Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.5, 2016

Rock Fragmentation Prediction using Kuz-Ram Model

Jethro Michael Adebola* Ogbodo David Ajayi Peter Elijah.O
Department of Minerals and Petroleum Engineering, School of Engineering, Kogi State Polytechnic, Lokoja, Nigeria
*P.O.Box 110, Ido Ekiti, Ekiti State, Nigeria

Abstract
Evaluation of fragmentation remains an ever important discussion in the mining parlance as it is the first step towards mineral recovery. Various software's and methods of predicting and analyzing the result of blasting exists, one of such is the Kuz-Ram model. This paper studied the development of the Kuz-Ram model from inception and the modifications that have been made. The methodology of its use and the discrepancies that exist between predicted results and the actual results generated by the design for similarities and correlation were examined. Predictions were made based on the input parameters of a limestone quarry and the blast design were varied to predict new design parameters that reduced the mean fragment size from 113cm to 105cm. This result shows a significant boost in the productivity of subsequent operations when the values estimated for burden and spacing were adopted. It was observed that the trend of the results remains valid in present day application even though there are significant differences in magnitudes of values. It was concluded that Kuz-Ram Model remains viable at making fragmentation prediction and a useful tool for pre assessing the effect of optimizing certain parameters of a blast design.
Keywords: Fragmentation analysis, Kuz-Ram Model, Optimization and Prediction

1.0 Introduction

The efficiency of a blasting operation is determined by the degree of matching the blast outcome and the required fragment size. Requirement specifications are usually governed by loading equipment, hauling equipment, and importantly, the primary crushing units. Fragmentation is one of the most important concepts of Explosives Engineering. Blasting is the first step of the size reduction in mining and it is followed by crushing and grinding unit operations. The efficiency of these unit operations is directly related to the size distribution of muck pile. (Esen and Bilgin, 2000). Kazem and Bahareh (2006) stated that the outcome of a good blasting operation leads to the productiveness of the next stages of mining, such as loading, hauling and crushing process.

Jimeno *et al,* (1995) observed that the outcome of blasting operations are determined by a number of indices or parameters, which can either, be controllable or uncontrollable. The controllable parameters are basic blast design parameters, which can be varied to adjust the outcome of the operations, and this produce close to accurate results assuming the rock mass is homogenous and without discontinuities. But the uncontrollable ones are inherent properties of the rock, geological structures, usually defined by fracture distributions, need to be factored and included in the blast design. They explained further that for the purposes of blast design, the controllable parameters are classified in the following groups: A- Geometric: Diameter, charge length, burden, spacing etc. B- Physicochemical or pertaining to explosives: Types of explosives, strength, energy, priming systems, etc. C- Time: Delay timing and initiation sequence. The uncontrollable factors includes but are not limited to: geology of the deposit, rock strength and properties, presence of water, joints, etc. (Hustrulid, 1999)

Methods to quantify the size distribution of fragmented rock after blasting are grouped as direct and indirect methods. Sieving analysis of fragments is the only technique in direct method. Though, the most accurate technique among others but is it not practicable because it is expensive and time consuming. For this reason, indirect methods, which are observational, empirical and digital methods have been developed (Esen and Bilgin, 2000).

Kanchibotla et al. (1998) pointed out that the Kuz-Ram model underestimates the contribution of fines. This deficiency of the model can be overcome by introducing a second uniformity index to describe the fines distribution, below the mean size. In the case of the finer fractions, it is hypothesized that they are produced by the pulverizing or crushing action of the explosive in a blasthole. The crushing zone radius around each blasthole is determined based on the peak blasthole pressure and the strength of the rock.

Kojovic et al. (1998) state that rock in the crushed zone is assumed to be completely pulverised to generate fines, which are assumed to be less than 1mm in size. The coarse part of the distribution is predicted using the conventional uniformity index based on blast design parameters proposed by Cunningham (1987) while the finer part is based on the percentage assumed pulverized around the blasthole.

Other authors have tried to develop other functions to bridge this gap occasioned by the Rossin-Rammler exponent, and this includes the TCM and CZM models both known as JKMRC models, Swebrec function, (Ouchterlony, 2005) in the KCO model.

