Optimizing Non-ideal Blasting for Ideal Grinding

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Abstract

The winning of metals often requires fine grinding of very hard ore. The US Bureau of mines measured compressive strengths exceeding 100,000 PSI (700 MPa) in Minnesota taconites. Grinding down to 300 mesh (50 µ) is required for some fine-grained taconites. While other metal ores may not be as strong, significant grinding costs are the rule rather than the exception. One author recently reported that a 7% drop in grinding costs would fully offset a doubling of the drill and blast budget. Another author found that drill and blast costs were 13% of the costs of producing iron ore concentrate while fine crushing and grinding were over 60% of the cost of producing concentrate.

This paper compares the cost of glass microballoons (GMB) to grinding costs. In large diameter blasting, microsphere sensitization is sometime overlooked since gassing or porous prill additions can allow the emulsions to detonate and in many cases appear to give reasonable results. The additional cost of adding GMB's may be viewed as expensive until a more detailed performance analysis is undertaken. Different means of sensitization can result in substantial changes in explosive behavior. Energy expended late in the combustion process may not be conducive to the development of microfractures necessary for efficient subsequent grinding. Reactions occurring at the C-J front may play a much larger role in the creation of microfractures than those occurring after the front had passed.

Although it is a separate topic, granular aluminum has also been added to the model. Aluminized ANFO has been effective product in taconite. However, several authors have cast doubt on the addition of granular aluminum to emulsions.

A simplistic model suggests that the cost of adding 1% GMB would be offset if grinding costs dropped by 1.2%. If 3% granular aluminum is also added, then powder costs would be offset if grinding costs dropped by 4.1%.

Introduction

Recent papers on non-ideal detonation mechanics in anfo blends has resulted in a lively debate on sensitizers- especially for pumpable anfo blends. Due to a shortage of experimental data, recent papers have speculated on the complex interactions governing energy partitioning and rock response. A poor understanding of fundamentals in conjunction with fierce unit price competition, has led the industry to our current state of optimization. Since one 'cannot manage what one cannot measure'; lower priced products are often the rational choice. Malfunctioning blasting agents are involved in a wide variety of problems in open pit metal mines. A short list includes:

- Orange smoke
- Oversize
- Failure to pull toe
- Ground vibration
- Flyrock
- Nitrates in discharge water
- Low productivity of shovels
- Low productivity of primary crusher
- Hazardous misfires

Previous Work

The US Bureau of Mines measured compressive strengths exceeding 100,000 PSI (700MPa) in Minnesota taconites (Jessop, 1995). Grinding down to 300 mesh (50μ) is required for some fine-grained taconites. While other metal ores may not be as strong, significant grinding costs are the rule rather than the exception.

One author recently reported that a 7% drop in grinding costs could fully offset a doubling of the drill and blast budget (Fidler, 2012). Another author found that drill and blast costs were 13% of the cost of producing iron ore concentrate while fine crushing and grinding were over 60% of the cost. (Pastika et al., 1995) Work by Bauer et al. (1984), and more recently by Fleetwood et al. (2012), indicates that there may be significant opportunities through a better understanding of the role of energy partitioning in the context of grinding energy and productivity. This paper looks at the cost of two bulk product components: glass micro balloons (GMB) and aluminum. In large diameter blasting, GMB's are viewed as unnecessary and expensive. Aluminum was commonly used in water gels, but has fallen out of favor in emulsion blends. It is true that GMB's drive up blasting costs and it is also true that critical diameter considerations do not come into play in large holes. However, energy expended late in the combustion process may not be conducive to the development of microfractures necessary for efficient subsequent grinding. Reactions occurring at the C-J front may play a much larger role in the creation of microfractures than those occurring after the front has passed. (Seller, Furtney and Onederra, 2012)

