenous grinding

Noranda's Brunswick mining has recently installed an on-line monitoring system to optimize feed sizes to maximize productivity for their new autogenous grinding mill (Figure 8).

Brunswick Mining, Belledune, N. B., Canada, smelter

Noranda's Brunswick smelting division has recently installed an on-line monitoring system to monitor and optimize return sinter size and uniformity for blast furnace optimization (Figure 8).

SUMMARY

Repeatable real time on line gradation measurements represents a significant input for the control of crushing and grinding operations. Optical image processing technologies are beginning to be used to provide such a capability to operators. Given their improved accuracy and sampling ability, and that they are also totally automated, on-line systems will certainly become more prominent in the future of the mining and materials handling industries.

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Figure 1. Typical "roving camera" approach to acquiring images for analysis.

Figure 2. Conveyor belt images.

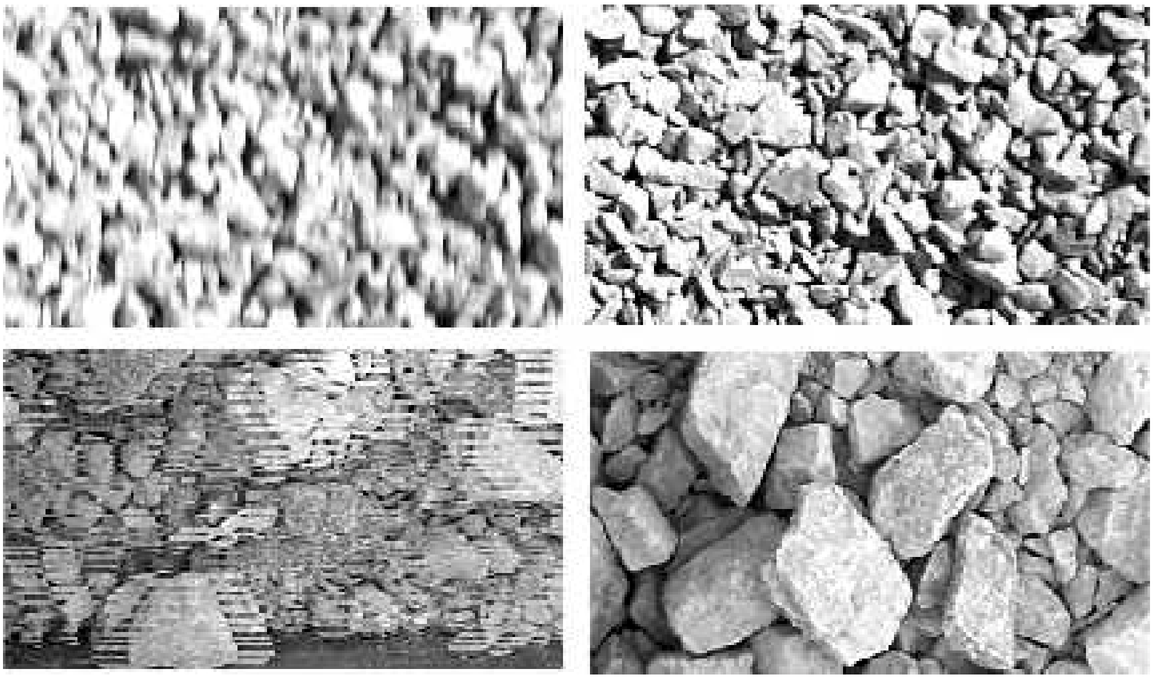

Figure 3. Examples of moving images. Top left: Shutter speed that is too slow. Top right: Adequately fast shutter speed. Bottom left: Interlaced image with high shutter speed. Bottom right: Interlaced removed.