Building a mathematical or empirical model which will accommodate both the blast design variables (controllable factors) and also quantify or allot definite values to the effect of inherent rock properties or the uncontrollable factors on the blast outcome is cumbersome. Therefore empirical models were developed to give a rough guide towards the prediction of rock fragmentation by blasting operation. Among these models are the Kuz-Ram, The KCO, SveDeFo, Larson's equation, Neural Network Analysis etc. Consequently, it is important to study the viability of Kuz-Ram Model.

2.0. Overview

Kuz-Ram Model

A variety of modeling approach, ranging from purely empirical to rigorous numerical models has been used to predict fragmentation from blasting. Amongst them and the most popular is the Kuz-Ram model developed by Cunningham (1983). He modified the Kuznetsov's empirical equation to estimate the mean fragment size (x), and used the Rossin-Rammler distribution to describe the entire size distribution. The uniformity exponent of the Rossin-Rammler distribution is estimated as a function of the blast design parameters. (Cunningham, 1987). The Kuz-Ram model for the prediction of rock was first presented at the 1983 Lulea conference on fragmentation by blasting. Since then, the model has been evaluated, improved and likely surpassed in performance by more complex fragmentation model. However, it is a simple model that gives reasonable approximations of blasting fragmentation results and, it is a three parameters fragment size distribution model, consisting of: the Kuznetsov's equation, the Rossin-Ramlers equation and Cunningham's Uniformity index. These three equations define three different parameters that constitute the prediction output of the model.

Kuznetsov's Equation

Kuznetsov (1973) developed an equation for determining the mean fragment size, denoted as (X_{50}) as shown in equation (1)

$$X_{50} = A * \frac{Q^{1/6}}{K^{0.8}} * \left(\frac{115}{REE}\right)^{0.633} \quad \text{.......................................}(1)$$

Where, A is the rock factor, Q is the mass of explosive been used in kg, K is the powder factor (specific charge) in kg/m^3 and REE is the relative effective energy of the explosive, this is derived by dividing the absolute weight strength of the strength of the explosive in use by the absolute weight strength of ANFO and multiplying by 100%. The mean fragment size is first estimated to give an overview of what outcome will be generated by the blast design parameters for effective prediction process.

Rossin-Ramlers Equation

The Rossin-Ramlers equation for percentage passing is determine in equation (2a). This is also important in characterizing muck pile size distribution (Faramarzi, *et al*., 2013).

$$\%\text{passing} = 100 - \left(100 * e^{-0.693} *^{\left(\frac{meshsize}{X_{50}}\right)^n}\right) \quad \text{.......................................}(2a)$$

$$R = e^{-\left(\frac{X}{X_c}\right)^n} \quad \text{.......................................}(2b)$$

Where R is the weight fraction of fragments larger than X, n is the uniformity exponent, Xc is the characteristic size and X is the fragment size. % passing represents the percentage of material that will pass through a screen of a particular mesh size (X).

Cunningham's Uniformity index.

Cunningham established the applicability of uniformity coefficient through several investigations by considering the effects of blast geometry, hole diameter, burden, spacing, hole length and drilling accuracy. This can be estimated using equation (3) as shown below.

$$n = \left[2.2 - 14\left(\frac{B}{D}\right)\right]\left[0.5\left(1 + \frac{S}{B}\right)\right]^{0.5}\left[1 - \frac{W}{B}\right]\left[\frac{L}{H}\right] \quad \text{.......................................}(3)$$

Where; B is the burden (m), S is the spacing (m), D is the hole diameter (mm), W is the standard deviation of drilling accuracy (m), L is the total length of drilled hole (m) and H is the bench height (m). Cunningham proposed the model in its most basic form, wherein the parameters required for the fragmentation prediction were basically controllable elements of the blast design. The equation set was as described in equations 1 to 3, but with a slight difference in the calculation of the uniformity index, as shown in the equation (4).

$$n = \left(2.2 - 14\frac{B}{d}\right)\left(1 - \frac{D_t}{B}\right) * \left(1 + \frac{(m_b - 1)}{2}\right)\frac{l_{cb}}{H_b} \quad (4)$$

where 'B' is the burden in m, 'd' is the hole diameter in mm, 'D_t' is the standard deviation of drilling accuracy in m, 'm_b' is the spacing to burden ratio, 'l_{cb}' is the charge length above grade level in (m) and 'H_b' is the bench height in (m).

