<u>Size Matters on the Mesabi Range</u>

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Abstract

The fragmentation distribution of the blasted ore is an important descriptor of blasting results. Traditionally it has been hard to measure quantitatively. Developments in image analysis over several years makes it more feasible to measure fragmentation before crushing on a continuous basis. Post crushing, mill feed distributions can also be measured.

Drill to mill studies and implementations have shown that large sums of money can be saved and production increased when fragmentation is calibrated to downstream needs. An essential component of this process is the ability to measure fragmentation and make adjustments when distributions trend away from optimum.

This paper discusses the history of fragmentation analysis on the Mesabi Range in Minnesota. The history of image analysis is discussed and current static and on-line analysis technology is described.

The paper also discusses recent truck tipping and conveyor belt systems installed on the Range. Goals for the systems and some results are presented.

Two conveyor belt on-line systems, for measuring the size distribution of greenball pellets are briefly discussed.

Introduction

The production of metal concentrates has two energy intensive components: haulage and size reduction. The advent of the microprocessor has spawned an ever-growing array of instruments which provide insight into the individual processes that make up a mine-plant flowsheet. The measurements from these instruments has led to improved control and management within the flowsheet.

Yet, there remains a 'blind spot' in flowsheet management. That is the run-of-mine (ROM) size of material. ROM size defines the end product of blasting and is the starting size for plant processing. Machine vision systems can now give a clear picture of this critical measurement

This technical paper will describe the evolution of sizing technology as well as outline case specific applications of automated vehicle conveyance analysis. It also describes recent developments on the Mesabi Range in measuring the size of material being fed to the plant while also evaluating the efficacy of blast techniques and the influence of rock mass characteristics of the geologic horizons.

Background and Previous Work

Mesabi Range efforts at establishing ROM size for taconite were underway by 1956. At that time a sample of under 100 tons was dumped on a concrete apron. The large fragments were hand measured and the finer material was loaded into a screening plant.

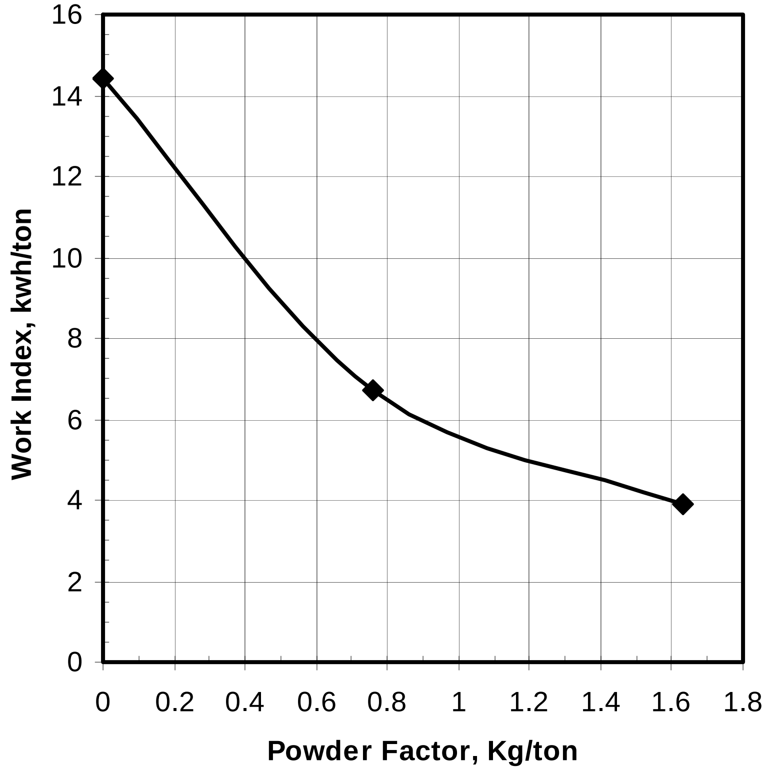
The Coleraine Minerals Research lab in Coleraine, MN conducted an extensive study of ROM size which was published in 1993. Pictures of train car loads of ore were photographed. The photos were hand scaled to create size estimates. One-twelfth scale models were created and measured for comparison. Also, aspect ratios for fragments were measured for ROM rock.

