Non-Ideal Blasting for Ideal Grinding - Part Two

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Abstract

Building on previous work, this paper expands the template for modeling the economic relationship between blasting and grinding. The actual efficacy of various blasting enhancements is not addressed, however, placing costs and potential benefits in proper context should aid in designing mine/mill optimization trials.

Mesabi Range taconite blasting parameters are used to predict break-even cost reductions in grinding that would be required to offset various blasting expenditures. The cost of the following are considered:

1) Doubling drill and blast cost
2) Doubling drilling
3) Doubling powder
4) Electronic detonators
5) Glass micro-balloons
6) Granular aluminum
7) Paint Grade aluminum

Modeling indicates the following results: Electronic detonators would require a mill cost reduction of 0.4%. Glass microballoons (adding 1%) require a 1% improvement. Paint grade aluminum (adding 3% Al) requires a 19% reduction and granular aluminum requires a 2% reduction. Doubling of drill and blast requires an 18% reduction and a doubling of powder cost a reduction of 12%.

Introduction

The production of metals can be broken down to three essential elements: 1) free the rock mass from the earth, 2) move material to processing facility and 3) reduce to liberation size. Miners today are held to the same laws of physics as in the distant past. “The ore which has been broken down carried out must be broken into pieces by hammer or minutely crushed so that the more valuable and better part can be distinguished from the inferior and worthless portions.”(Agricola, 1556)

Figure 1. Woodcut of early comminution (Agricola, 1556)

Blast engineers operate within rigid cost constraints and nearly all improvements in blast performance come with a price tag. Increased drill and blast expenditures are typically evaluated against reductions in mining and crushing costs. Economic justifications of improved fragmentation methods are difficult when the scope of downstream optimization is restricted to: loading, hauling and crushing. While the argument of the relationship between blast fragmentation and grinding effort is far from settled, a rational allocation of energy in the overall comminution process is a high priority concern for metal mines.

In a broader sense, energy usage is a national priority. According to a Department of Energy study (2007), metal mines use 552 TBtu/yr, of which forty percent of the total energy is consumed in grinding. This means that SAG, AG and conventional mills consume 221TBtu/yr (2.33 Tkj/yr or 6.48 x 1014 kwhr/yr) in grinding. The cost at $.05/kwhr is $3.24 ($US) billion per annum.

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The dynamic blasthole environment can be exceedingly hostile. Because detailed data on blast performance is difficult to collect, current products and methods may be selected on an ‘anecdotal basis’ rather than on data. The path toward improved blast performance should be guided by: a) adherence to best practices and b) careful monitoring performance of downstream parameters.

Interaction of Blasting and Grinding Processes

As the title of this paper denotes, this paper expands on previous work using a simplistic model which attempts to illuminate mine – mill economics. That paper focused on energy partitioning, detonation velocity and robust sensitizers. Using a similar template, this paper estimates the required improvement in mill productivity that would be necessary to offset various drill and blast expenditures. The reader is cautioned to avoid any inference that these drill and blast changes will, in fact, result in any milling improvements. This is a breakeven analysis that lends perspective when comparing blasting cost which is often considered in terms of dollars per hole versus milling cost which is controlled by tons per hour. These results should be considered very conservative in that loading, hauling and crushing are not included.

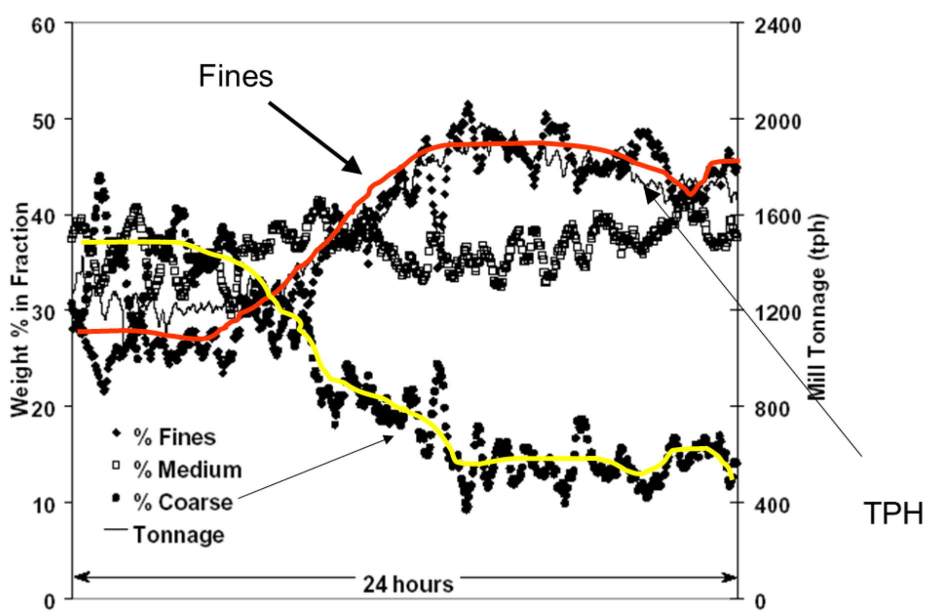

Figure 2. Fines and mill throughput (Dance, 2004)