Slight modification was made on the equation set in 1987, and the new equation set was as follows:

$$n = \left[2.2 - 14\left(\frac{B}{D}\right)\right]\left[0.5\left(1 + \frac{S}{B}\right)\right]^{0.5}\left[1 - \frac{Z}{B}\right]\left[0.1 + \frac{abs(L_b - L_t)}{L}\right]^{0.1}\left[\frac{L}{H}\right]P \quad (5)$$

Where, 'Lb' is the Bottom charge length, 'Lt' the top charge length, 'P' the blast pattern factor,

Z is standard deviation of drilling error (m), Gustafsson (1973) suggested 3 cm /meter drill hole as an acceptable number for the faulty drilling or drillhole deviation.

This index defines the uniformity of the blast results, i.e., the degree of uniformity in their sizes. The uniformity index, typically, has values from 0.6 to 2.2. The value of 'n' determines the shape of a curve. A value of 0.6 means that the muckpile is non uniform (dust and boulders) while a value of 2.2 means a uniform muckpile with the majority of fragments close to the mean size (Clark, 1987).

From reviews, it is normally desirable to have uniform fragmentation (values of 1 or greater), thereby avoiding both excessive fines and oversize fragments in the broken ground (Sean and Anton, 2006). Furthermore different versions of this index can be found in several literatures, all these attest to the fact that no singular factor can encapsulate all the variables in a blast design.

Cunningham (2005) made an adjustments to the equations stated above.The major changes to the model, however, was developed as a result of the introduction of electronic delay detonators (EDs), since these have patiently transformed fragmentation. Both the effect of assigned timing and the effect of timing scatter are accommodated (Cunningham, 2005). The new equation set includes changes in the uniformity and mean fragment size equations, which is as follows:

$$X_{50} = AA_T K^{-0.8} Q^{1/6}\left(\frac{115}{RWS}\right)^{19/20} C(A) \quad (6)$$

$$n = n_s\sqrt{\left(2 - \frac{30B}{d}\right)}\sqrt{\left(\frac{1 + S/B}{2}\right)}\left(1 - \frac{W}{B}\right)\left(\frac{L}{H}\right)^{0.3} C(n) \quad (7)$$

Where, 'A_T' is a newly introduced timing factor, which is applied to Equation 6 as a multiplier, and now incorporates the effect of interhole delay on fragmentation, '*C(A)*' a correction factor for the rock factor,

'n_s' is the uniformity factor governed by the scatter ratio. '*C(n)*' is a correction factor for the uniformity index. As with the rock factor A, it can happen that the uniformity index is just not what the algorithm suggests, in which case correction factor *C(n)* is provided to overlay the inputs and enable estimation of the effects of changes from a common base.

The values of controllable parameters can be fixed for optimum fragmentation after conducting trial blasts in a mine and quantification of fragmentation using post blast methods of fragmentation analysis.

Lilly's (1986) "blastability index A", was incorporated in the Kuz Ram model (Cunningham, 1983). He discussed that every assessment of rock for blasting should at least take into account the density, mechanical strength, elastic properties and fractures. He defined the rock factor A using equation(8) as given below

$$A = 0.06 * (RMD + JF + RDI + HF) \quad (8)$$

Where RMD, is the mass description, JF is the joint factor, RDI is the rock density influence and HF is the hardness factor. Details of the model can be found in Cunningham, (1987).

