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A review of the benefits for comminution circuits offered by rock blasting

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Abstract

Rock blasting is the first phase of comminution, completed by mechanical means downstream in the crushing and milling phases. Nevertheless, mineral processers and blasters seldom work together. The total energy of mechanical comminution depends on feeding grain size and on the internal resistance of the material to grinding. Blasting heavily influences both of these aspects: i) it induces visible fracturing: this is the particle size distribution visible to the naked eye, that is measurable by means of image analysis or sieving; ii) it induces invisible fracturing: this is the system of micro-fractures, invisible to the naked eye, that are detectable only by microscopic analysis but show their direct effect by reducing the grinding energy ("softens" the material). A proper management of blasting can greatly benefit the comminution circuit. In this article, the author analyzes data from literature and from field experiments and discusses the benefits that rock blasting can produce for the comminution process.

keywords: blasting, comminution, grinding, WI.

1. Introduction

Rock blasting is the first phase of comminution: it reduces the rock from the infinite size of the half-space (Boussinessq, 1885) to a transportable size. Being comminution a cascade process, and being blasting the utmost one upstream, it has everything to offer to facilitate the downstream operations of mechanical comminution.

Nowadays, it is widely accepted that blasting produces two effects on the broken rock:

1. Induces visible fracturing: the fragment size distribution in the muckpile; and
2. Induces invisible fracturing: micro-fractures, invisible to the naked eye, that reduce the grinding energy of comminution.

Considering these two aspects, Table 1 resumes what blasting has to offer to benefit the comminution circuits.

What comminution needs	What blasting offers
Small particle size	A particle size distribution adjustable to a desired range varying drill & blast parameters
Low internal resistance of the grains	A system of micro-fractures, invisible to the naked eye, that somehow "softens" the material, reducing internal resistance

Table 1
Benefits for comminution offered by blasting.

Bond's general law of comminution (1961) considers both of these aspects: the feeding particle size (F80) and the internal resistance of the grains (Work Index, WI).

$$W = WI\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right)$$

Nevertheless, these two variables influence the total energy of comminution with different weight: the particle size lays under a square root, meaning that the influence of the WI is squared the influence of the particle size on the total energy of comminution.

While fragmentation by blasting is a common subject, and the market abounds with versatile and accurate tools for the measurement of particle size distribution, the reduction in the internal resistance of the grains remains a somehow neglected topic, relegated to academic research amongst a small group of scholars, despite the evident industrial importance in terms of productivity and cost reduction.

State of the art

Rock fragmentation by blasting is a research field that is as old as the blasting science. The downstream effects of different particle size distributions have been widely covered by half a century of dedicated studies (such as Mackenzie 1967, Clerici *et al.* 1974 Scott, 1996, Bozic 1998, Sastry & Chandar 2004, Morin and Ficarazzo 2006, Mansfield & Schoeman 2010, Seccatore *et al.*, 2011, Cardu *et al.* 2012 and Dompieri *et al.* 2012). Today the blasting science possesses rather precise prediction models of the output of the blast in terms of particle size distribution, such as the widely-used KUZ-RAM (Cunningham, 1983, 2005) and the SWEBREC (Ouchterlony et al, 2006) among other studies (Ryu *et al.* 2009).

On the other hand, the discovery of blast-induced fractures within the fragmented rock after blasting is a more recent topic, albeit neither new nor recent as of 2017 (Nielsen and Kristiansen, 1996). Nielsen (1998) performed microscopic examination of blast fragments, producing proof by optical means of blast-induced micro cracks that occur along the mineral grain boundaries of the rock. Kemeny *et al.* (2003), elaborating on Nielsen's work, observe that "the surface area of induced cracks" is "10 to 100 times greater than the surface area of the fragmented rock formed during blasting", i.e. the macroscopic particle size distribution. They conclude that "since crushing and grinding are by their very nature the formation of surface area, the cracks formed during blasting will reduce crushing and grinding energy and should increase mill throughput".

