Blast Designs to Achieve a Plant Tonnage Goal in a New Mine

María Rocha, Rocha Blast Engineers
Fernando Fernandez, Split Engineering Chile
Rodrigo Fuentealba, Split Engineering Chile
Cristian Rodriguez, Split Engineering Chile
Tom BoBo, Split Engineering LLC
John Kemeny, Split Engineering LLC, University of Arizona

Abstract

This paper describes a case study that was conducted at a new mine in South America. This mine has significant geologic variations that will result in different distributions of hard and soft ore being mined at different periods of time over the mine life. A study was conducted to determine the optimum blast design that will meet the mill throughput requirement of 95,000 tonnes (104,720 tons) per day for the first 10 years of the mine life. As part of this study, field rock mass characterization and laboratory tests were conducted. This includes standard rock mechanics tests as well as rock breakage tests used in mill simulations. The geology of the ore body was broken up into four Geologic Units, and statistical variations in the properties were determined for each unit. Using this data along with the data on the occurrence of the different geologic units over time, simulations were made of the run-of-mine (ROM) fragmentation due to different blast designs, and these results were used in simulating the resulting throughput after crushing and grinding. Four blast designs were considered with powder factors of 0.44, 0.54, 0.64 and 0.94 kg/t. The results of this study show that determining the proper blast design is important in ensuring that the mill throughput requirement will be met over the mine life.

The JKSimBlast software was used to design and simulate the different blasts and obtain the run-of-mine particle size distributions (JKMRC, 2014). The Kuz-Ram fragmentation model and the JKMRC fines fragmentation model were utilized as part of these simulations. For the evaluation of the matching between the run-of-mine particle distributions and the production requirement of 95,000 tonnes (104,720 tons) per day, the JKSimMet software was used (JKMRC, 2014).

Introduction

A feasibility study is a fundamental process before opening a new mining project to determine the economic viability of the mineral resource. Feasibility typically starts with scoping studies to determine profitability of the resource. This is followed by preliminary engineering and design studies and capital appropriation. Typical types of information that are collected as part of a feasibility study include topography and land studies, site selection, field site and geological characterization, mining method selection, and metallurgical and capital cost estimation.

A detailed optimization of the blast design has not always been conducted as part of a feasibility study. However, because of the now established importance of mine-to-mill optimization, pre-mining studies to optimize the blast design for mill throughput is an important new component to mine feasibility studies. This is particularly important for sites that have considerable variability in rock mass and rock hardness conditions, and variability in what will be mined over the course of the mine life.

This paper describes a case study that was conducted at a new mine in South America. This mine has significant geologic variations that will result in different distributions of hard and soft ore being mined at different periods of time over the mine life. A study was conducted to determine the optimum blast design that will meet the mill throughput requirement of 95,000 tonnes (104,720 tons) per day for the first 10 years of the mine life. As part of this study, field rock mass characterization and laboratory tests were conducted. This includes standard rock mechanics tests as well as rock breakage tests used in mill simulations. The geology of the ore body was broken up into four Geologic Units, and statistical variations in the properties were determined for each unit. Using this data along with the data on the occurrence of the different geologic units over time, simulations were made of the run-of-mine (ROM) fragmentation due to different blast designs, and these results were used in simulating the resulting throughput after crushing and grinding. Four blast designs were considered with powder factors of 0.44, 0.54, 0.64 and 0.94 kg/t. The results of this study show that determining the proper blast design is important in ensuring that the mill throughput requirement will be met over the mine life.

The aforementioned software was used to design and simulate the different blasts and obtain the run-of-mine particle size distributions (JKMRC, 2014). The Kuz-Ram fragmentation model and the JKMRC fines fragmentation model were utilized as part of these simulations. For the evaluation of the matching between the run-of-mine particle distributions and the production requirement of 95,000 tonnes (104,720 tons) per day, the JKSimMet software was used (JKMRC, 2014).

This paper is broken up into five sections. The next section describes the data that was collected. The third describes the ROM simulations that were made for each of the four geologic units. The fourth describes the mill throughput calculations that were made based on mixtures of the four geologic units, for the four blast designs. The final section gives conclusions of this study and future works.