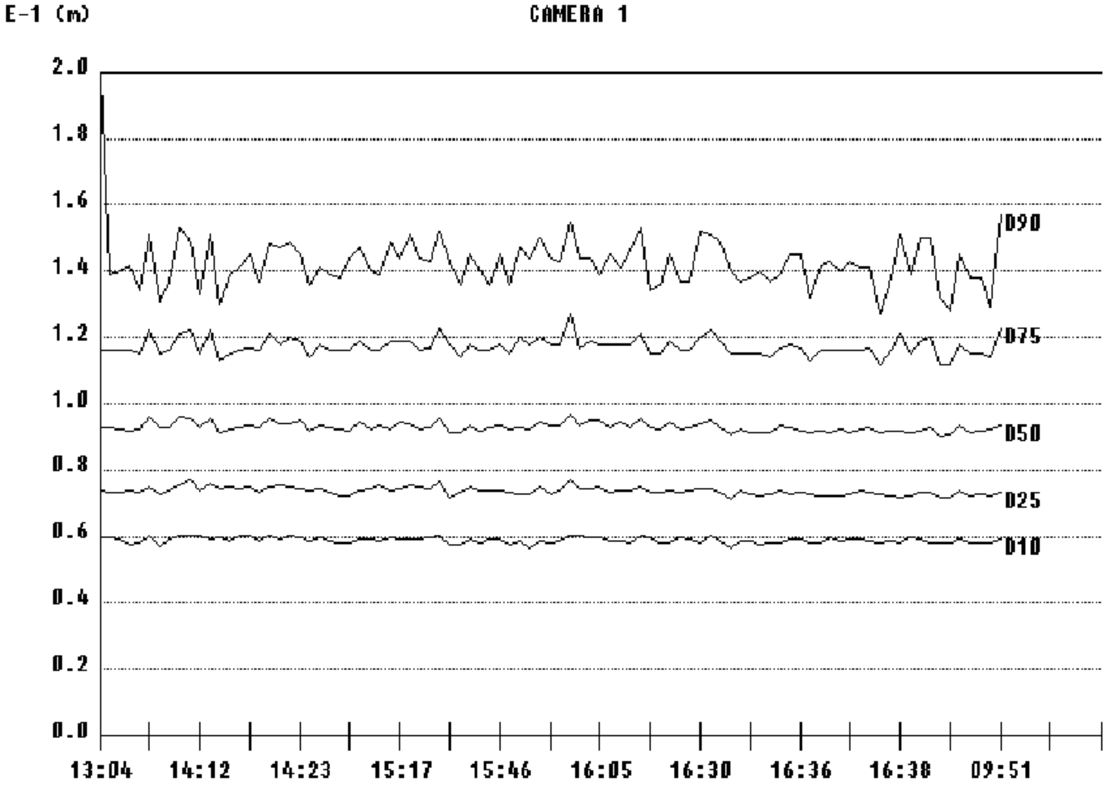

Figure 4. Time strip chart showing D_{90} (denoting size where 90% of the material by weight is finer and 10% coarser). Vertical axis is size in metres, horizontal axis is time of day.