The help that blasting offers to the downstream operation of mechanical comminution is a sum of these two components, none of which should be taken into account with exclusivity.

Paterson (2000) splits up the cost of the whole comminution process as expressed in Table 2.

Drill and blast	6%
Load and Haul	30%
Ancillary costs	4%
Mechanical Comminution	60%

Table 2
General figures of
distribution of comminution costs.

Although the details of these figures may vary on a case-by-case basis, the general order of magnitude does not vary. It is evident that every effort must be aimed to reduce the cost (therefore energy consumption) of mechanical comminution. Very large increases in blasting costs will only slightly affect the overall operational costs, while even a slight reduction of mechanical comminution costs can largely reduce the total costs.

Table 3 summarizes important experimental findings in terms of how blasting can produce positive conditioning of the material being processed that benefit the mechanical stages of comminution.

All of the laboratory research on small-scale blasts in rock blocks shows that changes performed on the specific explosive energy produce a conditioning of the blasted material that reduces its specific energy at mechanical milling. Since Bond's W.I. test, due to its homogenization of the particle size previous to ball mill test, is independent of the initial particle size distribution. This appears as a proof of the internal conditioning of the material, most likely by means of internal micro-fractures.

Full-scale research cannot easily separate the contribution of fragment size and internal resistance of the fragments. The results of this kind of tests, therefore, present the combined effect of fragmentation and micro-fracturing. What appears evident is that increases in specific explosive energy and better management of this energy in time (blast initiation timing) benefits the comminution circuits in terms of lower comminution energy, higher throughput of the equipment and lower overall costs of the operation.

A simulation conducted by Cremonese *et al.* (2015, ref. n.6 in Table 3) included both fragment size distribution prevision through the SWEBREC function and microfracture-induced WI reduction from experimental data. This allowed to simulate a best-option scenario between d&b and comminution costs to maximize profits in a more realistic way than merely considering the effect of fragmentation.

One must note that, despite reducing the particle size and the internal resistance of the grains are generally positive aspects, in some cases they can appear as a drawback. Elloranta (2001) observed that autogenous mills, that use the same blasted material as grinding media, loose productivity when P.F. is increased in the mine. Semi-autogenous mills (SAGs), on the other end, seem to benefit largely from pre-conditioned material (Table 3, ref. 8,9,10,11).

Table 3
Effects in comminution produced by blasting activity.

Blasting changes	Effects in comminution	Material	Type of test	Ref.
P.F. = 1.17 kg/m^3 (Granite type 1)	W.I. blasted = 0.89 W.I. unblasted	Granite	Small-scale	1
P.F. = 1.17 kg/m^3 (Granite type 2)	W.I. blasted = 0.91 W.I. unblasted	Granite	Small-scale	1
P.F. = 1.17 kg/m^3 (Granite type 3)	W.I. blasted = 0.95 W.I. unblasted	Granite	Small-scale	1
P.F. = 1.6 kg/m^3	W.I. blasted = 0.58 W.I. unblasted	Taconite	Small-scale	2
P.F. 0.8 kg/m^3 (distributed charges)	W.I. blasted = 0.78 W.I. unblasted	Marble	Small-scale	3
P.F. = 0.5 kg/m^3 (concentrated charges)	W.I. blasted = 0.76 W.I. unblasted	Marble	Small-scale	3
P.F. = 0.48 kg/m^3	W.I. blasted = 0.78 W.I. unblasted	Granodiorite	Small-scale	4
P.F. = 1.08 kg/m^3	W.I. blasted = 0.80 W.I. unblasted	Granodiorite	Small-scale	4
Shifting from spherical charge to column charge	W.I. - 10%	Granite	Small-scale	5
Drill & blast costs + 400%	Comminution costs -40%, Total Production Costs - 36%	Marble	Small-scale + simulation	6
P.F. + 240%, Speficic Priming (Delays/t) + 400%	Stops at the primary crusher -79%, Electricity Consumption at primary crusher - 27% , Total Production Costs -34%	Marble	Full-scale + simulation	7
P.F. + 40% (D&B costs +40%)	Mill throughput + 16%, Grinding costs - 19%	Gold ore	Full-scale	8
P.F. + 42%	Excavator productivity + 14% Crusher throughput + 30% Grinding throughput + 10%	Uncited	Full-scale	9
P.F. +25%	Mill Energy -10%	Metal ore	Full-scale	10
P.F. + 33%	Comminution Energy at SAG mill -29%, total Greenhouse emissions -20%	Gold ore	Full scale	11
P.F. + 65%	SAG mill throughput + 14%	Gold ore	Full scale	11