Data Collection

The geology of the mine consists of altered sedimentary and porphyry rocks. Some alterations render the rock hard, while other alterations render the rock soft. Overall, the rock is divided into four geologic units, referred to as SED-H, SED-S, POR-H, and POR-S. SED refers to sedimentary and POR refers to porphyry, and H refers to a hard alteration and S refers to a soft alteration. Some field and lab properties of the four geologic units are given in Table 1 below.

Table 1. Geological characteristics of the four geologic units

	SED-H	SED-S	POR-H	POR-S
Insitu block size (m)	0.2	0.2	0.5	0.5
Density (kg/m3)	2.6	2.6	2.6	2.6
UCS (Mpa)	110.1	58.1	164.6	81.1
Young`s modulus (Gpa)	22.215	22.215	28.46	28.46
Tensile strength (Mpa)	11.01	5.81	16.46	8.11

Table 1 illustrates the significant variation in rock properties. Variations occur between the hard and soft alterations, and also between the sedimentary and porphyry rock types. Comparing the hard and soft alterations, the two hard units have Unconfined Compressive Strength (UCS) values of 110 and 165 MPa, while the two soft units have UCS values of only 58 and 81 MPa. The tensile strength values show a similar trend. Comparing the two rock types, both sedimentary units have a much smaller block size (0.2 meters) compared with the porphyry units (0.5 meters). Based on these variations, blasting these four units with the same blast design is expected to result in significant differences in run-of-mine fragmentation. In addition to the mean values for each of the rock properties, variations in each of the properties were also determined, as illustrated for geologic unit SED-S in Table 2 below.

Table 2. Example of statistical information provided of each geologic unit

Ore Properties	SED-S				
	10% percentile	20% percentile	Mean	80% percentile	90% percentile
Density	2.46	2.53	2.63	2.70	2.73
FF /m	15.2	8.6	3.2	1.1	0.6
PLI - I50	0.7	1.5	2.5	3.9	5.0
UCS - Mpa	16.9	33.6	58.1	88.7	114.0
Young's Modulus-Gpa	18.6	20.8	25.0	29.2	31.4

Table 3 shows the variation in the mix of the different rock types that is expected to be mined over the mine life. It shows that in the first 5 years of the mine life, 78% of the rock will be the soft alteration while only 22% will be the hard alteration. At the end of the mine life, however, the trend is reversed, with 26% of the soft alteration and 74% of the hard alteration being mined in the last 10 years.

Table 3. Geologic unit distribution for different time periods

Period (Years)	1-5 (%)	6-10 (%)	11-20 (%)	21-30 (%)	31-LOM (%)	Total LOM (%)
SED-H	11%	23%	36%	34%	46%	37%
SED-S	31%	33%	24%	22%	15%	21%
POR-H	11%	7%	20%	17%	28%	21%
POR-S	47%	37%	20%	27%	11%	21%

In addition to field rock mass characterization and standard rock mechanics laboratory tests, laboratory rock breakage tests were conducted to provide the information needed for crushing and grinding simulation. Table 4 shows the rock breakage properties for the four geologic units. It is interesting that these properties show more differences between the sedimentary and porphyry rock types and fewer differences between the hard and soft alterations. Table 4 shows mean values for each of the rock properties. Statistical variations in these properties were also determined but are not shown here.

Table 4. Rock breakage properties for the 4 geologic units

Geological Units	SG	SPI	A	b	A*b	Ta	BMWi (KWh/t)
SED H	2.62	85.4	46.9	0.82	38.7	0.38	14.3
SED S	2.62	68.2	46.9	0.95	44.4	0.44	13
POR H	2.62	51.6	46.9	1.13	52.8	0.52	12.6
POR S	2.62	50	46.9	1.15	53.9	0.53	11.6

SG = Specific Gravity
SPI = SAG Power Index
A, b = Impact breakage parameters, are determined using a high energy impact breakage device called JK Drop Weight test
A*b = Hardness of the ore parameter
Ta = Abrasion breakage parameter
BMWi = Ball Mill Work Index

Run-of-Mine (ROM) Fragmentation Analysis

In this section, the effect of different blasting designs on the resulting fragmentation is determined, separately for the four geologic units. In the fourth section these fragmentation results are combined based on different mixes of the four geologic units in different time periods.