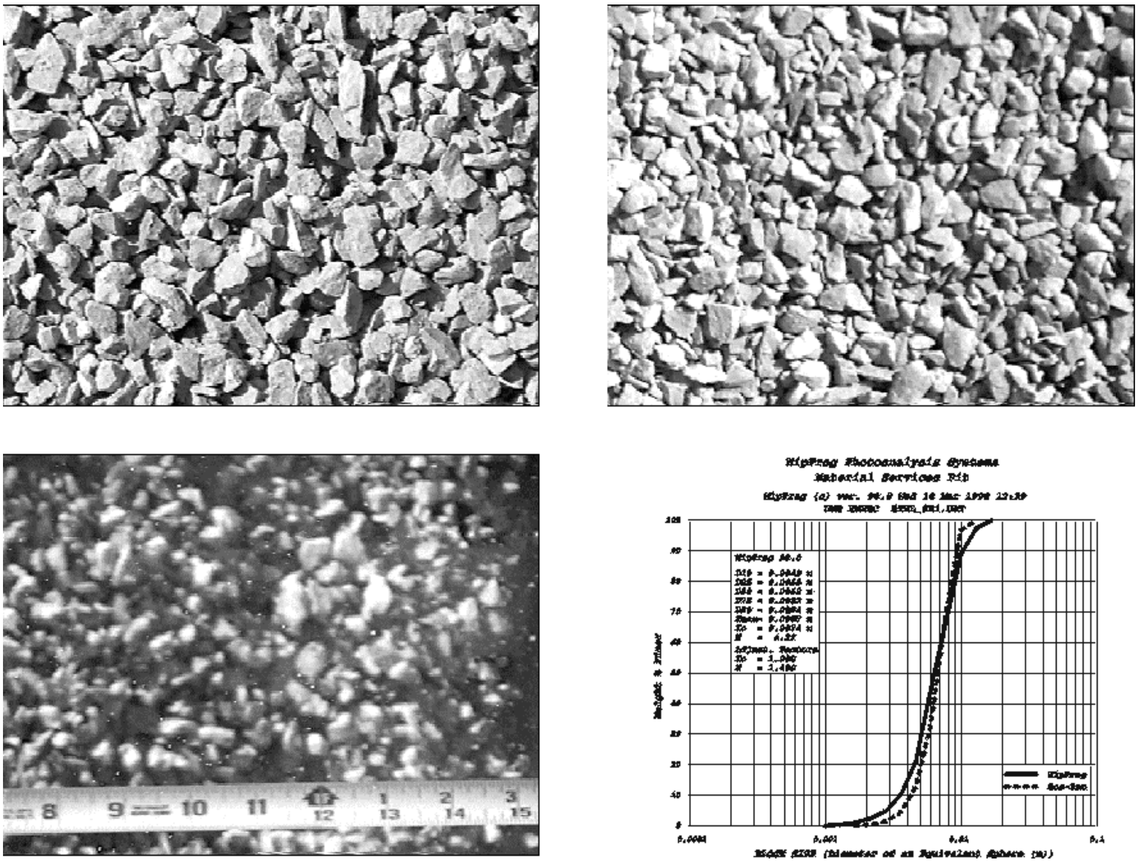

Figure 5. Images of a crusher run product. Top left: Static Image on stockpile. Top right: On moving conveyor belt. Bottom left: Falling off end of conveyor belt. Bottom right: Measured size distribution vs. Rosin-Rammler fit of sieved distribution.

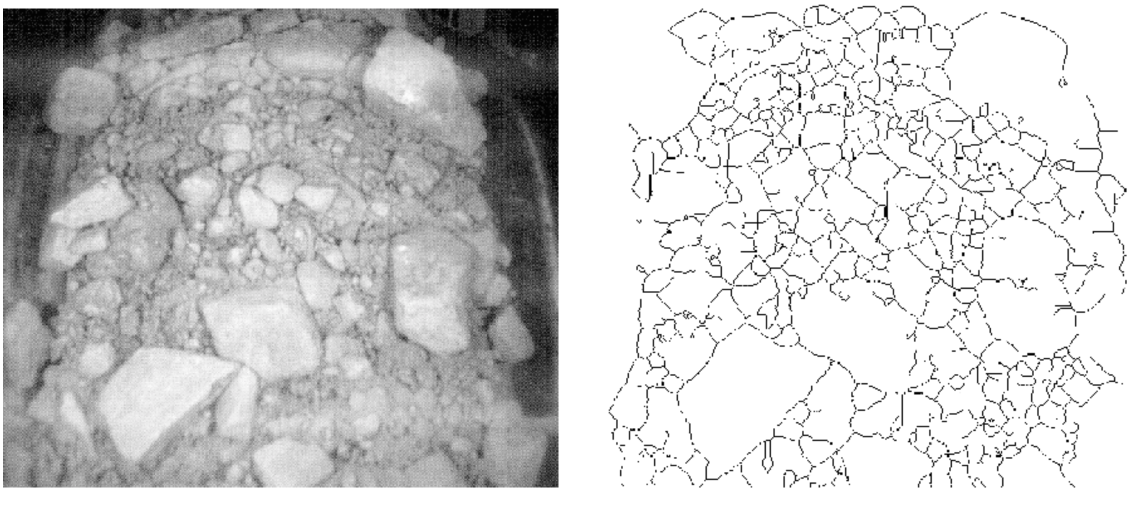

Figure 6. Typical Highland Valley copper image of ore free falling off the end of a transfer chute, and the WipFrag generated block outlines (Simkus and Dance, 1998).

