Optimized Iron Ore Blast Designs for SAG/AG Mills

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Abstract

Few “mine-to-mill” issues inspire as heated debates as blasting for SAG & AG mills. Increased blast energy may produce more surface area at a lower cost than mechanical milling. Decreased blast energy may, on the other hand, create more large pieces needed for grinding media. Rational allocation of energy in the comminution of ores is the essence of profitability and survival of taconite producers.

A case study shows that lower powder factor does not always to an increase in production of ‘media rock’. Comprehension of rock strength and existing jointing is essential to changes in blast design. If weak bedding planes are less than 9 inches apart; lowering the powder factor may only slow mill throughput while increasing energy consumption.

Introduction

The current environment for energy usage is ripe for optimization of energy usage in mining and milling. The 1988 paper by Revnitsev, "We Really Need Revolution in Comminution" offered a number of observations that demand close examination given the rising cost of electricity and petroleum fuels. Mineral processors have watched the advancement of products and methods that can now reduce energy usage and operating costs. However, commodity prices have been dropping and capital for new equipment and plant flowsheet changes has not been available. Now, 'push has come to shove'. In a backhanded way, higher energy bills have made it easier to justify outlays for changes. Many iron ore companies need payback periods of less than 24 months to get funding approval. Today's higher energy bills now shorten up the payback period.

The golden age of flowsheet optimization may well come to fruition in the next five years. If "one measurement is worth a thousand opinions", then the myriad of measurements that technology now affords us; will equal trillions of opinions.

Previous Work

Modern comminution theory goes back to 19th century Germany where Rittinger (1867) and Kick (1885) proposed models based on surface area and particle volume respectively. Bond (1951) proposed a third theory of comminution that is still widely used today. King and Schneider (1995) at the University of Utah have very recently demonstrated improved modeling of grinding circuits.

Overall blast optimization has more recent roots. MacKenzie (1966) reported on costs in iron ore from drilling through crushing. Udy and Thornley (1977) reviewed optimization through crushing. Gold (1987) tabulated and modeled overall mining cost related to blasting at Fording Coal. LeJuge and Cox (1995) reported overall costs in quarrying. Eloranta (1995) published costs in iron ore from blasting through grinding. Moody et al (1996) related dig times, crusher speeds and particle size to fragmentation in quarry operations. Furstenau (1995) used single-particle roll mill crushing to demonstrate a 10% energy savings in the drilling through grinding process by increasing powder factor by 25%.

Recent laboratory work has been aimed at tying mine and processing size reduction to common factors. These efforts include the work of Revnivtsev (1988) who related micro-cracks from blasting to energy use in subsequent crushing and grinding. McCarter (1996) has quantified blast preconditioning through the use of an ultra fast load cell. Nielsen (1996) has done extensive grinding tests on preconditioned rock and demonstrated changes in Bond work indices of nearly 3 to 1.

Fragmentation is controlled by bedding

Exploration drillers placed sections of drill core in a two-foot long core box for transportation and storage. These pieces came out of the core barrel in a various lengths. An unknown number of core pieces had to be broken to fit in the boxes; resulting in a shortening bias of length. However, a great deal of detail concerning bedding thickness is available for beds less than two-feet in thickness.

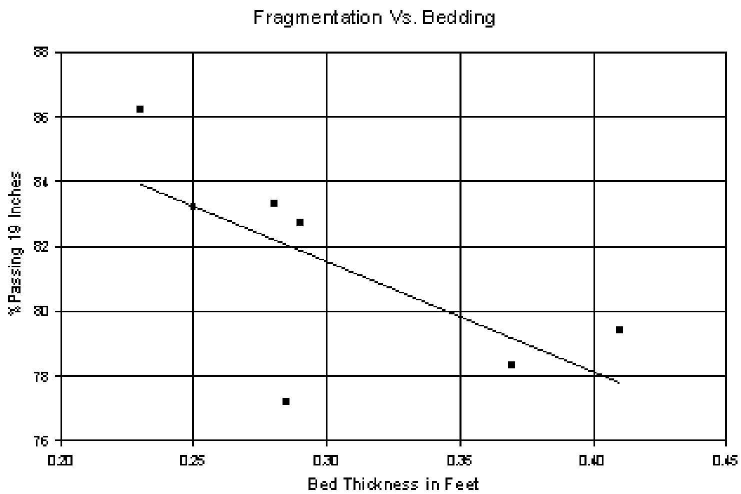

Figure 1

To relate core lengths to size distributions in run of mine rock involves a number of assumptions. If beam bending is used as the failure mode of blasted rock, then one might assume that bed thickness represents the shortest dimension of a fragment. Casual observation of muck piles seems to support this, as bedding surfaces are easy to identify in the Biwabik Iron Formation. Using an aspect ratio of 1:2:3, the two-foot long core limit translates to a maximum dimension of 6 feet. Six feet or less would account for all but a small fraction of run of mine rock. However, core pieces are broken to even shorter lengths to fill out core boxes. Because of intentionally broken core, geologic fragmentation should be augmented with other field data. The attached plot (Fig. 1) compares core lengths to resulting fragmentation measured by digital image analysis at the primary crusher. The thinner bedded areas result in better fragmentation.