US Steel – Minntac operated a prototype on-line size analyzer in 1994 and 1995. The project was jointly funded by area mines and the software was written by Steve Grannes of the USBM. Noramco Engineering Company subsequently licensed the technology, but was unable to successfully commercialize the product. They did install at least two units: one at Southern Peru Copper and one at the LTV mine in Hoyt Lakes, MN.

There is considerable evidence that blasting results affect downstream operations through grinding, and possibly even to mineral recovery. A previous paper (Workman and Eloranta, 2003) has shown that benefits are a result of "seen" and "unseen" fragmentation. The paper focused primarily on energy consumption in crushing and grinding. Using the Bond Work Index (Bond, 1952) calculations demonstrated that energy consumption in grinding is much higher than in other unit operations because of the large difference in grinding feed and product sizes.

Using data from earlier research (Nielsen, and Kristiansen, 1996) it was shown that the work index for taconite was affected by powder factor. Higher powder factors led to lower Bond work index (Figure 1). It was postulated that lower work index resulted from increased number of macrofractures and microfractures within individual rock fragments.

Figure 1: Work Index as a function of Powder Factor, after Nielsen and Kristiansen



It was further suggested that only the smallest macrofractures and the microfractures survive to the grinding feed stage.

The result of the lower Bond work index is very large savings in grinding energy cost. For typical taconite operations this was estimated to exceed 10 million dollars annually.

The higher powder factor also leads to a finer fragmentation distribution. This plus fragment softening due to internal fracturing may lead to increased crusher throughput, an important consideration in a high mineral demand and pricing environment.

As one studies the potential benefits of fragmentation calibrated to downstream needs, it becomes clear that an essential component of the approach is the ability to measure the fragmentation being obtained. Specifically, the ability to determine when fragmentation is trending away from optimum distributions becomes imperative. Modern technology provides for non-invasive size measurement by image analysis. This allows blast fragmentation to be analyzed at the face and continuously at the crusher. Post crushing continuous analysis can also be performed.

These are important tools when one considers the large savings in energy costs alone available from optimized blasting. Once optimized, blasting efficiency can be monitored to insure feed is continuously within specification. On-line sizing systems are ideally suited to monitor trends. Coupled with an automatic truck dispatch system trucks can be dynamically dispatched both to optimize shovel—truck haulage efficiency, and to keep feed coming from the mine within requirements.

Softening due to internal fracturing is the “unseen” part of fragmentation. However, it may well correlate to size distribution related to energy input in blasting. Therefore, future work will look at correlating size analysis results to crushing and grinding energy consumption. Whereas microfracture count is an awkward measurement most suited to the research environment, on-line analysis equipment may provide a measurable marker for optimum grinding feed. The same may be true for mineral liberation and recovery.

Several systems are now in place on the Mesabi range from which we expect to obtain important insights into the relationships between blasting and downstream effects, like throughput and energy consumption

Description of Size Analysis Equipment

Manual and automated rock sizing using digital image analysis has been well established. The methods work best under the controlled conditions of a conveyor belt, where camera angles and distances are constant, lighting is controlled, and sampling errors are at a minimum. Unfortunately, after the rock has passed through a primary crusher, the size distribution no longer reflects only the blasting process.
On the other hand, imaging and measuring the size of fragmentation on muck piles, while still useful, is problematic. Results can vary because of camera distances and angles, different lighting conditions change measurements, and most importantly, because only the surface of the muck pile is measured; resulting in sample bias and measurement errors.

The solution is to image 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, using this method results in significantly decreased sampling errors. However new technical difficulties enter into the picture, including the need for advanced triggering and vehicle tracking mechanisms.

