International Journal of Rock Mechanics & Mining Sciences 93 (2017) 324–329

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Multivariate analysis of fracture toughness, brittleness and blasting geometric ratios for the prediction of fragmentation output

Victor Abioye Akinbinu

Department of Mining Engineering, Federal University of Technology, P.M.B. 704, Akure, Nigeria

ARTICLE INFO

Keywords:
Fracture toughness
Brittleness
Blasting geometric ratios
Fragmentation prediction
Multivariate analysis

1. Introduction

It is advantageous to have a uniform fragments size distribution, avoiding both fines and oversize in bench blasting particularly for aggregate production. High-quality fragmentation is important to successful mining operation and equipment maintenance. It reduces machine wears and energy consumption in process; increases loader and excavator productivity and efficiency. Fragmentation prediction is important as it affect the overall mining process and profitability of the excavation industry. There is at present no satisfactory theoretical basis for predicting dynamic failure behaviour while such prediction can be very useful in the solution of many practical mining and civil engineering problems. For example, effectiveness of all the subsystems in the mining operation (e.g. Loading, hauling and crushing) is dependent on the optimal fragmentation quality prediction; as well as rapid mining of ore bodies, design of stable structures and the efficiency of rock fragmentation processes can be designed and evaluated with more accuracy.

Parameters for determination in fragmentation prediction of rock blasting are divided into controllable and uncontrollable parameters. The blasting geometric ratios and explosive related parameters are termed as controllable parameters while the mechanical and physical properties of rock are the uncontrollable parameters. The duo must be considered together to create a fragmentation prediction model. The Kuz-Ram model based on[1] considered as the generalised model for predicting fragmentation make use of the uniaxial compressive strength (UCS) and the Young's modulus (E) as the uncontrollable parameters. Fractures and fragmentation of rocks are propagated through crack growth and coalescence. Therefore, fracture toughness which is the resistance of rock to fracture propagation and brittleness simply the ease of fracture to propagate describe fragmentation better than the UCS and E, no current blasting models consider it. It has also been shown that fracture toughness related with the tensile strength of rock as contain in[2] since fracturing of rock is usually due to tensile failure. Therefore fracture toughness and brittleness might be an index for rock fragmentation. Apart from model[1] other several researchers have developed empirical techniques to improve the ability of the fragmentation model. These include.[3–5] After Cunningham,[5] major research works toward improving the Kuz–Ram model has been in the area of estimating fines. Prominent research addressing this has been done probably by [6–10] The researchers noticed that the Kuz-Ram model is deficient in predicting fines and come out with modifications.

Several other researchers have also used multivariate analysis techniques in predicting blasting fragmentation.[11] Used multivariate analysis procedures for prediction of blast fragmentation.[12] Used multivariate relation to predict rock fragmentation based on main data (300 datasets).[13] Show with regression and sensitivity analysis that the outputs of fragmentation is affected more by burden and stemming than specific charge. Several other researchers applied multivariate analysis procedures to predict rock fragmentation by blasting.[14–17] Other analytical means include neural network, Rock Engineering System and Monte Carlo simulation as a tool to predict blasting fragmentation.[18–21] However such techniques which are based on the data acquired from different rock blasting operations, in an unclassified rock types (either Class I or Class II) may be misleading to generalise various rock brittleness and the relative fracture resistance of different rocks conditions for fragmentation prediction.

Fragments size distribution of blasted rock is influenced by many factors group as the controllable and uncontrollable parameters. Hence optimal prediction of particles size distribution of blasted rock is a very

E-mail address: akinbinuvictor@gmail.com.

http://dx.doi.org/10.1016/j.ijrmms.2016.12.014
Received 15 January 2016; Received in revised form 7 December 2016; Accepted 25 December 2016
1365-1609/

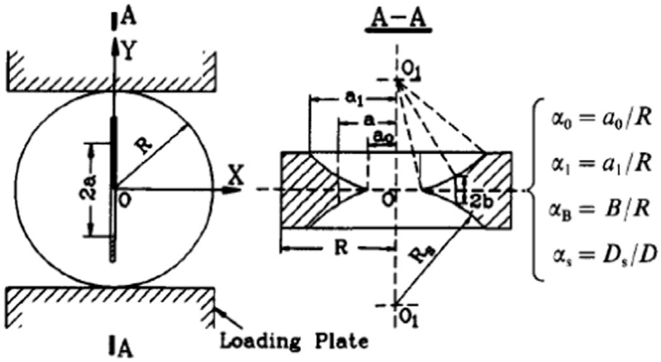

Fig. 1. The geometry of the CCNBD specimen ISRM (2007).

Table 1
Descriptive statistic of the data.

