New Predictive Blasting Model Oriented to Optimum Production Planning

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ABSTRACT

Most of the existing fragmentation models for blasting like the Kuz-Ram, the JKMRC and the Swebrec function, are empirically-based. These models have been mainly oriented toward material handling of ores characterized by a P80 previously agreed with the Plant. Model prediction of the fines fraction is biased in the majority of cases.

A new phenomenological fragmentation model based on the population balance concept is here reported. The nature of the model provides a physical sense to parameters and its relationship with the rock characteristics as well as the blasting conditions and the type of explosive in use.

Two fragmentation mechanisms are recognized. One driving toward an incomplete fracture of the coarse rocks and the other producing fines which follow a characteristic breakage pattern which comes from the geological formation of the orebody.

Accordingly, the fines profile is correctly predicted by the phenomenological model and as expected it drives to much more fines compared to estimations of the standard empirical models.

Several examples of application of the new model are given with emphasis in the optimization of production plans.

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INTRODUCTION

Blasting is the first fragmentation process of ores and it strongly impacts all subsequent steps in the production chain. In the past, blast was mainly optimized from the Mine point of view, but nowadays performance of the overall business is the preferred focus.

Business improvement should consider (Grundstrom, 2001): (i) Maximizing the SAG mill throughput by providing it with the optimum feed size distribution; (ii) Optimizing the blast fragmentation and muckpile profile to maximize the productivity of load and haul operations; (iii) Minimizing orebody dilution and high wall damage due to blasting and (iv) Minimizing the operation cost of the whole production chain.

Various models have been put forward over the years (see Table 1), attempting to predict the size distribution resulting from particular blast design (Cunningham, 1983, Roustan, 1987, Djordjevic, 1999). Most of the approaches fall into two categories:

- Empirical modelling, which infers finer fragmentation from high energy input, and
- Mechanistic modelling, which tracks the physics of detonation and the process of energy transfer in well-defined rock for specific blast layout.

By far, the empirical models are the ones used for daily blast design. Their granulometric results use to be calibrated by means of photography analysis. P80 values are reasonable predicted but the fines tails are often biased, particularly when the unimodal Kuz-Ram model is used.

Table 1 Some relevant fragmentation empirical models for blasting

Model	Type
Kuz-Ram	Empirical, 3 basic equations
JKMRC: “The Crushed Zone Model”	Empirical, bimodal Kuz-Ram type
JKMRC: “The Two Component Model”	Empirical, bimodal Kuz-Ram type
Ouchterlony (Swebrec function)	Empirical, bimodal

The JK models TCM and TZM are extension of the Kuz-Ram model. The concept of a crushed zone surrounding a blast-hole producing the fine material has been questioned by several authors (Ouchterlony, 2005). Most of the fine material is generated elsewhere, even in homogeneous rock.

Most fragment size distributions for rocks are clearly curve in log-log space (Djordjevic 2002). Both fines branches of the Rosin-Rammler curves of the CZM represent straight lines in log-log space. The TCM model also ends up with straight lines in log-log space. The same happens to the Swebrec function. An exception is the “extended” Swebrec function, mathematically corrected to satisfy log bimodality (Ouchterlony, 2005).

On the other hand, the PBM approach has been extensively used to describe all fragmentation process at the plant. They exhibit robust physical frame fairly combined with empirical parameters. This natural approach is the adopted in the present work as shown below.

MODEL DESCRIPTION

Frame

The PBM blasting model primarily depends on the specific rate of fragmentation S_i^E and the fragmentation habit b_{ij}. These parameters are defined for each physical rock quality in the orebody, which mainly depends on the massive rock quality and the structure rock quality. Model description is completed by the blasting design features and the explosive characteristics affecting the S_i^E and b_{ij} parameters. Figure 1 below shows main variables link in the proposed model.