Reconciliation of mine indicated versus plant actual ore grades is a common practice. Optimization of mine/mill fragmentation energy requires the same approach. Dance (2004) noted that controlling

SAG/AG mills required controlling the feed. Modern plant flow sheets achieve size reduction in two steps; the primary crusher followed by a sag mill. Older Mesabi Range flow sheets feature three or four stages of crushing feeding a rod mill which in turn feeds one or two ball mills. Capital costs are prohibitively high for conventional flow sheets in today's market. Dance points out that the new flow sheets leave the large mills highly vulnerable to changes in feed and may need additional ore preparation before milling. The nearby chart illustrates the wide fluctuations in mill throughput and the inherent relationship to feed characteristics. Size of feed is plotted along with tons per hour. In this case, throughput shows a variation in excess of 50% in a 24 hour period. Morrel and Valery (2001) compared feed size to mill throughput and specific energy. They found that"... the effect is considerable with the specific energy and mill throughput varying by about 30%". Figure shows the negative effects of higher feed size.

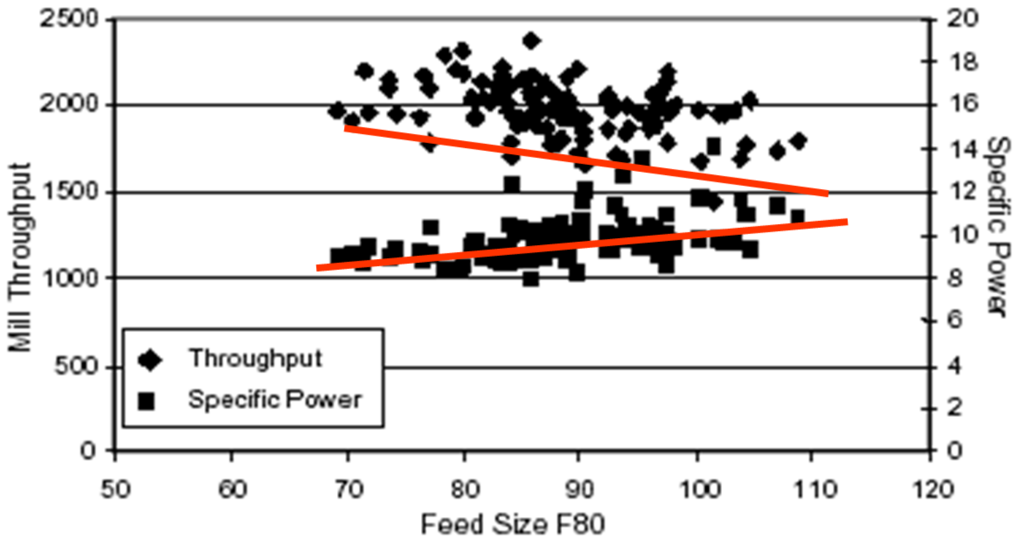

Figure 3. Mill power, throughput and P80 size (Morrel & Valery, 2001)

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 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. Katsabanis (2003) has done lab-scale test relating blast damage to grindibility.

Methodology

A base case design for Mesabi Range taconite is used to establish a starting point for cost comparisons. Taconite is particularly difficult to drill and to grind. Drilling is assumed to cost $6.00/ft ($19.68/m) and a grinding cost of $5.00/T on a concentrate basis. Weight recovery is assumed to be 28% which results in a grinding cost of $1.40/T on a crude ore basis.

Geometry		
Diameter (inches)	16	
Depth (FT)	40	
Spacing (FT)	32	
Burden (FT)	32	
Sub (FT)	3	
Stem (FT)	16	
Powder	7	
Density	1.35	
RWS	0.85	
$/# POWDER	$0.20	
ROCK DENSITY	200	
Rock Factor (A)	7	(7 to 13)
Uniformity Index(n)	1.3	.75 to 1.5

Powder		Density	RWS	$/#
Anfo	1	0.840	1	0.1195
460	2	1.100	0.94	0.1335
560	3	1.170	0.92	0.1355
660	4	1.260	0.91	0.1375
760	5	1.310	0.89	0.1395
IRHD	6	1.340	0.88	0.1395
HD65/35	7	1.350	0.85	0.2000

Unit costs	
BOOSTER	$5.00
DOWNHOLE CAP	$4.00
SURFACE CAP	$4.00
DRILLING $/FT	$6.00
1 or 2 PATH?	2

Volumes	
YD/FT	35
#/FT	118
#/HOLE	3176
YARDS	1517
LTONS	3724
LTON/FT	87
AE#/LTON	0.73
#/YD	1.78
Crush Zone	1%
Remote	30%

Cost/ton	$/HOLE	$/YD	$/TON	
DRILL	$258.00	$0.17	$0.069	
POWDER	$635.15	$0.42	$0.171	
PRIME	$26.00	$0.02	$0.007	
	$919.15	$0.61	$0.247	
		X50	9.5	Inches
		X63	12.6	Inches
		X80	18.2	Inches

Table 1. Base case spreadsheet values for blast design

Seven hypothetical changes in blast design are envisioned. Chosen for illustrative purposes, they run the gamut from a relatively common change (switchover from pyrotechnic detonators to electronic detonators) to uncommon notions including the use of pant grade aluminum. Input values are given in imperial and metric units in chart.