Objective

This paper has the goal of exploring possible opportunities in product enhancements. While a broader application may exist, the principal focus will relate to large diameter blasting in metal mines. The reasoning is that: 1) small-diameter formulations must already address critical diameter limitations, and 2) metal mines typically provide feed to fine grinding circuits that may benefit from enhanced fracture networks developed in blasting and 3) the author's principal experience lies in large-diameter, metal mining. The scope of the paper was originally limited to sensitizers, but discussion has been broadened to include granular aluminum

This paper looks downstream; particularly at grinding costs. Recent research has shed new light on reactions within and behind the C-J front, energy partitioning and non-ideal behavior in bulk products. Ideal explosives provide a high level of brisance as a result of intense reactions in a narrow band. While a detailed description of flame-front dynamics are beyond the scope of this paper, non-ideal products (heavy anfo blends in this case) exhibit a wide range of energy partitioning. Reactions occurring behind the front may not necessarily go to waste as they contribute to the gas bubble. However, if maximizing the fracture network can lead to lower grinding costs; then there may be economic motivation to assure product sensitivity. Figure 1 shows two areas of reaction. Red indicates the C-J front and the yellow zone shows later reactions. If it is true that the red zone contributes heavily to brisance and shattering and the yellow zone to gas and heave; then there may economic motivation in terms of grinding costs.

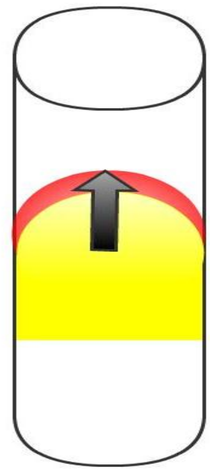

Figure 1. C-J Front

Quality Control

A military adage, 'No battle plan ever survives contact the enemy', holds to for blast plans. Depending on the severity of geologic and water conditions, designs are often compromised. Blast performance may not actually misfire, rather, it may 'suffer a death by a thousand duck bites'. Misfires get immediate attention, but variable performance can go unnoticed, unless downstream parameters are monitored and recorded. Blast designs are typically portrayed in a cross-section showing the initiation system, blasting agent and stemming. Those of us who spend too much time behind a desk and too little time on the bench may come to believe that loaded holes actually resemble the schematic diagram. We may pay insufficient attention to deviations resulting from:

- Engineering staking errors
- Drill setup errors
- Drill string wander
- Pre-existing cracks and voids (from previous blast or geological)
- Water/cuttings slurry at hole bottom
- Caved holes
- Entrained water
- Stemming penetration
- Floating primers
- Excessive sleep time
- Offsets and cutoffs during the blast

Andrew Scott (1992) opined that "the most common problem experienced in the field involves the very real differences between blasting operations 'as designed' and 'as built', and he estimates that 60% of the current blasting problems are caused by such differences" (Nielsen and Kristiansen, 1995).

Figure 2. Six Sigma

Attention to details is critical during loading. Blasters must: measure depth and powder rise, assess water conditions, accurately place boosters and know how to properly load water filled holes. A well-trained and motivated blast crew is essential. However, there is only so much they can do to overcome variations in drilling, geology, overbreak and water. If robust products and best loading practices are not employed, blasters stand little chance of obtaining consistent fragmentation.

Six Sigma

Quality standards in manufacturing (notably in automotive and electronics) have tightened in the past several decades. The red zone in figure 2 illustrates the exacting standard of 3.4 failures per million opportunities. The author speculates that prevailing practices in large-scale surface blasting quality standards are in the range of 3 to 4 sigma.

Figure 3. Stemming penetration test stand

Stemming penetration

The benefits of prepared stemming are well documented. Mesabi Range mines use stemming up to nearly fist-size. Large stemming, when dropped 20 feet or more, will penetrate emulsion blends. Augered products are less susceptible and if stemming is dropped through water; penetration is reduced. Testing (see figure 3) has shown penetration of up to 6 feet with drop distances of less than 10 feet and stemming size of ¾ inch. Figure 4 illustrates the effects of stemming penetration. Two serious implications include: a) poor fragmentation in cap rock situations can result and b) if primers float, they may end up outside the powder column.

