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Modified Kuz—Ram fragmentation model and its use at the Sungun Copper Mine

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ABSTRACT

Rock fragmentation, which is the fragment size distribution of blasted rock, is one of the most important indices for estimating the effectiveness of blast work. In this paper a new form of the Kuz—Ram model is proposed in which a prefactor of 0.073 is included in the formula for prediction of X_{50}. This new equation has a correlation coefficient that is greater than 0.98. In addition, a new approach is proposed to calculate the Uniformity Index, n. A Blastability Index (BI) is used to correct the calculation of the Uniformity Index of Cunningham, where BI reflects the uniformity of the distribution. Interestingly, this correction also can be observed in the Kuznetsov—Cunningham—Ouchterlony (KCO) model, which uses In situ block size as a parameter for calculating the curve-undulation in the Swebrec function. However, it is in contrast to prediction of X_{50} as the central parameter in Swebrec and Rosin–Rammler distribution functions. The new model is a two parameter fragmentation size distribution that can be easily determined in the field. However, it does not consider the timing effect, or upper limit for sizes, as does the original Kuz—Ram model. The model is used at the Sungun Mine, and it does a good job of predicting the fines produced during blasting.

1. Introduction

The Kuz—Ram model, which was proposed by Cunningham, has been used as a common model in industry for predicting rock fragmentation size distribution by blasting [1,2]. Although it has been used extensively in practice, it has some deficiencies; one is timing effect, the other is lack in prediction of fines.

There are some models that proposed to improve the Kuz—Ram's model's inability to predict the fragment size distribution. The CZM [3] and TCM [4] models are two examples of extended Kuz—Ram models to improve the prediction of fines; they are known as JKMRC models.

In the CZM model, the size distribution of rock fragments consists of coarse and fine parts. According to CZM, two different mechanisms control the rock fragments produced by blasting. The coarse part is produced by tensile fracturing, and the Kuz—Ram model is used to predict this part of the size distribution. However, fines are produced by compressive fracturing in the crushed zone, for which the Rosin–Rammler function gets a different value of n and X_C.

In the TCM model, two Rosin—Rammler functions are used for ROM size distribution. TCM is a five-parameter model in which two of the parameters are related to the coarse fraction, one is related to the fines fraction, and the other two are related to fines part of the distribution.

In addition, by replacing the original Rosin—Rammler equation with the Swebrec function, the Kuznetsov—Cunningham—Ouchterlony (KCO) model is arrived at to predict the ROM size distribution [5]. Like Rosin—Rammler, it uses the median or 50% passing value X_{50} as the central parameter but it also introduces an upper limit to fragment size X_{max}. The third parameter, b, is a curve-undulation parameter. The Swebrec function removes two of Kuz—Ram's drawbacks—the poor predictive capacity in fines range and the upper limit cut-off of block size.

Spathis suggested that X_{50} should have the prefactor $(\ln 2)^{1/n}/\Gamma[1+(1/n)]$. He claimed that the correction indicates that the original implementation of Kuz—Ram will overestimate the size of the rock fragments which may say that the original Kuz—Ram underestimates the fines faction when the uniformity index is 0.8–2.2 [6].

Riana et al. [7] presented a new method to determine the rock factor A in the Kuz—Ram model. This factor was correlated to drilling index for two different types of Indian rock types, sandstone and coaly shale [7].

2. Review of blast fragmentation models

An empirical equation for the relationship between the mean fragment size and applied blast energy per unit volume of rock

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(powder factor) has been developed by Kuznetsov [8] as a function of rock type. He reported that initial studies had been carried out with models of different materials and the results were later applied to both open pit mines and an atomic blast. Considering the nature of mining and the variability of rock, a degree of scatter between fragmentation measurements and prediction was shown and was to be expected as well. The model predicts fragmentation from blasting in terms of mass percentage passing through versus fragment size. Kuznetsov's equation is [8]

$$X_m = A\left(\frac{V_0}{Q_e}\right)^{0.8} Q^{1/6} \quad (1)$$

where X_m is the mean fragment size (cm), A is the rock factor, (7 for medium hard rocks, 10 for hard highly fissured Rocks, 13 for hard, weakly fissured rocks), V_0 is the rock volume broken per blast hole (m^3), and Q_e is the mass of TNT containing the energy equivalent of the explosive charge in each blast hole (kg) and the relative weight. The strength of TNT compared to ANFO (ANFO = 100) is 115. Hence, Eq. (1) based upon ANFO instead of TNT can be written as

$$X_m = A\left(\frac{V_0}{Q_e}\right)^{0.8} Qe^{1/6}\left(\frac{S_{anfo}}{115}\right)^{-19/30} \quad (2)$$

where X_m is the mean fragment size (cm), A is the rock factor, V_0 is the rock volume broken per blast hole (m^3), Q_e is the mass of explosive being used (kg), S_{anfo} is the relative weight strength of the explosive to ANFO (ANFO = 100). Since

$$\frac{V_0}{Q_e} = \frac{1}{K} \quad (3)$$

where K is the powder factor (kg/m^3), Eq. (2) can be rewritten as

$$X_m = A(K)^{-0.8} Q_e^{1/6}\left(\frac{115}{S_{anfo}}\right)^{19/30} \quad (4)$$