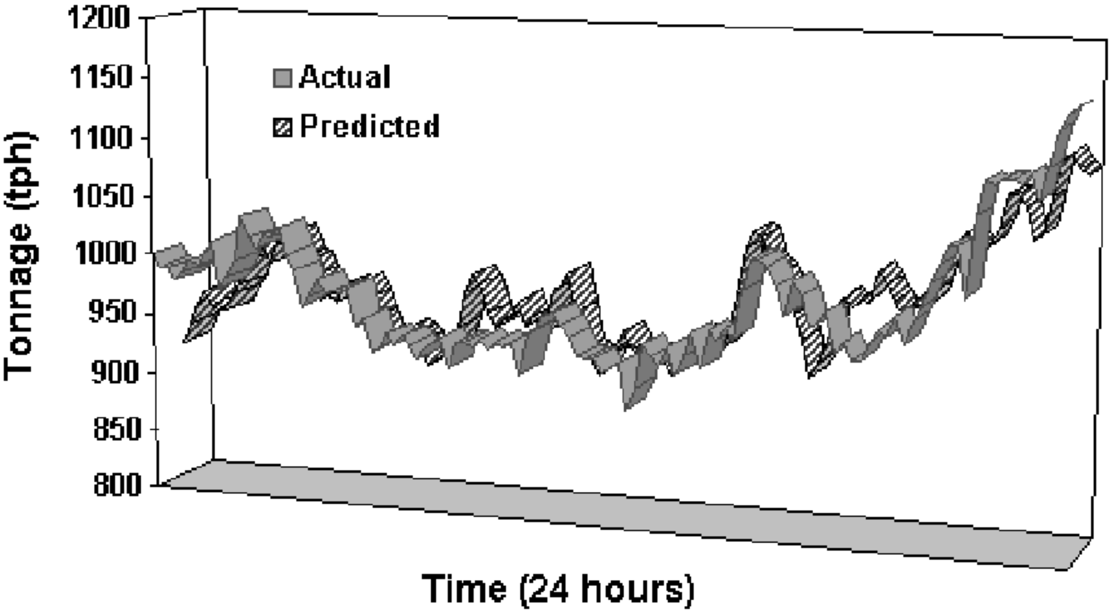

Figure 7. Comparison of predicted (modeled) vs. actual mill throughput based on input parameters of size and hardness (Simkus and Dance, 1998).

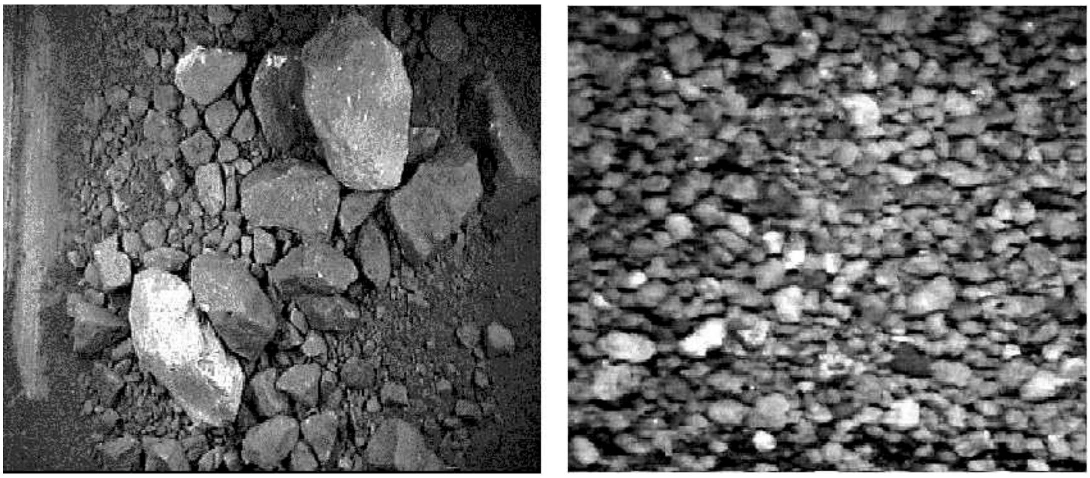

Figure 8: Brunswick Images. Left: Fragmented lead ore rock on conveyor belt in grinding mill; Right: Sinter (lead concentrate) on conveyor belt in smelter.