Case Histories

Size distribution is a critical component of managing any mining operation; from drilling & blasting to the final product, material size dictates all downstream operating costs.
In the beginning, the only way to measure a size distribution was to stop production, manually collect a sample, pass the sample through a battery of screens, weigh the material on each screen and plot the data on a granulation curve to reflect what size the material was at the time of sampling. This method is slow, cumbersome, disruptive and not practical for the sizing of blasted material where the particles can range in size from microns to meters. Even though sieve analysis offers a high degree of precision and accuracy within the sample, the sample size is traditionally very small making the results much less representative.

In 1987 the WipFrag photoanalysis system was developed to characterize the size distribution of blasted material. This system offered significant advantages over it’s predecessor such as; speed, ease of use, non-disruptive, and was practical for sizing any material which could be successfully imaged, including blasted material.

Since then, photoanalysis has been used in a number of applications around the world, such as the analysis of; muck piles, conveyor belts, surge bins and most recently vehicle conveyances.

Muck Pile Analysis

Sizing analysis of muck piles has been done for many years; a detailed review of this method is given by Franklin et al. (1996). Various studies attest to the success of this approach (Bartley and Trousselle, 1998; Chiappetta, 1998, Ethier et al., 1999; Barkley and Carter, 1999; Palangio and 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 and Zhou, 1999; Maerz, 2001). From these studies the following factors were identified as most important in improving the accuracy of the measurements:

1. Consistent image quality, including uniform and constant lighting.
2. Fixed scale of observation.
3. Elimination of sampling biases.

Consistent image quality, lighting, and camera position must be maintained when using this system, however the advantages include mobility, versatility, and effort relative precision since this system allows the user to take as many image samples as they want and to merge them together to increase the statistical base.

The only equipment required to collect muck pile samples are a suitable scale device and a camera (video or still) which the collected image samples can be post processed at a later date. Figure 2 shows field technique and figure 3 illustrates typical output from such systems.

