Correlation between uniaxial compressive strength (UCS) and blasting geometry on rock excavation at PT Agincourt Resources

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Abstract. To achieve the set objectives, an analysis of uniaxial compressive strength and blasting geometry was used in five different rock types. Blasting is categorized successfully if the blasted material size distribution is ≤45 cm above 85%. With twenty-two times of blasting in five rock types, analyzed fragmentation distributions <45 cm in size. The result of analysis obtained by type of BPM 16.5 MPa with pf 0.64 kg/m^3 and drill pattern dimension is 16.34 m^2 has distribution of fragmentation 94.44%; SBPM 70.5 MPa with pf 0.92 kg/m^3 and drill pattern dimension is 11.85 m^2 has distribution of fragmentation is 92.47%; VAN 81.6 MPa with pf 0.96 kg/m3 and drill pattern dimension is 9.45 m^2 has distribution of fragmentation 88.65%, VANh 51.1 MPa with pf 0.86 kg/m^3 and drill pattern dimension is 12.54 m^2 has distribution of fragmentation 86.32% and VBX 74.0 MPa with pf 0.94 kg/m^3 and drill pattern dimension is 12.19 m^2 has distribution of fragmentation is 86.31%. The blasting result for all rock types was distributed above 85%. From the correlation of measured variables, it was observed that there is a good correlation between blasting geometry and uniaxial compressive strength. It was observed that blasting geometry increases with decrease in uniaxial compressive strength and an increase in blasting geometry will decrease the powder factor.

Keywords: blasting geometry, explosives, uniaxial compressive strength, fragmentation, split engineering software

1. Introduction

The main concern of any blasting is fragmentation. The objective of a blasting engineer in a mine is to generate a suitable muck pile having a suitable size distribution of the rock that can be efficiently loaded, transported and milled. So that, good fragmentation is a subjective matter and depend on the end use of the rock also depend upon the type and size of equipment which is used for the subsequent handling of the rock (Gregor, 1987). There are many factors that affect fragmentation of blasting results, it has classified into three namely; explosive parameters, rock parameters and charge-loading parameters or blast geometry (M.A. Saliu *et al*, 2013).

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The explosive parameters are density, detonating velocity, detonation impedance, detonation pressure, gas volume, and available energy. The charge-loading parameters are diameter, length, stemming, decoupling, type of initiation, and point of initiation which play important role in the fragmentation process. Rock parameters on fragmentation process include density, propagation velocity, characteristics impedance, energy absorption, compressive and tensile strength, variability and structure of the rock (Brady and Brown in M.A. Saliu et all, 2013).

Unlike metals, where the compressive strength and tensile strength have comparable values, for most rocks the tensile strength has a much lower value than that of compressive strength. When the ratio of compressive to tensile strength is higher, the rock is more brittle (Gokhale, 2011). One of the important characteristics of rock that is crucial to the fragmentation process is a high ratio of compressive strength to tensile strength.

An increase in the strength of rock means increase in the amount of explosive required for the fragmentation of such rock (Jimeno, 1995), it's mean that uniaxial compressive strength has contribution in fragmentation process . This research worked therefore correlates between the blasting geometry and uniaxial compressive strength of different types of rock with a few to finding a blasting solution to achieved fragmentation distribution.

2. Method

2.1. Study Area

Martabe Gold Mine is located in Desa Aek Pining, Batangtoru District, South Tapanuli District, North Sumatra Province, Indonesia (Figure 1). The Martabe Project lies within Latitudes 04 ° 21 '08 "N - 1 ° 54 'N and Longitudes 98 ° 54 '72" E - 99 ° 24' 180 "E. The area has been sufficiently be studied and presented by Jan jan Hertrijana in IAGI Conference (2005).

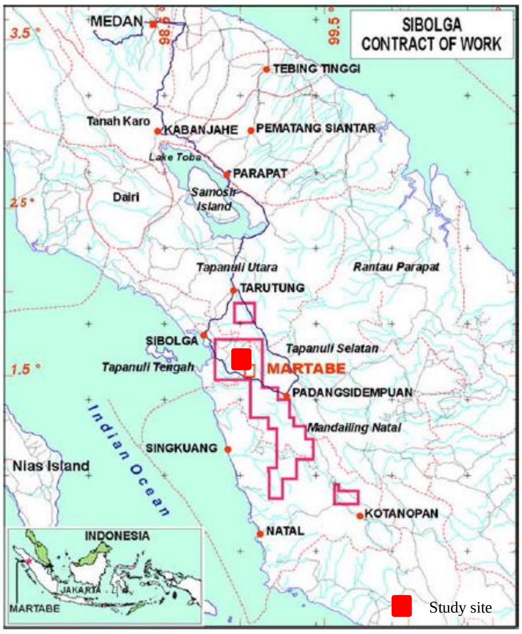

Figure 1. Study Site and Location of Martabe Gold Mine

2.2. Geology

The Martabe district is situated in a fore arc basinal setting with a subduction zone to the west and active volcanism along the eastern side (the Barisan Mountains). Multi phase magmatism and periods of sedimentation have been recognized in this area, which are provisionally divided into several major units. From the oldest to the youngest, the Martabe district rock units in are as follows; Palaeozoic carbonaceous meta-sediments of the Tapanuli Group (Put), Mesozoic Uluala Nagodang granite (IGR), Barus Sediments (SED), Tertiary Angkola Volcanics (VAN, VBS), Late-Tertiary Dacite Andesite