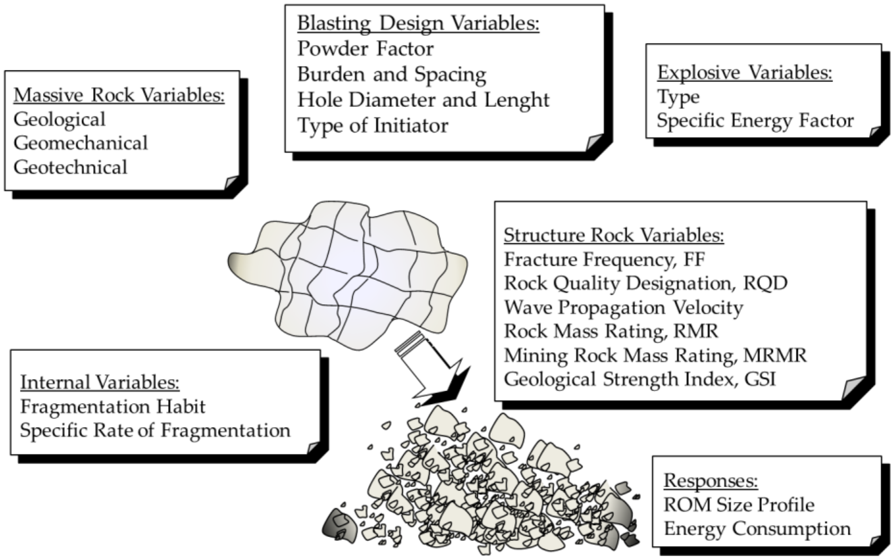

Figure 1 Conceptual description of the DRM fragmentation model

Detailed Description

Blasting is a batch fragmentation process. The explosive is arranged in a net of holes fired at specific times, producing massive rock fragmentation. The blast design at each bench considers the specific characteristics of the volume to be blasted such to get the target in fines required by the plant, but subjected to appropriate geotechnical constrains to minimize ore body dilution and wall damage.

The differential fragmentation habit b_{ij} is defined as the mass fraction in situ existing in size class x_j that after a primary fragmentation event reports in size class x_i. The specific rate of fragmentation or reduced selection function is S_i^E defined as the rock mass in size class x_i broken per unit of energy consumed in the blasting process an also per unit of mass initially existing in that size class x_i. This phenomenon is well-described by the differential population mass balance equation:

$$\frac{d\,w_i(\bar{E})}{d\bar{E}} = -S_i^E\, w_i(\bar{E}) + \sum_{\substack{j=1\\ i>1}}^{i-1} b_{ij} S_j^E\, w_j(\bar{E}) \qquad (1)$$

Equation 1 is solved for $w_i(0) = w_{i0}$ driving to the well-known solution (Reid, 1965):

$$w_i(\bar{E}) = \sum_{j=1}^{i} a_{ij} e^{-S_j^E \bar{E}} \qquad (2)$$

Where

$$a_{ij} = \begin{cases} 0 & i<j \\ w_i(0) - \displaystyle\sum_{\substack{k=1\\ i>1}}^{i-1} a_{ik} & i=j \\ \dfrac{1}{S_i^E - S_j^E} \displaystyle\sum_{k=j}^{i-1} S_k^E\, b_{ik}\, a_{kj} & i>j \end{cases} \qquad (3)$$

The reduced selection function and the fragmentation habit recognize bimodal dependency in size, because blasting is a distributed energy process, either spatially and also in time.

S_i^E and b_{ij} depend on blast design parameters, the explosive characteristics, the massive rock quality and the geo structural features of the volume to be blasted.

Same macroscopic mass balance equation 1 can be set in terms of the retained cumulative mass R_i as:

$$\frac{d\,R_i(\bar{E})}{d\bar{E}} = \sum_{\substack{j=1\\ i>1}}^{i-1} B_{ij} S_j^E\, w_j(\bar{E})\,; \qquad \text{with} \;\; B_{ij} = \sum_{k=i}^{n} b_{kj} \qquad (4)$$

If the compensation condition or zero-order production of fines is valid in the blasting process (Herbst and Fuerstenau, 1968), then for a blend of k different physical quality rocks it is easily demonstrated that:

$$P_i = 1 - \sum_k f_k \left(1 - F_i\right) \exp\left(-\left[S_{ik}{}^E\right] \bar{E}\right) \qquad (5)$$

Equation 5 is similar to the Kuz-Ram equation for a single component and very large in situ rock size, as well as when $S_i^E\, E = (x_i/x_{50})^n$. The shape of the apparent blasting selection function (here also called the selection function) make the real difference as shown in equation 6:

$$S_i{}^E = a\left(\frac{x_i}{x_0}\right)^{\alpha_1} \left(\frac{1}{1+\left(\dfrac{x_i}{x_0}\right)^{\alpha_2}}\right) + b\left(\frac{x_i}{x_1}\right)^{\beta} \qquad (6)$$

S_i^E includes the effect of the fragmentation habit because $S_i^E = B_{ij} S_j^E$. Figure 2 shows the log-log bimodal shape of S_i^E and also the meaning of the parameters. The two "modes" are related to massive and partial fragmentation processes. In the first case a complete fragmentation is evidenced in the fines high energy zone, followed by an incomplete but also massive fragmentation appearing in the intermedia energy zone. Finally, stone boulders appear in the right low energy zone, corresponding to partial fragmentation process.