Table 5. Characteristics of the blast designed

	Case1	**Case2**	**Case3**	**Case4**
Powder Factor (kg/t)	**0.44**	**0.54**	**0.64**	**0.94**
Drilling diameter (mm)	270	270	270	270
Bench Height (m)	15	15	15	15
Hole Length (m)	17	17	17	17
Burden (m)	6.5	5.9	5.4	4.5
Spacing (m)	7.5	6.8	6.2	5.2
Sub-drilling (m)	2	2	2	2
Used Explosive	Emulsion	Emulsion	Emulsion	Emulsion
Powder Factor (kg/t)	0.444	0.539	0.646	0.932
Energy Factor (MJ/t)	1.575	1.914	2.294	3.307

When considering different blast designs for the mine, certain variables will be fixed. This includes the drill diameter of 270 mm (10.63 in), the bench height of 15 meters (49.21 ft), and the drill hole length of 17 meters (55.77 ft). The explosive used is also fixed, a Fortran Mex65 emulsion. The properties of the emulsion include a density of 1.3 kg/m^3, a VOD of 5,200 m/s (17,060 ft/s), an energy of 3.55 MJ/kg, and

RWS and RBS values of 1.16 and 1.97, respectively. The primary variables in blast design, therefore, are the burden and spacing. By varying the burden from 6.5 m (21.33 ft) to 4.5 m (14.76 ft) and the spacing from 7.5 m (24.62 ft) to 5.2 m (17.06 ft), four case studies have been conducted with powder factors of 0.44, 0.54, 0.64 and 0.94 kg/t. This is shown in Table 5. Case 1 with a burden of 6.5 m (21.33 ft), spacing of 7.5 m (24.62 ft), and powder factor of 0.44 kg/t, is considered to be a normal blast design, while the others have elevated energies to assist with mine-to-mill optimization. Also, the 0.94 kg/t powder factor is only considered for the hardest rock unit, POR-H.

Once the blast designs are defined, fragmentation analysis is performed with the help of blasting simulation algorithms or software. Many algorithms and software are available, and in this paper the JKSimBlast software has been used (JKMRC, 2014). In particular, a Kuz-Ram algorithm is utilized along with a JKMRC fines adjustment (Hall & Brunton, 2001). For each of the four geologic units, simulations are performed for each of the four blasting designs (cases 1 through 4). An example of a blasting simulation using the software is shown in Figure 1, and the resulting run-of-mine particle size distributions for SED-H, SED-S, POR-H and POR-S are shown in Figures 2a through 2d, respectively.