Cunningham(2005) made further adjustment to this by introducing a correction factor, arriving at the rock factor A as a critical part of the process, but it is impossible to cater for all conditions in this simple algorithm. Normally, it is soon apparent if A is greater or smaller than the algorithm indicates, and, rather than trying to tweak the input, possibly loosing some valid input, a correction factor *C(A*) is now introduced. If preliminary runs against known results indicate that the rock factor needs to be changed, then *C(A)* is used as a multiplier to bridge the gap from the value given by this algorithm. The final algorithm is therefore given in equation (9)

$$A = 0.06(RMD + RDI + HF) * C(A)\text{.....................}(9)$$

The correction factor *C(A)* would normally be well within the range 0.5–2. (Cunningham, 2005)

Q= Mass of explosive in blast hole (excluding sub drill) (kg) and K= Technical Powder Factor (excluding sub drill) (kg/m³)

$$K = \frac{mass\ of\ \exp losive\ (Q)}{Volume\ of\ rock\ blasted}\text{.................................}(10)$$

3.0 Data Collection

Based upon the blasting operations carried out at obajana Cement Company, a database was prepared as indicated in Table 1. In this database, burden (B), spacing(S), diameter of hole (D), bench height (H), blast pattern factor (P), stemming length (L), length of bottom charge (Lb), length of column or top charge(Lt), powder factor(K), relative effective energy of explosive(REE), mass of explosive per hole and standard deviation of drilling error were measured or calculated as in put parameters to the model.

4.0 Results and Discussions

Using equations (1), (5) and (2): Mean fragment size (X_{50}) =113.55, the uniformity index (*n*) =1.37634 and the %passing = 26.85% respectively. These results were the predictions made based on the blasting parameters currently in use at the quarry as shown in Table 1.

For uniform fragmentation and optimum mean fragment size, the best burden and spacing value from the above result is 2.5 and 6.0 respectively. These values yield a uniformity index of approximately 1.5, and will produce a mean fragment of 105.5cm, which represent an improvement from the earlier result of 113cm obtained from the database currently used as blast design at the quarry.

Although a huge difference in magnitude of value was observed from the end result of the blasting operations and the predicted value for the mean particle size, nevertheless the trend of overall fragment size was reduced. The huge difference in the mean size values are due to the underestimation of fine materials by the Kuz-Ram model which is said to be produced by a different mechanism in the physics of blasting which is not covered by the size distribution parameter of the Kuz-Ram model.

Using the 2005 version of the Kuz-Ram model where data are available, and the correction factors being incorporated produce better predictions. A great positive correlation still exists where multiple results are examined even with the obvious difference in magnitudes of the values.

5.0 Conclusions

Being an empirical model, which infers finer fragmentation from higher energy input, it is more about guidance rather than accuracy. The results obtained remain a starting point to give an overview of what is expected of an adjustment to a preexisting blast design.

It can also serve as a basis for evaluating different designs, investigating the effect of changing certain variables and predicting the size distribution to be produced by the design. Inclusion of the newer multiplier prefactors introduced by other authors also increases its accuracy at prediction.

Furthermore, the simplicity of the model and the relative ease of gathering the data required to serve as feed to the model remains a major advantage of the model and putting it on the forefront of fragmentation prediction models. Other sophisticated and rather accurate model has evolved over the years, but suffers ambiguity. A general overview of results from various designs can also be examined using this simple model. The most important function of Kuz–Ram is to guide the blasting engineer in thinking through the effect of various parameters when attempting to improve blasting effects (Cunningham, 2005).

ACKNOWLEDGEMENTS.

Gratitude goes to the management of Obajana Cement Company for granting us the permission to carry out this research work at their quarry site and for considering the research work. Likewise the staff of Minerals and Petroleum Resources Engineering department, School of Engineering, Kogi Polytechnic, were all appreciated for their contributions.

References

Chung, S. H. and Katsabanis, P.D. (2000). "Fragmentation prediction using improved engineering formula." FRAGBLAST – Int. J .Blast. Fragment. 4: pp 198-207.

Clark, G. B. (1987). Principles of Rock Fragmentation. John Wiley & Sons, New York. pp 2, 432-442.