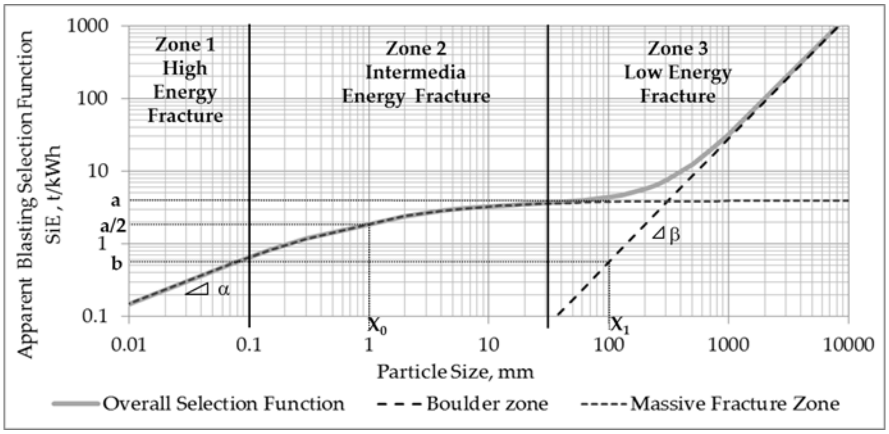

Figure 2 The apparent blasting selection function

The specific energy consumed is a function of: (i) The applied powder factor FC and the specific energy content Pe of the explosive under use, (ii) The blast design parameters, pi , (iii) The massive rock parameters and (iv) The geo estructural parameter. Mathematically:

$$\bar{E} = \underbrace{FC\,P_e}_{\text{Explosive Parameters}} \overbrace{\prod_i \left(\frac{p_i}{p_{i\,Ref}}\right)^{\varepsilon p_i}}^{\text{Blast Design Parameters}} \underbrace{\prod_i \left(\frac{q_i}{q_{i\,Ref}}\right)^{\varepsilon q_i}}_{\text{Massive Rock Parameters}} \overbrace{\prod_i \left(\frac{r_i}{r_{i\,Ref}}\right)^{\varepsilon r_i}}^{\text{Geo estructural Parameters}}, \quad [\mathrm{kWh/t}] \tag{7}$$

RESULTS AND DISCUSSION

The present blast simulation model has been successfully applied at CODELCO DGM, AMSA Antucoya, BHP Spence and CODELCO DRT, among others, either for diagnosis, optimization or production planning purposes. A specific example of application is given below for illustration purpose. This is not directly related to none of the above-mentioned applications.

Study Case

Three physical rock quality classes has been identified at a given porphyry copper deposit, called Q1 to Q3 from the weakest to the strongest physical competence. Figure 2 shows the results on powder factor per physical quality applied to these ores along a 2-year survey. A certain correlation between rock quality and powder factor is observed in Figure 2, but this is weak and it is not observed in a number of cases. Two bands are recognized, the first one with powder factors about 300-500 g/t and the other one ranging around 200 g/t. The white circles (Q2) should appear in the middle band, but actually they are located either in the upper or in the lower band. No clear match between the physical quality classification and the applied blasting conditions is found in this case.

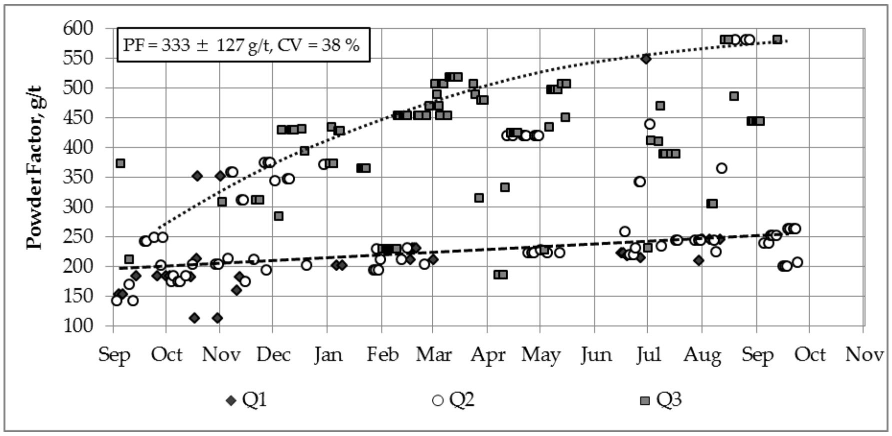

Figure 2 Powder factor along a 2-year operational survey

The more competent rocks tend to produce the coarser P80 values and the reverse is also true. A wide variability in the P80 values of the ROM size profiles is observed in Figure 3. It is attributed to variability in the applied powder factors or/and to deficient physical quality classification.