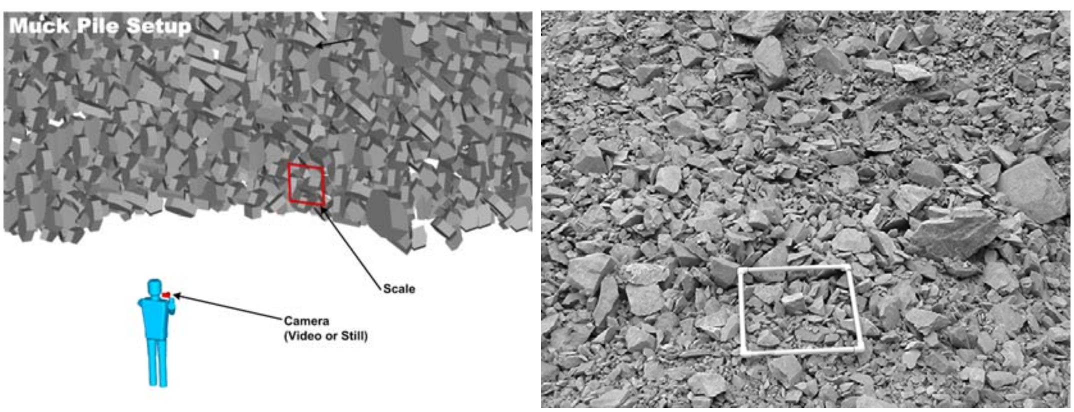


Figure 2: Obtaining Muckpile Photography for Sizing Analysis

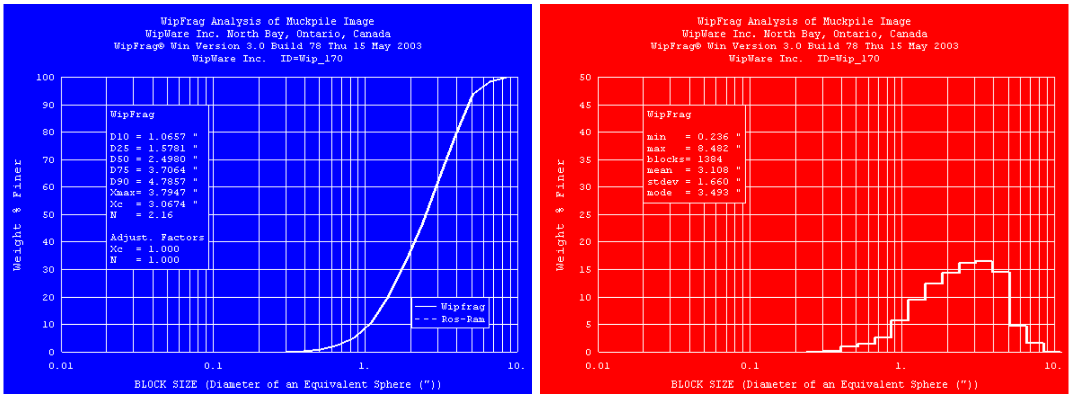


Figure 3: Typical Output from Static Size Analysis Computations

Conveyor Belt Analysis

Measurements made on conveyor belts, 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 bias is significantly reduced because:

1. All the materials are sequentially paraded before the camera
2. 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 system begins after the primary crusher. However, these systems have proven to be indispensable with regards to data collection, process control, circuit anticipation of coarse/fine material as well as simple control loops to ensure that the crusher hydro set is properly adjusted so that the material entering the mill is the optimum size. Realtime information is provided 24/7/365. These systems can also be employed for numerous other uses including the detection of off standard conditions i.e. greenball quality control for example.

The equipment required is a camera frame, high definition camera, suitable lighting, sensor and a camera control box at the analysis point, a Microprocessor workstation running WipFrag Momentum. Multiple analysis points are possible with this type of system. Figure 4 illustrates the typical conveyor belt system arrangement