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dome and diatreme complex (BPM, VDA, VANh, VBX). The startigrafi on martabe geology map of purnama and baskara prospect (figure 2).

Detail report on Martabe High Sulphidation Gold Deposits North Sumatra, Indonesia (Jan Hertrijana in IAGI Conference (2005).

*2.3.Uniaxial Compressive Strengt***h**

The uniaxial compressive strength test is the most widely used measure of the strength, deformation and fracture characteristics of the rock because of its accuracy. Many studies have been conducted to show that UCS is related to other physical properties of the rock samples. In plain words, compressive strength means ability to resist compression. When a cylindrical rock sample is subjected to increasing axial compressive force as shown in (Figure 3). It's axial length goes on reducing and at the same time its diameter goes on increasing.

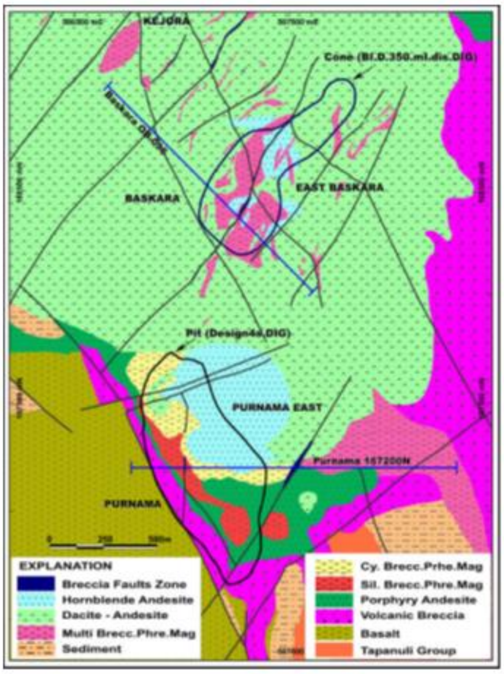


Figure 2. Martabe Geology Map of Purnama and Baskara Prospect

Stress exerted on rock sample is calculated as:

$$\sigma = F/A \qquad (1)$$

The strain that results from the test is calculated as:

$$\varepsilon = \Delta L/L \qquad (2)$$

Explanation of the symbols F, d, L is contained in (Figure 3). Thereafter the compressive strain keeps on increasing even when the axial load is not increased, or in fact even when it is decreased, resulting in unchanged or reduced compressive stress. The maximum value of stress to which the rock specimen is subjected in such a test process, is called compressive strength. The commonly adopted procedure for determination of UCS is as per American Standard ASTM D2938 (Gokhale, 2011).

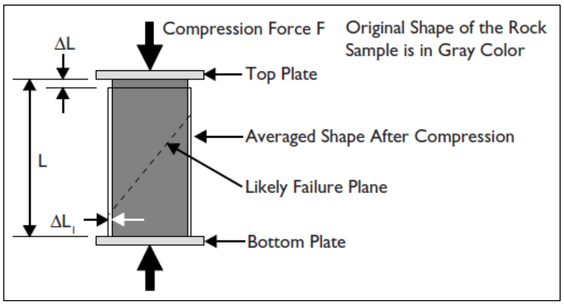


Figure 3. Uniaxial Compression Test

2.4. Material Types

There are five types of material under study, where the rock properties test results have been reported in Golder report (Job No. 023-2373R9).

Figure 4. Material Type For Uniaxial Compressive Strength Test

Table 1. Martabe Rock Characteristics

Rock Type	Density	RQD	UCS (MPa)	Blastability
BPM (Breccia Phreatomagmatic)	2.21	84	16.5	Average
SBPM (Silicified Breccia Phreatomagmatic)	2.63	78	70.5	Hard
VAN (Andesitic Volcanics)	2.77	83	81.6	Average
VANh (Porphyritic Hornblende Andesite)	2.39	78	51.1	Hard
VBX (Volcanic Breccia)	2.51	87	74.0	Hard

2.5. General Blasting Parameter

Based on geology database and rock properties test as uniaxial compressive strength and RQD, D&B engineer designed: hole diameter 127 mm; hole depth 5 and 10 m, burden 2.3-4.3 m; and spacing 2.8-5.4 m, coefficient of *S/B* = 1.5, stemming high 2.3-4.4 m, powder facotr 0.25-1.24 kg/m^3. Explosive used emulsion mixed Trojan 2870HV, booster daya prime 400 gr. Stemming materials used gravels 1.2-22 mm, tie in used nonel with various delay 17MS, 25MS, 42MS and 67MS.