	Mean	Std. deviation
X50(m)	0.175120	0.0609381
Kic (MPa*m^0.5)	1.619500	0.1682377
S/B	1.014679	0.0968141
H/B	4.491356	1.2152266
D/B	0.002767	0.0006125
pf(Kg/m^3)	0.448894	0.2617687
(E-M)/M	−0.170305	0.0407027

complex issue due to multiplicity of the effective parameters. Therefore no single method or equation can predict the blast fragmentation. The available empirical models are based on data obtained from various blasting of outcrop of different conditions of rock brittleness and fracture toughness. This research considered partitioning fragmentation models for rocks based on their brittle nature (Class I or Class II rocks). Since the response of both Class I and Class II rocks differs under static and dynamic loading conditions while Class I is ductile, the Class II are much brittle. Increasing brittleness of rocks promotes fragmentation. Fragmentation of Class II rocks are energy efficient process as result of its self-sustaining fracturing behaviour, the Class I rocks on the other hand are energy intensive process as much of the energy are used in plastic deformation process ahead of breakage.[22,23] Opined that as rocks tend to show characteristic Class II behaviour, rocks exhibit higher micro-crack propagation velocity with deformation becoming self-sustaining thereby enhancing fragmentation. Therefore the grouping of fragmentation model into Class I and Class II will allow to determined the energy delivered by explosive and better prediction of fragmentation output. By separating fragmentation model for the Class II rocks will increase our ability in controlling the controllable parameters. Therefore this work is based on blast from several granitic outcrops with characteristic Class II rocks. Other possible outcrops that might show characteristic Class II behaviour under axial loading condition include hard brittle rock like quartzite, gabbro, basalt and mottled anorthosite etc. Future research will look into model for prediction of fragmentation for Class I rocks that may include for example dolomite, marble and limestone outcrops etc.

Wawersik and Fairhurst [24] Classified rocks into Class I and Class II according to their failure behaviour in a uniaxial compression test. Beyond the post peak region, either the curve continuously increases in strain or it does not. If it increases in strain, it is Class I; if it does not then it is Class II rocks are generally referred to be brittle than Class I rocks. The fragments size distribution produced during blasting depends to a large extent on the energy available to cause fragmentation (from explosive), fracture toughness and brittleness of the rock. In the literature it appears that no research has attempted to link fracture toughness, brittleness and fragmentation behaviour. Rock failure under dynamic loading conditions as experienced in blasting, rockbursting, and the resulting fragments size distribution is a little-understood phenomenon. The fracture toughness and brittleness of the rock has a significant effect under such loading conditions and the fragments that result.

2. Methods

The fracture toughness (mode I) values of the rocks were estimated according to[25] recommendation using cracked chevron notched Brazilian disc (CCNBD) specimens with the use of a closed-loop servo-controlled testing machine. The geometry of the CCNBD specimen is shown in Fig. 1 with all the dimensions of the geometry converted into dimensionless parameters with respect to the specimen radius R and diameter D.

The fracture toughness of the specimen is calculated by the following formula

$$K_{IC} = \frac{P_{\max}}{B^*\sqrt{D}} {}^*Y_{\min}{}^* \tag{1}$$

Where P_{max} is the maximum load and $Y^*_{\min}$, is the critical dimensionless stress intensity value for the specimen, which is determined by the specimen geometry dimensions α_0, α_1 and α_B only.

$Y_{min}{}^*$ is calculated by the following formula

$$Y_{\min}{}^* = u^* e^{v-\alpha_1} \tag{2}$$

Where u and v are constants determined by α_0, α_B from table u and v included in[25].

The pre- and post-failure moduli were determined for the rocks according to[25] with the use of a closed-loop servo-controlled testing machine. The blast data are gotten from aggregate quarrying opera-

Table 2
Coefficients of correlation and significant values of the data.

	X50 (m)	Kic (Mpa*m^0.5)	S/B	H/B	D/B	pf (Kg/m^3)	(E-M)/M
Pearson Correlation X50 (m)	1.000	−0.505	−0.172	−0.494	−0.404	−0.722	−0.804
Kic (MPa*m^0.5)	−0.505	1.000	−0.690	0.575	0.255	0.382	0.522
S/B	−0.172	−0.690	1.000	−0.322	−0.056	0.213	−0.015
H/B	−0.494	0.575	−0.322	1.000	0.936	0.282	0.784
D/B	−0.404	0.255	−0.056	0.936	1.000	0.201	0.719
pf (Kg/m^3)	−0.722	0.382	0.213	0.282	0.201	1.000	0.715
(E-M)/M	−0.804	0.522	−0.015	0.784	0.719	0.715	1.000
Sig. (1-tailed) X50 (m)	–	0.047	0.296	0.051	0.097	0.004	0.001
Kic (MPa*m^0.5)	0.047	–	0.007	0.025	0.212	0.110	0.041
S/B	0.296	0.007	–	0.154	0.432	0.254	0.481
H/B	0.051	0.025	0.154	–	0.000	0.187	0.001
D/B	0.097	0.212	0.432	0.000	–	0.265	0.004
pf (Kg/m^3)	0.004	0.110	0.254	0.187	0.265	–	0.004
(E-M)/M	0.001	0.041	0.481	0.001	0.004	0.004	–