Ref.: [1]Katsabanis *et al.*, 2008; [2]Nielsen and Kristianen, 1996; [3]Seccatore *et al.*, 2015: [4]Katsabanis *et al.*, 2004; [5]Joon Kim, 2010; [6]Cremonese *et al.*, 2016; [7]Dragano, 2016; [8]Kanchibotla, 2000; [9]BaranovTangaev, 1988; [10]Fuerstenau *et al.*, 1995; [11]Kanchibotla and Valery, 2010

Lessons acquired from the state of the art

The paragraph above shows precious experience gained from scientific research and industrial applications. From such information, the following points can be highlighted:

· While fragmentation modelling, simulation and measurement is widely performed, micro-fracturing (i.e. W.I. reduction) of the blasted material still lacks widespread research and application tools

· In laboratory tests, it is widely observed that increasing specific explosive energy decreases the internal resistance of the blasted fragments;

· In full-scale experiences, it is widely observed that at increasing specific explosive energy the two main advantages observed for comminution are the increase of equipment throughput and the reduction of specific energy of mechanical comminution;

· Through simulation based on experimental data, it has been shown how, by quadrupling d&b costs, one can reduce total production costs by 1/3;

· Semi-autogenous mills benefit from smaller grains with lower internal resistance;

· For fully autogenous mills, producing smaller grains with lower internal resistance can be a drawback because it reduces the impact effectiveness of the grinding medium;

· The mechanical comminution has a specific cost by orders of magnitude higher than the comminution by means of explosives, meaning that increasing blast costs always benefits the overall costs of the operation.

2. Discussion and conclusions

From the data and experiences presented above, the general idea that blasting can condition the material to be processed in a way to greatly benefit the mechanical comminution circuits seems to be a well understood and accepted concept. Nevertheless, decisions to take advantage of this aspect to benefit the overall production chain are rarely taken at the industrial level.

Eloranta (2002) reports a story that highlights how managerial issues are the key to the lack of application of technical improvements: “The general manager [...] suggested that the mine and mill manager work out a budget for the next year, wherein the savings in milling costs would reduce the mill managers budget while the mine manager’s budget increased. Given the long history of budgeting battles between the two, no agreement was ever reached. Realistically, no one wants their budget cut while the other guy gets an increase”.

Cremonese *et al.* (2016) comment on this subject: “[it is] imperative [for] the mining business to be managed as a whole. In a cascade productive chain as mining is, responsible strategic choices must be taken looking at the entire production framework. Compartmentalized managerial staff and budgets for separated production areas (mine on one side, plant on the other) are not acceptable anymore.”

On the other hand, when relating a case of success of mine-to-mill management, Grundstrom *et al.* (2001) point out how the key for success was the communication and collaboration between the project stakeholders: “Excellent cooperation and communication with all stake holders (mine and mill departments) and between the [support research teams] was essential to the success of this project. […] To date the project has been successful only because of the open working relationships developed between all parties”.

It appears that the key for applying the lessons that have been already assimilated at theoretical level, and applying them on the field, is the lack of a holistic approach. While hard skills have clearly demonstrated the benefits for the comminution circuits offered by blasting, soft skills like communication, integrated leadership and human resources management must be involved to apply those benefits in the field.

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