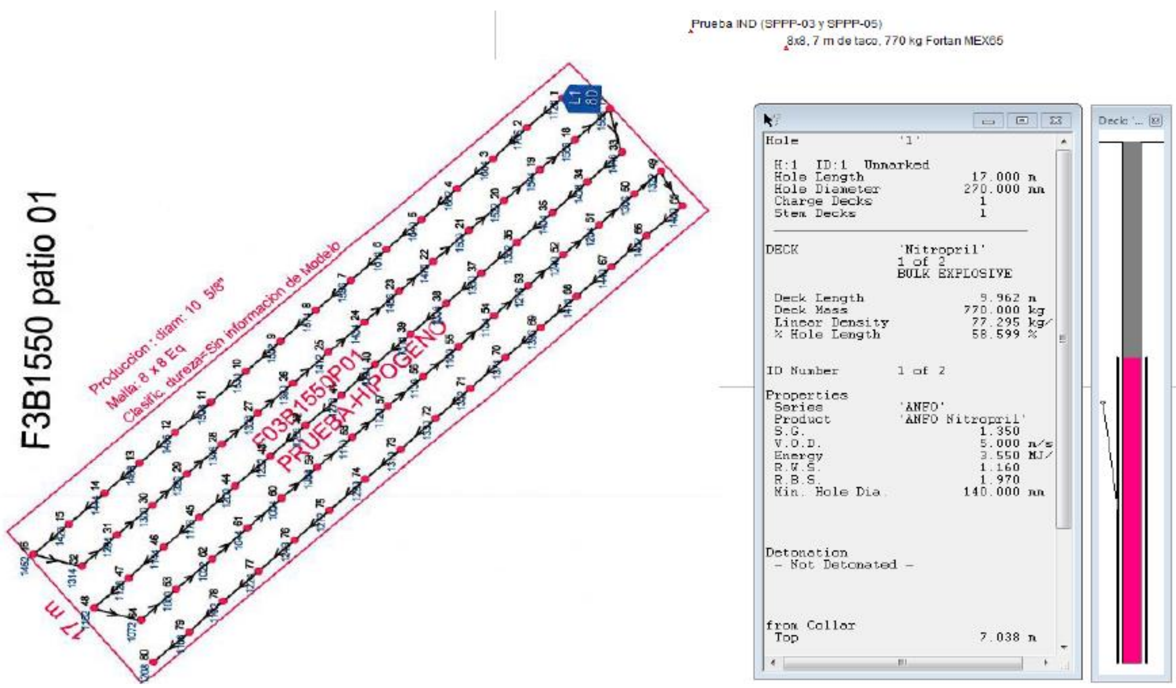

Figure 1. Example of fragmentation analysis using JKSimBlast software.