Penetration rate vs. bed thickness

Yin & Thompson have led the implementation of the Stratalogger™ drill monitoring system in iron ore. Dance has described the implementation of the Aquila™ system in open pit copper. Without a firm understanding in changes in geology and ore characteristics; optimization efforts are difficult at best. In flat-lying ore deposits, such as the Mesabi ores, closely spaced bedding planes can profoundly increase drill penetration rates. This may be due to spalling, as the tungsten carbide projection on the bit breaks larger than normal pieces as the weak bedding plane is encountered. If the piece is yet small enough to pass up the annular space between the drill steel and the wall of the hole; energy is saved that would otherwise be wasted in creating additional surface area in the cuttings, rather than advancing the hole.

In this manner, penetration rate can be controlled by mean bed thickness. Mill operators are interested in mean bed thickness as it, in turn, has a dominating effect on ROM size distribution.

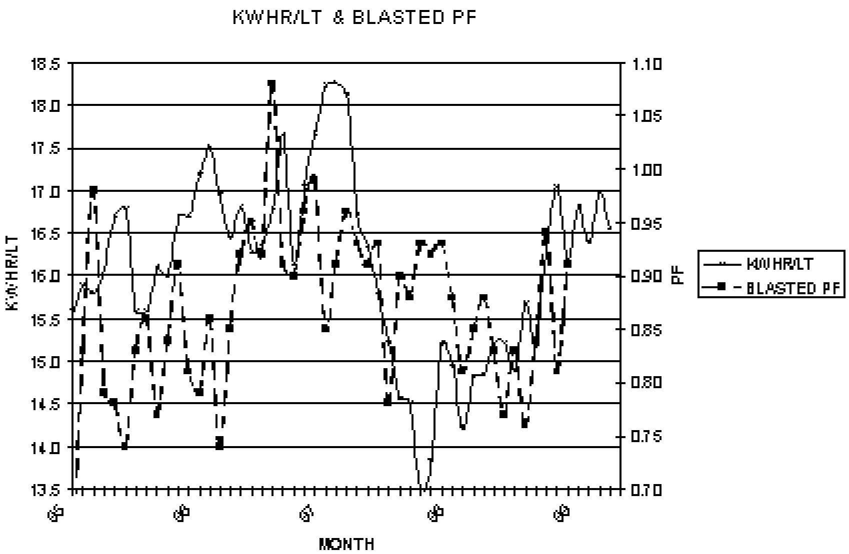

Figure 2

SAG energy vs. powder factor

Reduction in capital costs and reduced operating costs through the reduction or wholesale elimination of grinding media led to adoption of SAG and FAG flow sheets in certain iron ore plants recent developments in the understanding of blast through mill size reduction call into question the actual economies of SAG/FAG mills. Figure 2 compares blast energy to electrical consumption in the SAG mill. The concern at this operation was that excessive blast energy was depleting the source of media rock. Although that problem has been documented for some types of ore; excessive blast energy does not appear to be the culprit in this case. Note that local maximums and minimums of powder factor and SAG mill energy actually run counter-cyclical.