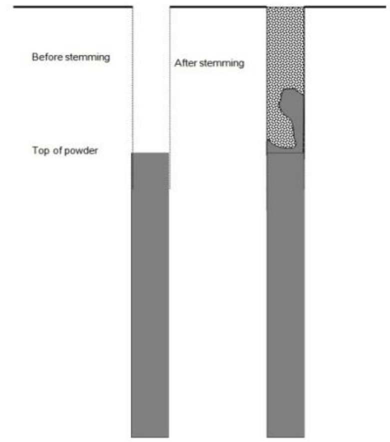

Figure 4. Stemming schematic

Bottom hole drill cuttings

Water and cuttings at the bottom of the hole may mix with and dilute blasting agents. Poor fragmentation at the toe or even misfiring can result from low order detonation at the bottom of the hole. Best practice is to weight primers at some distance off the bottom. The addition of robust sensitizers may be useful in this area.

Entrained Water

A commonly loading practice for wet holes is to dewater the hole, lower the primer and then lower the hose to a level just above the primer. This is done to reduce the chance of a floating primer. However, any water that remains or accumulates on the hole gets trapped at the bottom. Due to density differences, this water tends to migrate upward. Depending on a number of variables (density, time, viscosity), water inclusions may remain at detonation. Robust sensitizers may help by quickly restoring detonation velocity above the water inclusions.

Sleep

Excessive sleep times can lead to a host of deviations from design. Small voids achieved through gassing can coalesce into larger bubbles. Emulsifiers can deteriorate which allows groundwater to contact prills. Heavy precipitation can wash out anfo. Settling and compression can stretch and damage downlines. MSHA (57.6306) states: “Loading and blasting shall be conducted in a manner designed to facilitate continuous a process with the blast fired as soon as possible following the completion of loading.” This is certainly a good rule. However, delays do occur. The author is aware of compromised blast results following long, unplanned sleep times. A 12-inch rainfall event inundated a lower bench pattern where a boat was required to complete the tie-in. In another case, a labor stoppage led to a multi-month sleep time. Weather can delay blast when unfavorable surface winds, blowing directly in nearby neighborhoods have persisted for weeks.

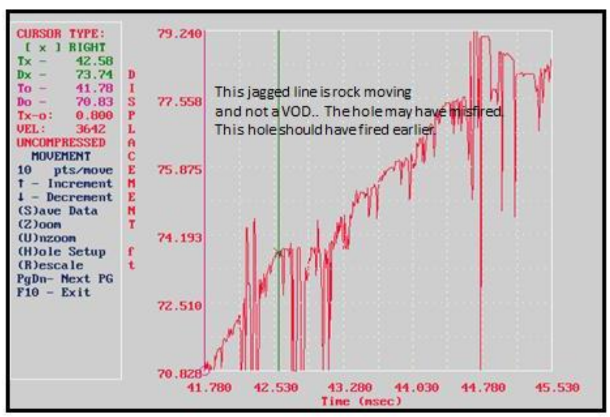

Figure 5. VODR trace

Blast Dynamics

The success of precision detonators must certainly be related to a reduction of disrupted powder columns due to excessive inter-hole time. Clear evidence of powder column disruption can be seen in VODR traces (see figure 5). Good records have always been difficult to obtain on holes other than the point of initiation. The author has been involved with dozens of VOD measurements (courtesy of Butch Maki of Dyno Explosives). Efforts to acquire clean records included, 1) centering the cable in the powder column and 2) adding a protective jacket (small-diameter PVC pipe) around the cable. The failure of these methods to reduce noise in the data raises the likelihood that significant disruptions are routinely taking place in most powder columns. Figure 6 illustrates a potential source of noise in VOD records. If shifting occurs, gaps in the powder column due to offsets may result in low order detonation or a complete cut off. Critical diameter limits may be exceeded in spite of having drilled a large hole. In this situation, the added cost of robust sensitizers may be justified.