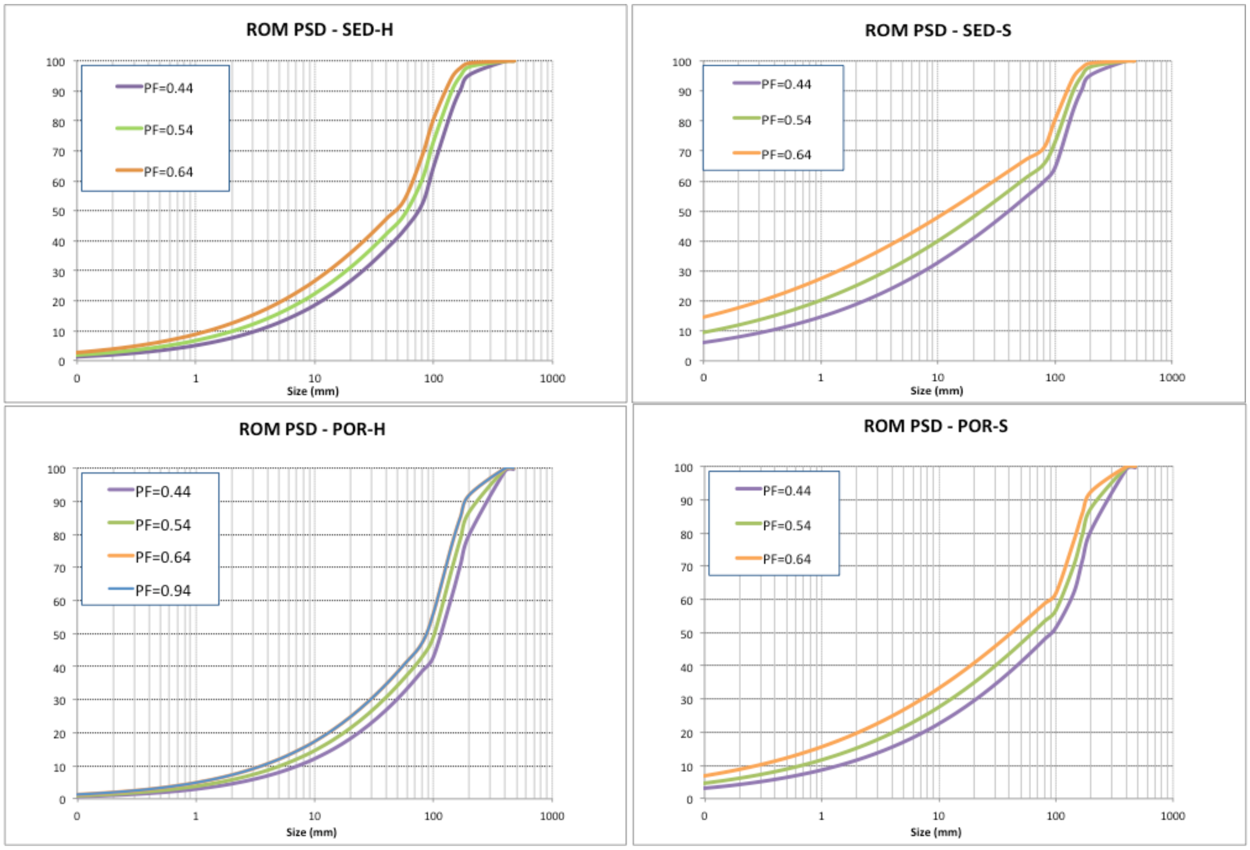

Figure 2. Run-of-mine particle size distributions for the four geologic units (SED-H, SED-S, POR-H, POR-S) and for the four blast design case studies (0.44, 0.54, 0.65, 0.94 powder factors). The 0.94 powder factor only used for POR-H.

The curve shapes in Figure 2 are not typical Kuz-Ram type shapes because of the fines adjustment that is computed. As expected, Figure 2 shows significant differences in fragmentation between the four geologic units. The two hard alterations result in significantly courser fragmentation, and the sedimentary units have smaller fragmentation due to the smaller in-situ block size. The most difficult unit to blast is POR-H, even when a powder factor of 0.94 kg/t is used.

The next step is to use these ROM curves to estimate mill throughput for time periods 1-5 years and 6-10 years, as described in the next section. It will be assumed that the same blasting design is used for all four rock units, and the mixed fragmentation will be calculated using the distributions shown in Table 3.

Throughput in the Metallurgical Plant Using the ROM Size Distributions

The requirement for the mine for the first 10 years is a throughput in the metallurgical plant of 95,000 tonnes (104,720 tons) per day. To achieve this goal, the optimal blast design must be determined, and it must consider the mix of rock types that will be mined in the first 10 years. It is assumed that the same blast design will be applied to all rock types in a given time period, but the blast designs for different time periods can be modified. The primary blast design variables, as discussed in following section, are the burden and spacing, and four cases have been considered resulting in powder factors of 0.44, 0.54, 0.64, and 0.94 kg/t, as shown in Table 5.

Mill throughput is calculated using mill simulation algorithms or software. An example of the simulation of primary crushing using the SED-H rock type with a powder factor of 0.44 kg/t is shown in Figure 3. Figure 3b shows the particle size distribution before and after primary crushing. As expected, most of the size reduction occurs in particles above about 70 mm (2.75 in). An example of the simulation of the grinding circuit using the SED-H rock type with a powder factor of 0.44 kg/t is shown in Figure 4. This grinding circuit is based on crusher product feed to a SAG mill, followed by ball mills.