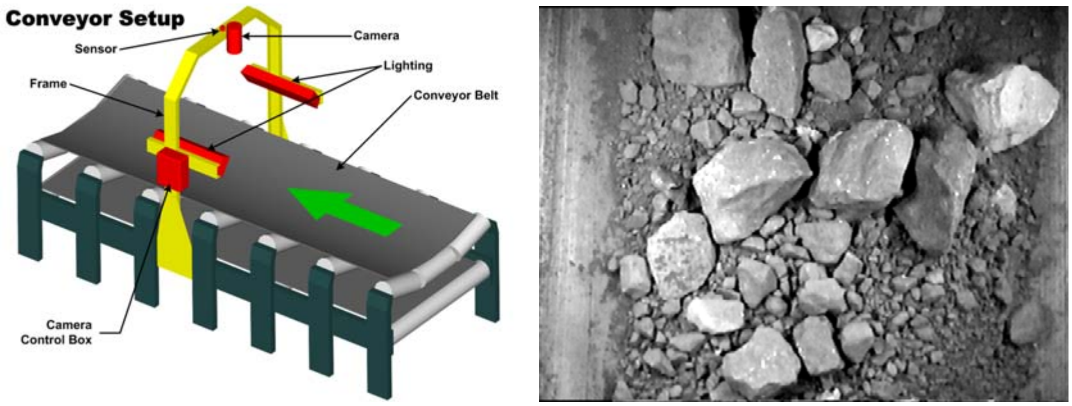


Figure 4: Typical Layout for Size Measuring on Conveyor Belts

Figure 5 is an example of continuous strip-chart output from such a system

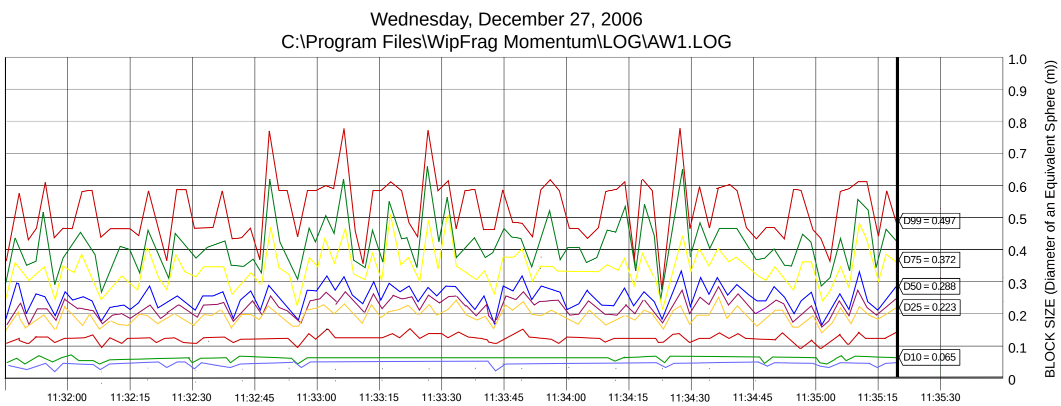


Figure 5: Time Based Output From a Conveyor Belt Sizing System

Primary Crusher Analysis

Automated analysis of blast fragmentation is to image and analyze the fragmented material in transit between the muck pile and crusher in the conveyance vehicles. This implies both surface and underground HD type (Haul Dump) and LHD type (Load Haul Dump) vehicles.

These sophisticated systems exhibit near human qualities and execute many complex functions in order to obtain suitable images such as:

“Sense” the presence of a sample
“Wake up” from a dormant state
“Identify” the vehicle number and origin of material
“Determine” whether or not the vehicle is full or empty
“Image” the vehicle
“Discard” any non-blasted material from the image
“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 require significant expansion of sensory capabilities, breakthrough development of system logic and the tight integration of tracking technology with analysis results.

The equipment required a high definition camera, suitable lighting, RFID tags, RFID Antenna at the analysis point; plus a Microprocessor workstation running WipFrag Reflex; Dispatch system integration is also possible to further enhance data analysis and correlation activities. These systems provide realtime information 24/7/365 as well as valuable production information (cycle time, material origin)

Figure 6 illustrates the system. Figure 7 shows typical output.