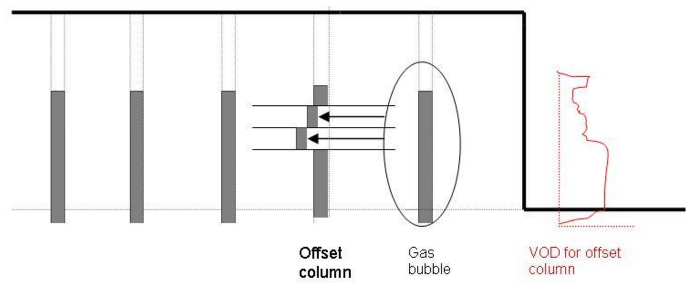

Figure 6. Offsets and cutoffs

VOD Affects Grinding

Nielsen and Kristiansen (1995) conducted fragmentation studies in a test chamber. Cubes were sawn from several rock types and shot with high and low velocity dynamite. Grinding effort was compared for the resulting fragments. Figure 7 shows a relationship between the Bond Work Index and the VOD of the explosive.

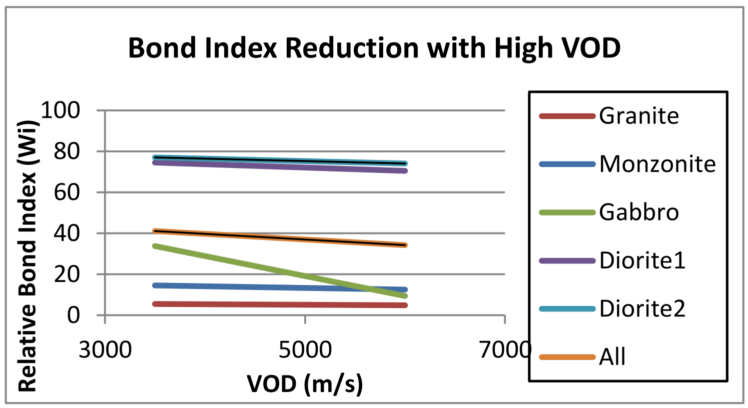

Figure 7. Velocity vs. Bond index

Aluminum

The following discussion of aluminum is a separate topic. Granular aluminum is not considered in terms of sensitivity. Aluminized bulk water gels were used with great success on the Mesabi Range well into the 1980's and aluminized anfo was an excellent match for difficult horizons when water was not present (Lerick, 1984). However, economics changed sharply in the late 1980's

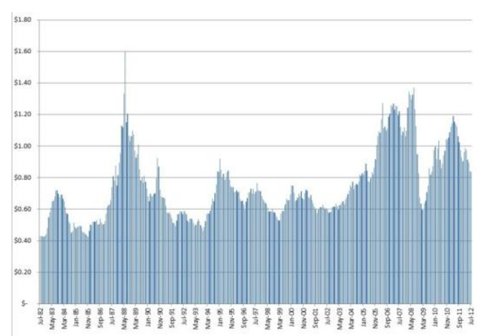

Figure 8. 30-year aluminum price history

- Bulk emulsion blends became available.
- Aluminum prices spiked. (figure 8)
- Natural gas prices fell. (figure 9)
- Iron ore prices continued to fall.