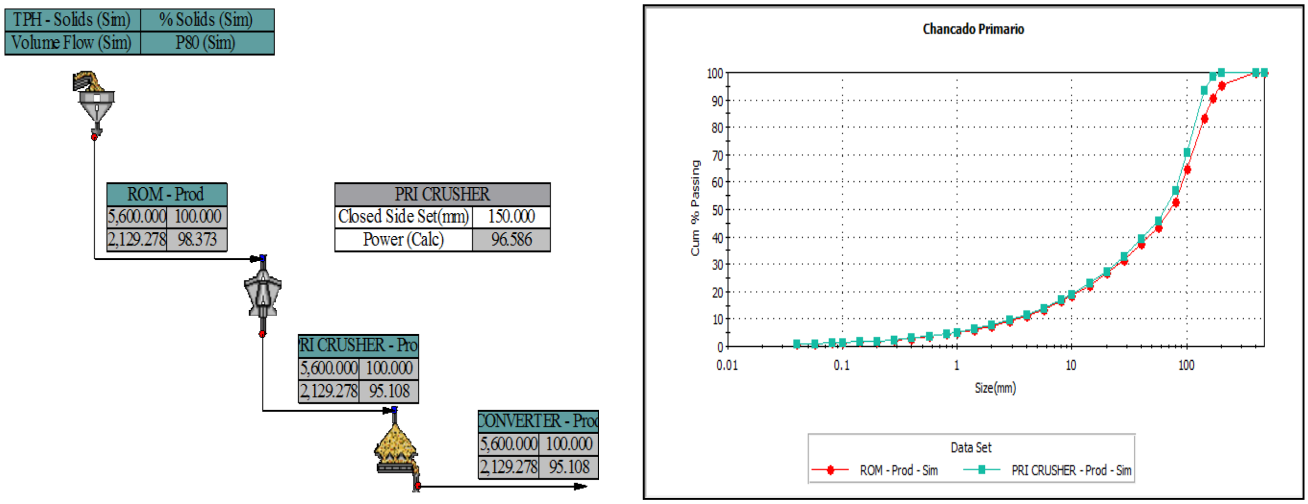

Figure 3. Simulation of primary crushing using SED-H rock type with powder factor of 0.44 kg/t.

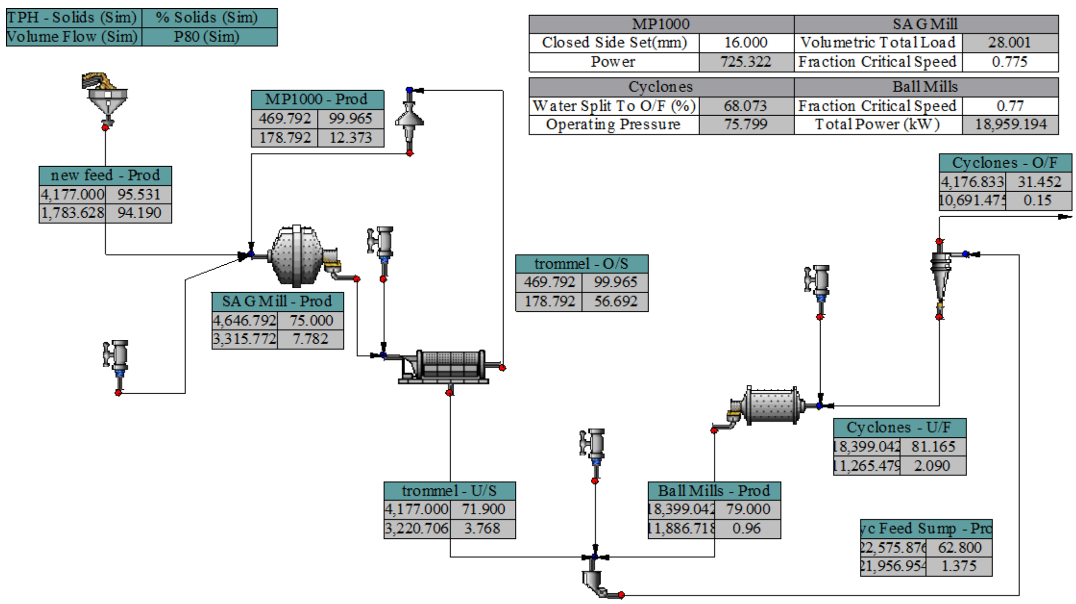

Figure 4. Simulation of grinding circuit using SED-H rock type with powder factor of 0.44 kg/t.

Using the simulation software described above, mill throughput was calculated for the time periods 1-5 years and 6-10 years. Table 6 shows the distribution of the four geologic units to be mined in these two time periods.

Table 6. Geologic unit distribution for time periods 1-5 and 6-10

Period (Years)	1-5 (%)	6-10 (%)
SED-H	11%	23%
SED-S	31%	33%
POR-H	11%	7%
POR-S	47%	37%

Figure 5 shows the predicted SAG feed particle size distributions for the two time periods 1-5 years and 6-10 years, calculated using the primary crusher simulator shown in Figure 3. For each time period it shows the results of the four blast designs resulting in powder factors of 0.44, 0.54, 0.64, and 0.94 kg/t. Figure 5 shows that as expected, the soft alterations dominate the size distributions in the first 10 years of mine life.