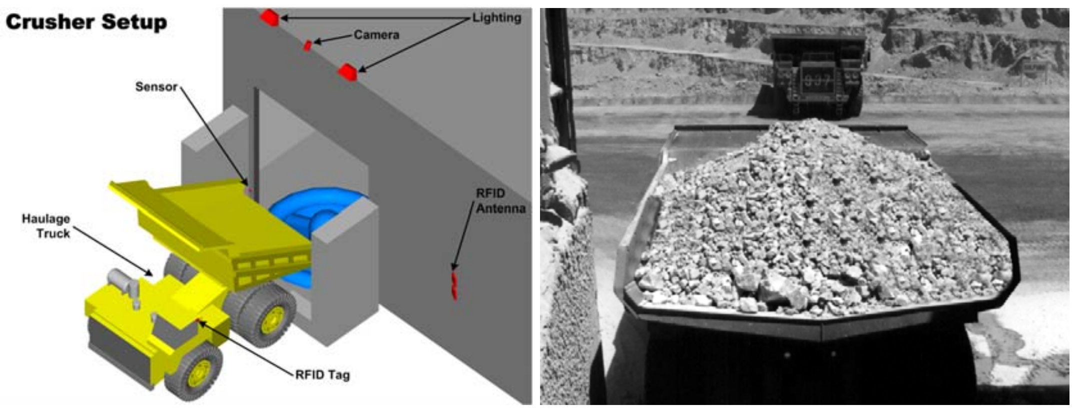


Figure 6: Primary Crusher Size Analysis System

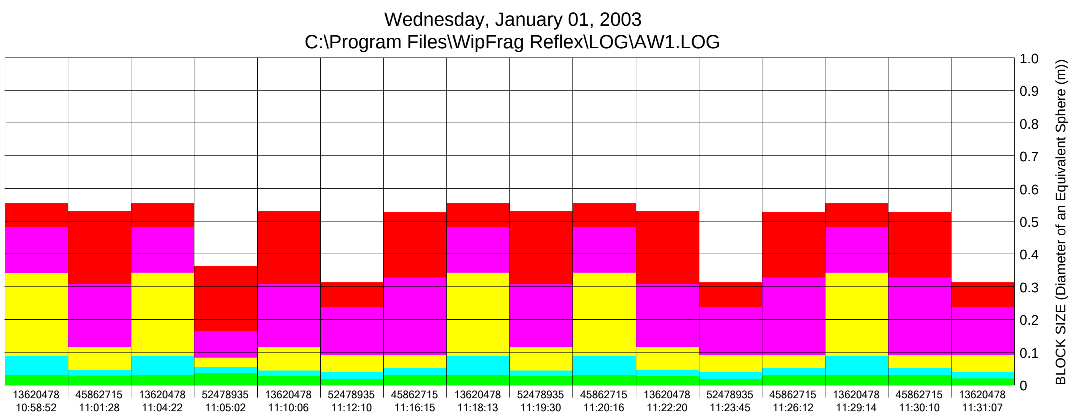


Figure 7: Typical Output From a Crusher System Versus Time

Sizing Results at a Primary Crusher Product Belt

In 2004, cameras were installed over the two takeaway belts at the primary crusher at Hibbing Taconite Company (HTC) as a part of a comprehensive mill optimization study funded by The US Department of Energy. HTC has a flowsheet which is unique on the Mesabi range in that 36-foot, fully autogenous (AG) mills are used. Ore is crushed to nominal 9-inch top size and then sent directly to the AG mills. Other Range plants use up to four stages of crushing followed by up to 3 stages of rod or ball mill grinding. As a result, HTC mills can be very sensitive to changes in blast fragmentation.

Research done in anticipation of construction of HTC indicated that AG mills would best suit the type of ore available. Furthermore, studies showed that millfeed should have adequate coarse material to act as grinding media. The resulting millfeed spec was:

40%	Minus 3-inch
20%	3-inch to 6-inch
40%	Plus 6-inch

Blast designs were instituted to provide 'grinding media' sized rock. While other Mesabi mines used powder factors in the range of 0.7 to 1.0 lbs per long ton; HTC kept their's to below 0.4 lbs per long ton for many years. If mills experienced bouts of low productivity, shovels were moved to muck piles with more chunky material in hopes that rates would rise.

In early 2005, data systems were fully in place to begin comparing measured millfeed size versus mill tons per hour. A new picture of the actual fragment size emerged. Figure 8 summarizes 46 days sizing. Actual percentages of feed sizes is shown with the desired optimum feed in parenthesis.

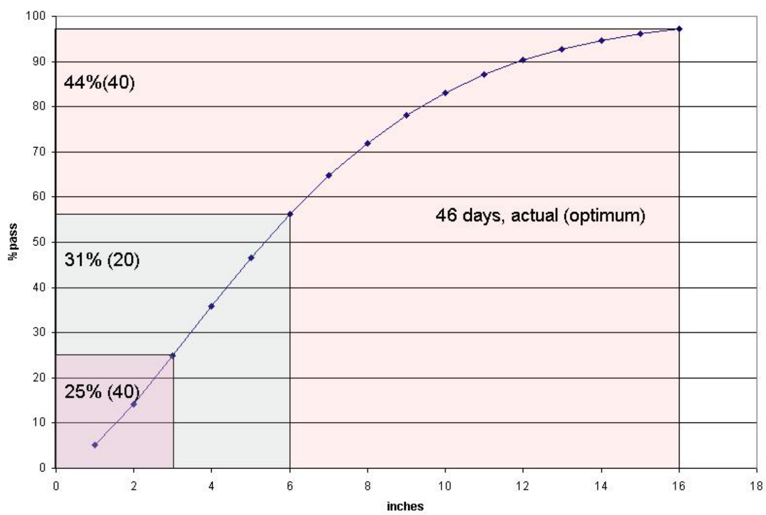


Figure 8: Forty Six Days Mill Feed Size Analysis

The chart shows an excess plus 6-inch rock, excess mid size and a shortage of fines. While it is true that fines do tend to settle to the bottom of the belt and are, thus, understated by a camera viewing the top; the percentage difference is too great to be ignored. Furthermore, another approach shows the same phenomenon in a different way.