Input Assumptions	Imperial	Metric
Drilling Cost	$6.00/ft	$19.68/M
Bulk Explosives	$0.20/lb	$0.44/kg
Pyrotechnic Detonators	$4.00/ea	$4.00/ea
Electronic Detonators	$20.00/ea	$20.00/ea
Granular Aluminum	$2.00/lb	$4.40/kg
Paint grade Aluminum	$10.00/lb	$22.00/kg
Glass Microballoons	$1.50/lb	$3.30/kg
Grinding Cost	$5.00/T	$5.00/T
Aluminum Usage	3%	3%
GMB Usage	1%	1%
Powder Factor	.85 lb/T	.40 kg/T
Weight Recovery	28%	28%

Table 2. Imperial and metric input values for design changes

Results

The results of modeling are given in table. Each of the scenarios is listed with the associated base case cost, the added cost and the required savings in milling necessary to offset the increase in drill and blast. It is important to note that loading, hauling and crushing savings are not part of this model, which adds conservatism to the calculations.

	Base Case	Added cost	Required Milling Improvement
Doubling Drilling cost	$0.07/T	$0.07/T	5.0%
Doubling Powder cost	$0.17/T	$0.17/T	12.1%
Doubling D&B cost	$0.25/T	$0.25/T	17.9%
Electronic Detonators	$0.007/T	$0.006/T	0.4%
Granular Aluminum (3%)	$0.00/T	$0.031/T	2.2%
Paint Grade Aluminum (3%)	$0.00/T	$0.26/T	18.6%
Glass Microballoons (1%)	$0.00/T	$0.013/T	0.9%

Table 3. Output of cost model indicating required mill improvement

The same results are given in figure in bar chart format.

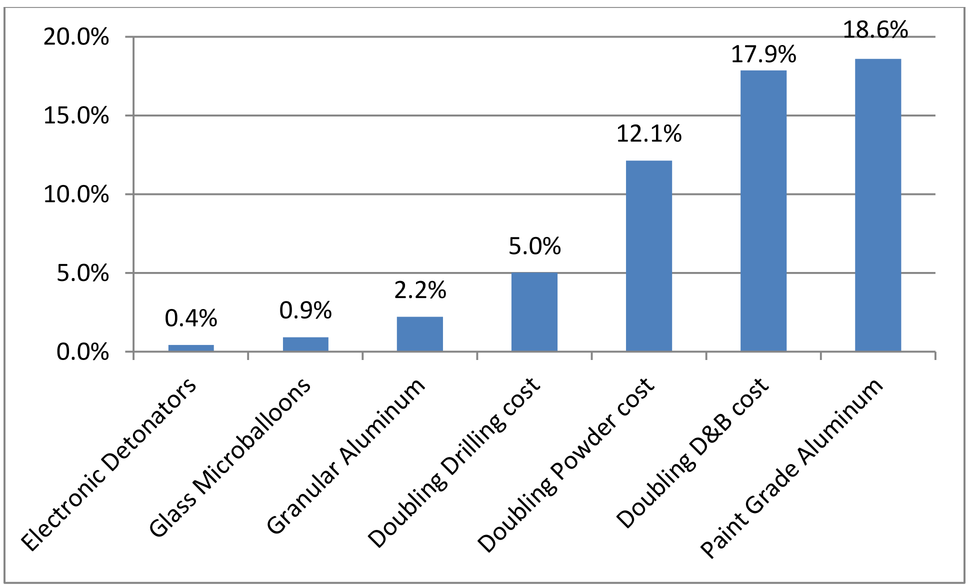

Figure 4. Required mill improvements necessary to offset blasting enhancements

Conclusion

Nothing in this paper can be classified as “findings”, since the model simply represents mathematical gymnastics. Also, it is important to note that none of the ‘blasting improvements’ included in the model are actually evaluated in terms of efficacy. However, to optimize the disparate disciplines of blasting and comminution; a common frame of reference is required. That frame of reference is lowest overall cost. Modeling indicates that the ranges of cost increases are within the range of 24 hour variations in mill throughput. Clearly, there are many other factors that impact mill throughput. However, blast design changes that seem expensive should not be discounted out of hand.

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