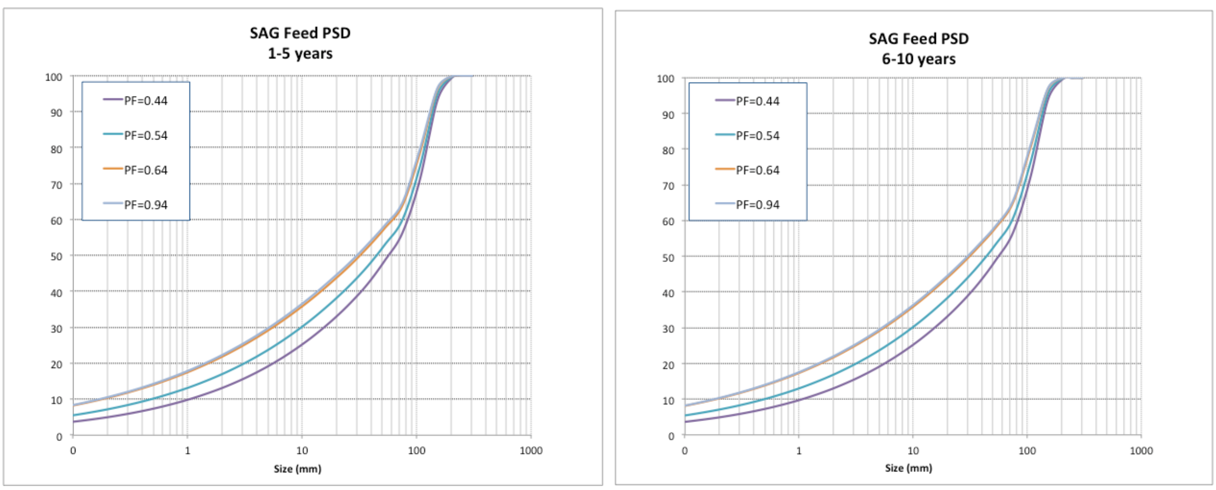

Figure 5. SAG feed particle size distributions for rock mined 1-5 years and 6-10 years

Figure 6 shows the grinding circuit throughput predictions for the two time periods 1-5 years and 6-10 years, calculated using the grinding circuit simulator shown in Figure 4. Figure 6 is a plot of tonnes per day (TPD) throughput vs. powder factor. It shows the results of the four blast designs that result in powder factors of 0.44, 0.54, 0.64, and 0.94 kg/t. Figure 6 shows very clearly that a powder factor of 0.64 kg/t (based on burden of 5.4 m (17.72 ft) and spacing of 6.2 m (20.34 ft) can achieve the goal of 95,000 tonnes per day (104,720 tons per day). It also shows that not much extra throughput is achieved from the high-energy blast of 0.94 kg/t.

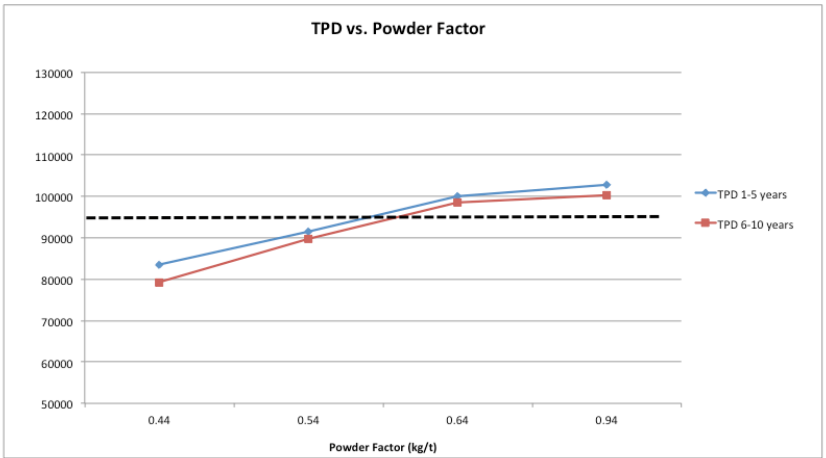

Figure 6. Comparision of tonnes per day (TPD) vs. powder factor.