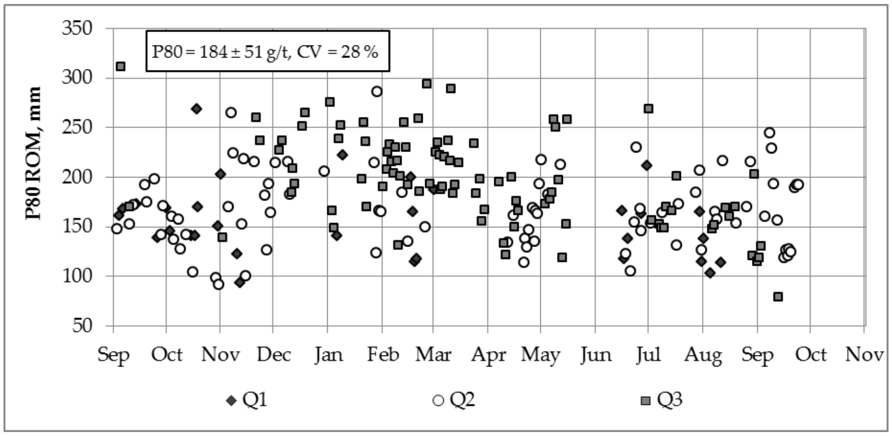

Figure 3 P80 ROM size reported by the Mine for a 2-year survey

A two-step procedure was employed to fit parameters of the blasting model. Data from photography was considered for sizes over 2″. For the smaller sizes a model of the crushing plant properly fitted to the industrial operation was used in a back-calculation mode, that is, an inverse simulation was performed starting from the crushed plant product and the ROM size profile as unknown. Comparison between the calculated and real crushing plant product granulometry is shown in Figure 4. Agreement is reasonable.

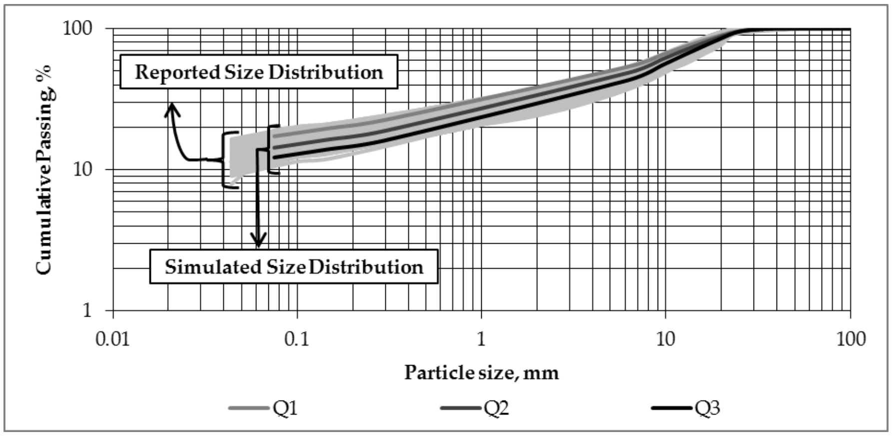

Figure 4 Real and calculated crushing plant size profile along a two-year survey for different physical quality blends

Once the ROM and crushed product size profiles are properly connected, the parameters of the blasting model are fitted considering data on powder factor, burden, spacing, drill length and diameter, type of iniciator and physical quality composition. It is worthwhile to note that the amount of fines is much larger than that estimated by the classical Kuz-Ram model as shown in Figure 5.

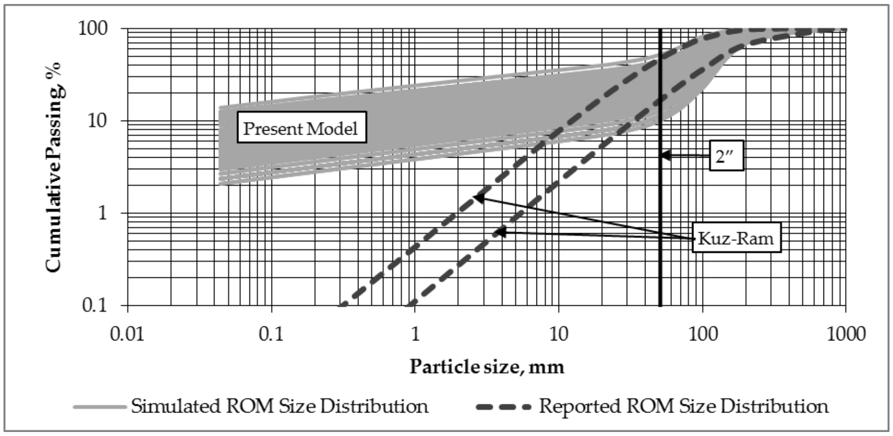

Figure 5 ROM size profiles computed by the phenomenological model and the Kuz-Ram model

The model can also be used to conciliate the estimated physical quality composition with their actual behavior in the blasting operation, as shown in Figure 6.