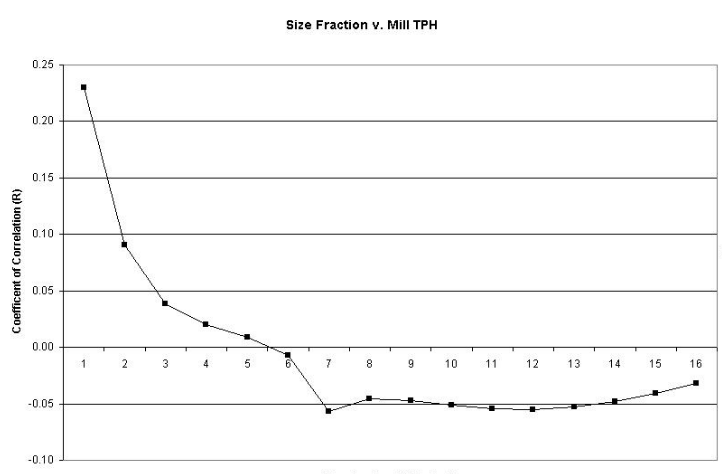


Figure 9: Regression analysis of Mill Feed Data Set

For the same data set, linear regressions were for mill throughput versus incremental size bins. Figure 9 shows that the R coefficient is positive for sizes under 6 inches and negative for the larger sizes. In simple terms, this means that more fine material helps mill TPH while more coarse fee lowers mill throughput.

Size Measurements of Tipping Trucks

In 2006, United Taconite Company installed a camera which captures images of ore in trucks taken as the load is dumped into the primary crusher. The mine is involved in comprehensive testing of electronic detonators and chose optical size analysis as one of the key measures. This project is in its early stages, therefore the data available at present is preliminary in nature.

The larger goal of the system is to provide factual information for the overall optimization of the mining and milling system. This will include factors such as:

- Powder factor
- Tie measured fragmentation to specific muckpiles
- Crusher speeds
- Hydroset settings
- Production throughputs
- Energy consumption (explosive, haulage, crusher, mills)
- Consumable consumption and cost

A sizing system for truck dumping has been delivered and will be installed at another iron ore mine on the Range in early 2007.

The goals of this system are the same as those described above.

Other Recent Applications on the Mesabi Range

A size measuring systems for conveyor belts was installed at a pellet plant in late 2006. Another belt system will be installed at a different pellet plant in early 2007.

The purpose of these systems is to monitor the size of greenball pellets produced from concentrated and finely ground iron ore. These pellets are subsequently fired in indurating machines before being shipped to steel mills.

Producing these pellets within a certain size range is an important quality parameter for balling drum or disc operation. The greenball pellet obtained is affected by several parameters. These include:

- Ore grind size
- Drum or disc RPM
- Moisture content
- Bentonite addition

The first goal of the systems is to monitor the size of the green pellets and use this information to manually adjust parameter settings on a much more rapid and exact basis than can be accomplished by traditional means.

Ultimately, it is intended to use this information, probably in conjunction with on-line microwave moisture measuring equipment to provide a control loop for the automatic control of balling circuit parameters.

While these are not blasting related optimization measurements, they do indicate the broad application of on-line size analysis in mining operations.

Conclusions

Fragmentation is important to downstream mining operations through to the grinding process. Traditionally, it has been costly and invasive to measure fragmentation. Modern imaging algorithms and equipment make on-going size measurement much more feasible.

Previous work has shown that a great deal of money can be saved and production increased when the ore is properly prepared for downstream operations.

Recently, several imaging systems have been installed at iron operations in Minnesota. One belt based on-line system has already provided important results for efficient operation and led to new understandings of optimum mill feed requirements.

It is expected that the recently installed systems for measuring fragmentation distribution as trucks dump into the crusher will also yield data from which new knowledge is derived.

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