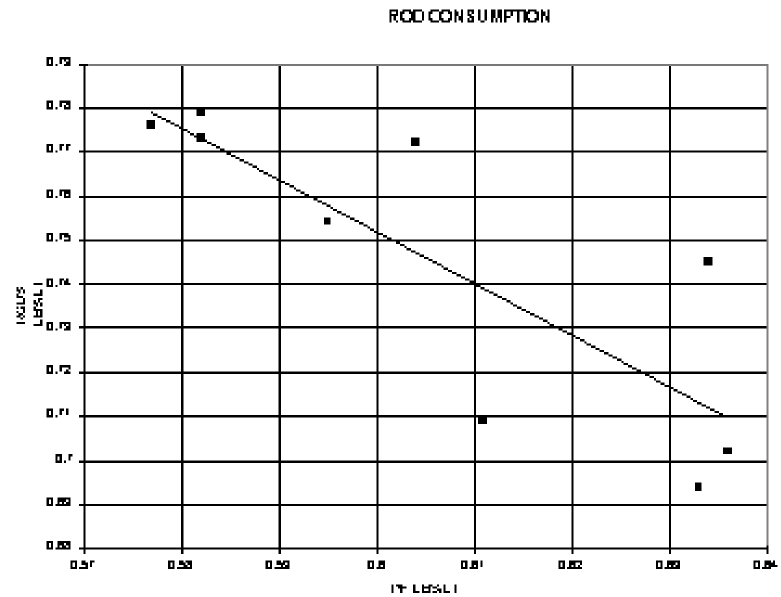

Figure 3

Consumption of grinding media

Figure 3 compares rod consumption to powder factor. Each point represents one year of operations in which over 50 million tons of feed were processed. Although, this is example is from conventional grinding; this phenomenon of rock weakening through higher powder factors is starkly apparent. This example suggests that the cost of higher powder factors may be fully offset by rods alone.

Powder factor vs. Total cost

The assumption underlying the upper and lower envelopes in figure 4 is that an inverse relationship *does* exist between blasting and downstream costs and that the purpose of the plot is to shed light on the slope of that line. The broad scatter is due to seasonal changes, geological variations and large purchases in one month. Validation will require higher powder factor tests in the lower right area of figure 4.

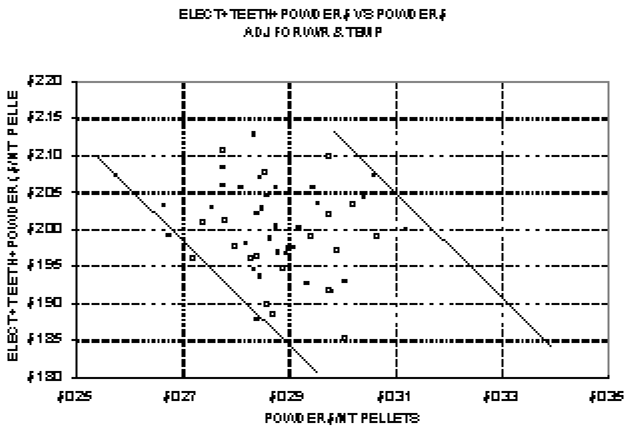

Figure 4

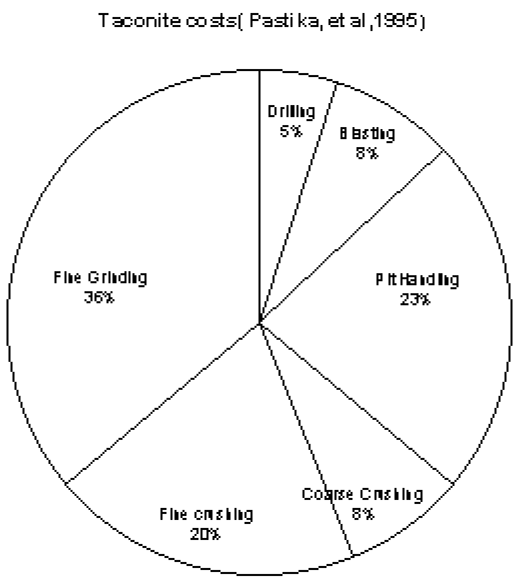

Figure 5

Total size reduction costs

Figure 5 summarizes the distribution of costs in producing concentrate. The significance of this pie chart lies in the relative costs involved in drilling and blasting versus those for grinding. Drill and blast costs have been reduced to where they represent about 13% of concentrate costs. The question is whether minimizing individual cost leads to an overall minimum.

Management Structures

Close communication between blast and mill engineers has resulted in breakthroughs in process operations. In the previously mentioned Red Dog example, it is significant that the mill and blast engineers are married to one another. In other instances cited herein, the mill engineer took a special interest in learning more about blast operations. The authors experience is one where mill engineers were highly cooperative and willing to openly discuss problems. This is often no the case, where competition for budgets and blame for ore grade issues between mining and milling personal curtails constructive dialog. Cutting the budget for mill operators is often the only means to free up moneys to test higher powder factors. Once it becomes 'us against them'; optimization falls by the wayside.

Conclusions

1. Greenfield operations will need to understand the equation relating operating costs and capital costs of conventional vs. SAG/FAG flow sheets.

2. Fragmentation costs may favor blasting over milling wherever feasible.

3. The growing shortfall of electrical demand may be eased through implementation of increased powder factors.

4. Blasting will not create larger pieces of media rock where fissile bedding and highly jointed predominate.

5. Drill monitoring and video image analysis are the two key technologies for optimizing mine through mill efficiencies.

6. Blast engineers and mill engineers need to work together.

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