THE EFFICIENCY OF BLASTING VERSES CRUSHING AND GRINDING

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ABSTRACT

This paper compares energy requirements for blasting, crushing and grinding. By tracking electrical consumption for various powder factors, a general trend has appeared. This study involves over 100 million tons of ore and powder factors ranging from .5 lbs/LT to .8 lbs/LT. Actual energy usage is compared to predicted energy based on the Bond equation. Blasting may enjoy as much as a 3:1 cost advantage over grinding. This is a startling notion considering that energy is cheaper when purchased as electricity by ratio of 5:1 when compared to powder. This combination suggests that the blasting process has a marginal efficiency advantage of 15:1. Estimates of 1% to 2% efficiency for grinding and 15% to 30% for blasting would fit this ratio.

INTRODUCTION

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 which is still widely used today. King and Shcneider(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 tieing mine and processing size reduction to common factors. These efforts include the work of Revnivtsev(1988) who related microcracks from blasting to energy use in subsequent crushing and grinding. McCarter(1996) has quantified blast preconditioning through the use of a 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.

BOND EQUATION

In the early 1950's, Bond proposed an equation for comminution which was based on feed size, product size and a rock property factor.

W = 10Wi(1/P^.5 - 1/F^.5)
where:

W = work input in kw-hr/ton
Wi = work index for rock type in kw-hr/ton
P = product size (80% passing) in microns
F = feed size (80% passing) in microns

Although recent work, including that of King and Schneider (1995) and by McCarter (1995) has advanced comminution theory; the Bond approach will be used in this study to tie in to the wealth of case histories over the past half century.

SIZE REDUCTION

The in-situ size of the rock mass is unknown. Attempts to quantify the size include measurement of bed thickness as seen in drill core (Eloranta,1996). Drill core was examined for breaks in the core along bedding planes. The joint frequency in the bedding planes was found to be much greater than in the vertical planes. The in-situ pieces therefore tend to be tabular with an aspect ratio of about 1:2:3. However the imprecision of this value is not a significant problem since Bond energy is relatively insensitive to in-situ size. Whether it is 1 m or 10 m; the work in blasting pales beside the work done in grinding to 60 microns. In-situ size is estimated at 4 m (13 ft.)for the purposes of this analysis. Run of mine rock size is measured as it enters the primary crusher through the use of a video camera and a pc-based, digital image analyzer.(Grannes,1994) A size of 80% passing .5 m(19 in.) is used. Crushing is done in three stages, reducing to 80% passing 2 cm (3/4 inch). Rod and ball mills take the ore down to an 80% passing size of 60 microns (270 mesh).

METHODOLOGY

The Bond equation is a useful tool to compare predicted and actual values of energy requirements for each step in taconite comminution. Crushing and grinding energy are measured in kw-hrs per long ton. The following conversions are used to put powder in the same units.

If:

1kcal = 1.163watt-hours
1kcal/gram = 452 k-cal/lb
powder factor = .9 lbs powder/long ton rock
relative weight strength(rws) = .9 (compared to anfo)
cost of powder = $0.20/lb

And:

(k-cal/lb anfo) * (kw-hr/k-cal) * rws = kw-hr/lb of powder
(kw-hr/lb of powder) * (powder factor) = kw-hr/lton rock

Then explosive energy is .473 kw-hr/lb and blast energy is .426 kw-hr/long ton. Since the measured energy for size reduction from in-situ to final product is known; the value for the Bond work index can be calculated. This value is then used to estimate the energy required for each step: blasting crushing and grinding. Now these values can be compared to measured energy usage.

RESULTS

The following table summarizes actual energy usage for size reduction.

TABLE 1

	KW-HR/LTON	**$/KW-HR**	**$/LT**
Blast	0.43	$0.38	$0.16
Crush	3.24	$0.07	$0.23
Grind	17.82	$0.07	$1,25

Summarizing Bond calculations and actual energy for size reduction.(Wi = 16.71)

TABLE 2

PROCESS	**FEED**	**PRODUCT**	**W(CALC)**	**W(Actual)**	**Apparent**
	SIZE	**SIZE**	kw-hr/lt	kw-hr/lt	**Efficiency**
Blast	4 m	.5 m	.15	0.43	36%
Crush	.5 m	2 cm	.95	3.24	29%
Grind	2 cm	60 micron	20.39	17.82	114%
TOTAL	4 m	60 micron	21.49	21.49	

Table 1 shows a dramatic difference in energy cost between powder energy and electrical energy. Table 2 shows that blasting consumes .43 kw-hr/lton, whereas Bond predicts only .15 kw-hr/lton. The apparent efficiency of blasting would seem to be 36%. Crushing consumes 3.24 kw-hr/lton compared to a Bond prediction of .95 kw-hr/lton; resulting in an apparent efficiency of 29%. Grinding consumes 17.82 kw-hr/lton compared to a Bond prediction of 20.39 kw-hr/lton; resulting in an apparent efficiency of 114%.

DISCUSSION

The apparent efficiencies are useful when compared to other estimates of published absolute efficiency estimates.

PROCESS	EFFICEINCY	AUTHOR
Blast	20%	Brinkman(1987)
Crush	.70-80%	Morrrell(1992)
Grind	1%	Willis(1988) Hukki(1975)

The most striking difference lies in the grinding efficiencies. Why should grinding take less energy than predicted? Perhaps the Bond work index value was changed in the course of blasting. The role of blasting in metal mines may include pre-conditioning as well as size reduction. The overall efficiency of blasting on a cost basis may be three times that of grinding(Eloranta,1995). The cost of energy in powder is at least 5 times higher than electricity as shown in Table 1. This would make blasting at least 15 times more efficient than grinding at the margin. This would be consistent with grinding estimates of 1% to 2% and blasting estimates of 15% to 30%.

IMPLICATIONS ON OPTIMIZATION

The above discussion of efficiencies allows us to apply these findings to overall optimization of size reduction. Speculative cost curves can now be replaced with known data. Figure 1 summarizes the overall cost for various anfo equivalent powder factors(aepf). Drill and blast costs rise linearly with powder factor and are easily predicted. Processing costs are known only up to .74 aepf and are assumed to asymptotically approach a minimum of $.50/ long ton. The author provides no justification for that cost. However, regardless of the actual minimum, it can be seen that the slope of the right limb of the curve is much shallower than the left limb. The lesson here appears to be that the penalty for under-shooting is greater than over-shooting the rock.

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