Low iron ore prices drove mines to cut costs. Paint grade aluminum and guar gums contributed to the high cost of high-end water gels. Aluminized emulsion blends were substituted. Shredded aluminum cans were added. After published reports by Eck and Machacek (1990) and by Rollins (1990), cast

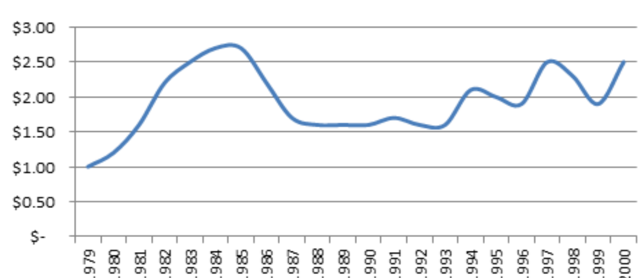

Figure 9. Natural gas price 1979- 2000

doubt on the effectiveness of aluminum in emulsion blends, aluminum was largely discontinued. The combined effect was a rapid movement away from aluminum. Technology allowing us to measure the fragmentation process far outstrips what was available a quarter century ago. It, therefore, makes sense to revisit the economics of product formulations.

Cost Model

A spreadsheet was created using the following cost inputs. The following table summarizes breakeven values for a range of anfo blend combinations

Table 1. Model Inputs

Granular Al	$ 1.20	$/lb
AL Usage	3%	
GMB	$ 1.50	$/lb
GMB Usage	1%	
Straight Emulsion	$ 0.25	$/lb
Prills	$ 0.20	$/lb
Powder Factor	1.20	LB/T
Weight Recovery	30%	
Grinding cost	$ 5.00	$/T

Table 2. Cost model of required grinding savings

Bulk Products			Additives		Calculated Powder Cost					Required Grinding Savings		
%	%		GMB	AL	Powder $/lb		%	Delta $/T		Al	GMB	Total
ANFO	Emulsion	$/lb	$/lb	$/lb	Delta	Total	Rise	Crude	Conc	only	only	
0%	100%	0.25	0.02	0.04	0.05	0.30	20%	0.06	0.20	2.9%	1.2%	4.1%
10%	90%	0.25	0.01	0.04	0.05	0.29	20%	0.06	0.20	2.9%	1.1%	4.0%
20%	80%	0.24	0.01	0.04	0.05	0.29	20%	0.06	0.19	2.9%	1.0%	3.8%
30%	70%	0.24	0.01	0.04	0.05	0.28	20%	0.06	0.19	2.9%	0.8%	3.7%
40%	60%	0.23	0.01	0.04	0.05	0.28	20%	0.05	0.18	2.9%	0.7%	3.6%
50%	50%	0.23	0.01	0.04	0.04	0.27	19%	0.05	0.17	2.9%	0.6%	3.5%
60%	40%	0.22	0.01	0.04	0.04	0.26	19%	0.05	0.17	2.9%	0.5%	3.4%
70%	30%	0.22	0.00	0.04	0.04	0.26	19%	0.05	0.16	2.9%	0.4%	3.2%
80%	20%	0.21	0.00	0.04	0.04	0.25	19%	0.05	0.16	2.9%	0.2%	3.1%
90%	10%	0.21	0.00	0.04	0.04	0.24	18%	0.05	0.15	2.9%	0.1%	3.0%
100%	0%	0.20	0.00	0.04	0.04	0.24	18%	0.04	0.14	2.9%	0.0%	2.9%

Conclusions

In small-diameter applications, sensitivity limitations have forced blasters to use highly reliable products. However, in metal mines where large diameter holes are common; the robust flame

front is thought to assure efficient combustion which overcomes difficult blasthole conditions. Furthermore, trends in the price of raw materials seem to favor using increased powder factors rather than product refinements.
However, blasthole environments have a profoundly adverse effect on the performance of bulk anfo blends. Even if one ignores the dynamics of: offsets, cutoffs and dead pressing; powder columns are compromised by bottom-hole sludge, water inclusions and stemming penetration. The dynamic blasthole environment is a poorly understood phenomenon. The difficulty in obtaining clean VOD traces may be the best evidence of powder column disruption.
The simplistic model offered in this paper suggests that a 4.1% reduction in grinding costs in iron ore would justify the addition of 1% glass microballoons plus 3% of granular aluminum.

Acknowledgements

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