Conclusions

In this paper, a blast design analysis was conducted for a new mining operation. Based on site characterization and lab testing, the mine geology was partitioned into four geological units. There was a significant variation in strength between these four units, and also different mixtures of these geological units are to be mined in different periods of the mine life. This presents a challenge in terms of optimizing the blasting for mill production throughout the mine life. The goal of the mine is a mill throughput of 95,000 tonnes per day (104,720 tons per day). Based on this goal, run-of-mine fragmentation analysis was conducted for four blasting designs resulting in powder factors of 0.44, 0.54, 0.64, and 0.94 kg/t. The powder factor of 0.44 represents a standard blasting design, while the 0.54 and 0.64 kg/t designs are high-energy blasts specifically to assist with mill production. The 0.94 kg/t design was investigated for the one geologic unit with very high strength. The results of the run-of-mine fragmentation analysis was input into a crushing and grinding simulation model to predict the mill throughput for the time periods of 1-5 years and 6-10 years. The results of this analysis are summarized below.

Table 9 shows mill production (tonnes per day) for the 1-5 and 6-10 year time periods, for the four blast design powder factors. The boxes shaded in green are the ones that achieve the production goal of 95,000 tonnes per day. Table 7 shows very clearly that a powder factor of 0.64 kg/t (based on burden of 5.4 m (17.72 ft) and spacing of 6.2 m (20.34 ft)) can achieve the goal. It also shows that not much extra throughput is achieved from the high-energy blast of 0.94 kg/t.

Table 7. Production data for the four blast designs

Powder Factor	**0.44**	**0.54**	**0.64**	**0.94**
TPD 1-5 years	83,524	91,598	99,921	102,913
TPD 6-11 years	79,289	89,807	98,466	100,370

Based on these results, the following blast design is proposed for the first ten years of mine life.

- Material: Mixtures of the four rock units that occur in first 10 years
- Blast Pattern: 5.5 m (18.04 ft) × 6.0 m (19.69 ft)
- Stemming lenght: 6.0 m (19.69 ft)
- Explosive Material: Emulsion
- Energy Factor: Aprox. 2.30 MJ/t
- Powder Factor: Aprox. 0.640 kg/t

References

Bailey, C, Lane, G, Morrell, S and Staples, P. (2009), *What can go wrong in comminution circuit design?, in Proceedings Tenth Mill Operators' Conference, pp 143–149.*

Brent G.F., Hawke S.J., Gómez R (2012), *Ultra-High intensity blasting for improved ore comminution, Fragblast10, Nueva Delhi, Noviembre.*

Hall J. & Brunton I. (2001), *Critical Comparison of JKMRC Blast Fragmentation Models, EXPLO2001.*

JKMRC, 2014. JKSimBlast and JKSimMet software, http://www.jkmrc.uq.edu.au

Napier-Munn, T J, Morrell, S, Morrison, R D and Kojovic, T. (1996), *Mineral Comminution Circuits, their Operation and Optimization, JKRMC Monograph Series in Mining and Mineral Processing 2, Ed.*

Rocha M., Kemeny J., BoBo T., Rodriguez C. (2014), *Calibration of a Fragmentation Model for a New Mining Operation, 40th Symposium ISEE, Denver, February.*

Singh S.P., Abdul H. (2013),*Investigation of blast design parameters to optimize fragmentation, Fragblast10, Nueva Delhi, Noviembre.*

Stark, S, Perkins, T and Napier-Munn, T J. (2008), *JK drop weight parameters – A statistical analysis of their accuracy and precision and the effect on SAG mill comminution circuit design, in Proceedings Metallurgical Plant Design and Operating Strategies 2008, pp 147-156.*

Thornton D., Kanchibotla S. and Brunton I. (2001), *Modelling the Impact of Rockmass and Blast Design Variation on Blast Fragmentation, EXPLO2001.*