Cunningham, C.V.B. (1983). The Kuz–Ram model for prediction of fragmentation from blasting. Proceedings of 1st International Symposium on Rock Fragmentation by Blasting, Lulea, pp 439–454.
Cunningham, C.V.B. (1987). Fragmentation estimations and the Kuz–Ram model – four years on. Proceedings of Second International Symposium on Rock Fragmentation by Blasting, Keystone, Colorado. pp 475–487.
Cunningham, C.V.B. (2005) The Kuz-Ram Model-20 years on. Brighton Conference Proceedings. pp 201-210
Esen, S. & Bilgin, H.A. (2000) Effect of explosive on fragmentation. The 4th Drilling and Blasting Symposium.
Faramarzi, F.; Mansouri, H.and Ebrahimi Farsangi, M.A.(2013). A rock engineering systems based model to predict rock fragmentation by blasting, International Journal of Rock Mechanics & Mining Sciences 60, pp 82–94
Gustafsson, R. (1973). Swedish Blasting Technique. Published by SPI, Gothenburg, Sweden. pp 61-62.
Hustrulid, W. (1999). Blasting Principles for Open Pit Mining. Vol. I. A.A. Balkema, Rotterdam. pp 27- 31,854-855.
Jimeno, C. L., Jimeno, E. L. and Francisco J. A. C. (1995). Drilling and Blasting of Rock. Published by A.A. Balkema. Rotterdam. De Ramiro, Yvonne Visser translated to English. pp 30, 56-61, 179-183, 190.
Kanchibotla, S.S. Morrell, S. Valery, W. and O'Loughlin, P.O. (1998). Exploring the Effect of Blast Design on SAG Mill Throughput at KCGM. Mine to Mill Conference, Brisbane, pp153-157.
Kazem O, Bahareh A. (2006). Prediction of Rock Fragmentation in Open Pit Mines, using Neural Network Analysis. 15th international symposium on mine planning and equipment selection, Turin, Italy.
Kojovic, T., Kanchibotla, S.S., Poetschka and Chapman, J. (1998). The Effect of Blast Design on the Lump: Fines Ratio at Marandoo Iron Ore Operartions. Mine to Mill conference 1998, Brisbane, Qld. Exploring the relationship between mining and mineral processing performance. pp 150.
Kuznetsov, V.M.(1973). The mean diameter of fragments formed by blasting rock. J Min Sci;9:pp 144–148.
Lilly, P.A. (1986). An empirical method of assessing rock mass blastability. Proceedings, Large Open Pit Mining Conference (J.R. Davidson, ed.), The Aus IMM, Parkville, Victoria. Pp 89-92.
Ouchterlony, F. (2005). The Swebrec function: linking fragmentation by blasting and crushing. Mining Technology (Trans. Inst. Min. Metall. A), March 2005, Vol.114, pp. 29-44.
Sean R. and Anton G., (2006). Defining the Effect of Varying Fragmentation on Overall Mine Efficiency. Kumba Resouces. South Africa. *8th international symposium on fragmentation*. pp. 313-320.

Table 1: Blast design database for the Quarry

Benchmark	**Values**
Burden (B)	3m
Spacing (S)	5.5m
Diameter of hole (D)	0.127m
Bench height (H)	10.5m
Blast pattern factor (P)	1.1
Stemming length(L)	3m
Length of bottom charge (L_b)	2m
Length of column or top charge (L_t)	5.5m
Powder factor (Kg/m^3)	0.638
Relative effective energy of explosive(REE)	1.5
Mass of explosive per hole (Kg)	110.4
Standard deviation of drilling error(W)	0.3m

Table 2.0: Result of Simultaneous variation of blast design parameters

Spacing	Burden	Powder Factor	Uniformity index	Mean Size (X_{50})
4.0	3.0	0.876	1.249	88.33
4.5	3.0	0.778	1.292	97.13
4.5	4.0	0.584	1.177	122.18
5.0	3.5	0.601	1.272	119.41
5.0	3.0	0.701	1.335	105.57
5.5	3.0	0.637	1.376	113.98
5.5	2.0	0.956	1.509	82.37
5.5	2.2	0.869	1.485	88.90
5.5	2.5	0.765	1.445	98.45
5.5	2.8	0.683	1.404	107.80
5.5	3.2	0.597	1.348	120.05
6.0	3.0	0.584	1.416	122.18
6.0	2.5	0.701	1.490	105.57
6.5	3.0	0.540	1.455	130.08
6.5	2.0	0.809	1.606	94.14