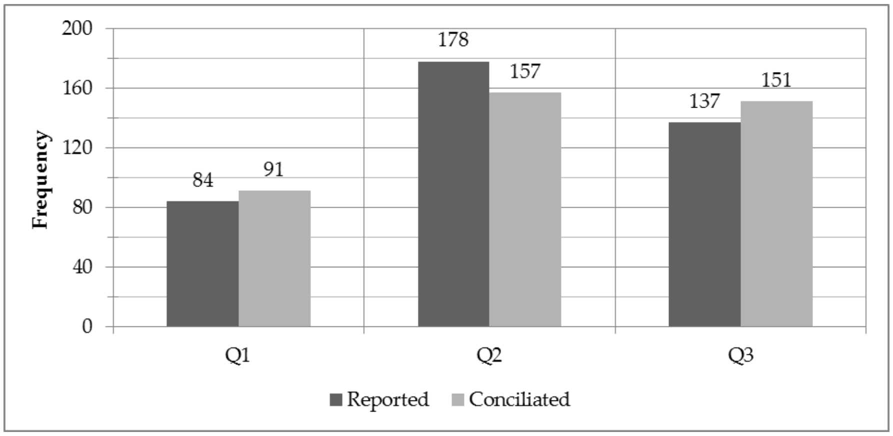

Figure 6 Reported physical quality composition and conciliated values with blasting response

This exercise recursively performed drives to close agreement between predictions and real blast results for any blend of physical quality ores. Figure 7 shows results of such exercise.

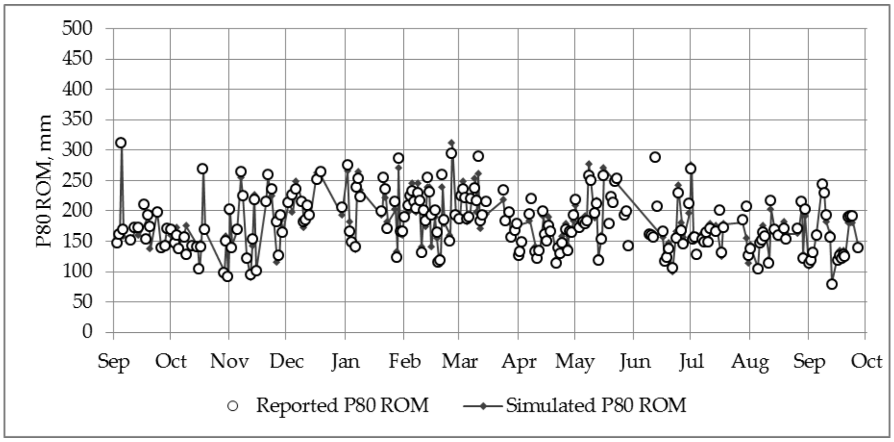

Figure 7 Simulated and real ROM P80 values for different physical quality ores

CONCLUSIONS

A new phenomenological model useful for simulation of the blasting process has been developed, It has clear advantages over the state of the art.

Fragmented rocks in blasting usually follow a bimodal profile in log-log scale fairly predicted by the present model.

Bimodal size distributions are attributed to a dual fragmentation mechanism. One driving toward an incomplete fracture of the coarse rocks and the other producing fines which follow a characteristic breakage pattern with root in the geological genesis of the orebody.

The fines profile is correctly predicted by the phenomenological model. It drives to more fines compared to those estimated by the empirical standard models. A back-calculation procedure at the crushing plant support the validity of the blast size-model estimations.

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NOMENCLATURE

$\bar{E}$	Specific energy consumed in the blasting process
f_k	Mass fraction of physical quality k in the volume to be blasted
S_i^E	Simplified selection function for size i ans physical quality k.
a, α	Parameters defining the region of fine rocks
x_i	Size class i, mm
x_0	reference size class, usually 100 mm
b, β	Parameters defining the region of coarse rocks
b_{ij}	Differential fragmentation habit
w_i	Weight fractions of size i

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