Eq. (4) can now be used to calculate the mean fragmentation (X_m) for a given powder factor. Solving Eq. (4) for K gives

$$K = \left[\frac{A}{X_m} Q_e^{1/6}\left(\frac{115}{S_{anfo}}\right)^{19/30}\right]^{1.25} \quad (5)$$

One can calculate the powder factor required to yield the desired mean fragmentation. In his experiments, Cunningham indicated that lower limit for A was 8, even in very weak rock mass, whereas the upper limit was $A = 12$.

The Blastability Index, which was first proposed by Lilly [9], has been adapted for Kuznetsov's model (Table 1), in an attempt to better quantify the selection of rock factor A [2]. Cunningham stated that the evaluation of rock factors for blasting should at least take into account the density, mechanical strength, elastic properties and structure. The equation is

$$A = 0.06 * (RMD + JF + RDI + HF) \quad (6)$$

The Rosin–Rammler formula is then used to predict the fragment size distribution. It has been generally recognized as giving a reasonable description of fragmentation in blasted rock. This equation is [10]:

$$R_m = 1 - e^{-(X/X_C)^n} \quad (7)$$

where R_m is the proportion of material passing the screen, X is the screen size (cm), X_C is the characteristic size (cm), and n is the index of uniformity. The characteristic size X_C is one through which 63.2% of the particles pass. If the characteristic size X_C and the index of uniformity n are known, a typical fragmentation curve can be plotted. Eq. (7) can be rearranged to yield the following expression for the characteristic size:

$$X_c = \frac{X}{\sqrt[n]{-\ln(1-R_m)}} \quad (8)$$

Since the Kuznetsov formula gives the screen size X_m for which 50% of the material would pass, substituting the values $X = X_m$ and $R = 0.5$ into Eq. (8) gives

$$X_c = \frac{X_m}{\sqrt[n]{0.693}} \quad (9)$$

A useful indirect check on the index of uniformity has been performed by Cunningham [2]. He based his prediction of fragmentation on the Kuznetsov equation and used the relationship between fragmentation and drilling pattern to calculate the blasting parameter of the Rosin–Rammler formula. The blasting parameter, n, is estimated by

$$n = \left(2.2 - 14\frac{B}{D}\right)\left(\frac{1}{2} + \frac{S}{2B}\right)^{0.5}\left(1 - \frac{W}{B}\right)\left(\frac{L}{H}\right) \quad (10)$$

where B is the burden (m), S is the spacing (m), D is the borehole diameter (mm), W is the standard deviation of drilling accuracy (m), L is the total charge length (m) and H is the bench height (m). Where there are two different explosives in the hole (bottom charge and column charge), Eq. (10) is modified to:

$$n = \left(2.2 - 14\frac{B}{D}\right)\left(1 - \frac{W}{B}\right)\sqrt{\left(\frac{1}{2} + \frac{S}{2B}\right)} \times \left(0.1 + abs\left(\frac{BCL - CCL}{L}\right)\right)^{0.1}\left(\frac{L}{H}\right) \quad (11)$$

where BCL is the bottom charge length (m) and CCL is the column charge length (m). When using a staggered pattern, this equation must be multiplied by 1.1. The value of n determines the shape of the Rosin–Rammler curve. High values indicate uniform sizing. Low values, on the other hand, suggest a wide range of sizes

Table 1
Rock factor parameters and rates.

RMD		Rock mass description
Powdery/friable		10
Vertically jointed		JF*
Massive		50
JPS		Vertical joint spacing
<0.1 m		10
0.1 m to MS		20
MS* to DP*		50
JPA		Joint plane angle
Dip out of face		20
Strike perpendicular to face		30
Dip into face		40
RDI		Rock density influence
RDI = 25 RD*−50		**RD**; rock density (t/m^3)
HF		Hardness factor (GPa)
Y/3		If $Y<50$
UCS*/5		If $Y>50$
*	Meaning	Unit
MS	Oversize	m
DP	Drilling pattern size	m
Y	Young's modulus	GPa
UCS	Uniaxial compressive strength	MPa
JF = JPS+JPA		