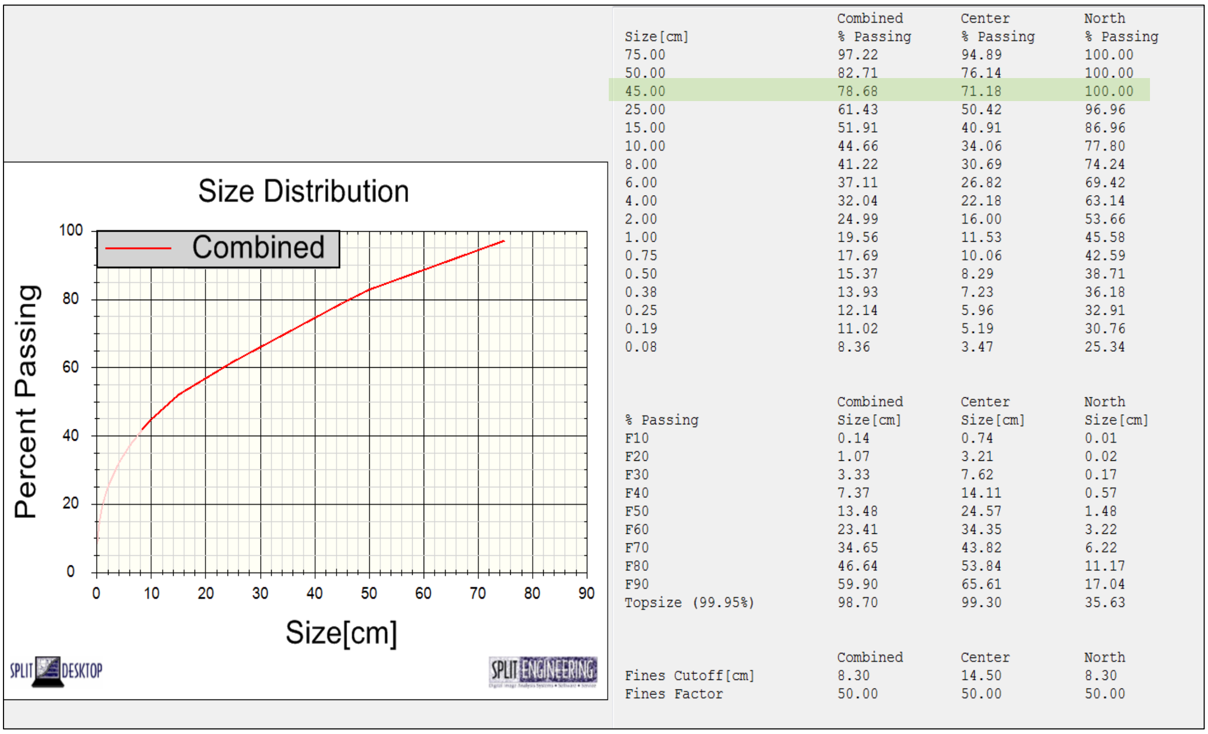
2.6. Analysis Tools

Blast design parameters of bench blasting are the controlling parameters which regulate (standard for vibration and air blast) and the desired fragmentation level of a particular blast. Rock mass properties and blasting parameters control the efficiency of a blasting operation. Hole diameters 127 mm, hole depth in 5 and 10 m, were used depending on their bench height. A few blasts were performed by the existing blast design practiced in the mine and after each blast twenty-two times, scaled digital photographs throughout the complete mucking of the fragmented rock pile were taken as well as loading efficiency of the excavator was recorded. Fragmentation characteristics such as fragmentation degrees occurring as a result of blasting were calculated by using digital images by split engineering software split-destop version 3.1 (Figure 6).

The rock properties of rock sample collected at Martabe projects are presented in Table 1. Fragmentation analyses were carried out for all the blasts in different segments. The view of the post blast results of different benches at Martabe is depicted in Figure 5. At this project crusher plant recommends as an ideal entry material, fragments to the size of < 45cm.

Figure 5. View of The Detonation Sequence of Bench Blast at Martabe Project (Type:BPM)

Figure 6. Fragmentation Analysis by Split Engineering Split-Desktop Version 3.1 Software



Size[cm]	Combined % Passing	Center % Passing	North % Passing
75.00	97.22	94.89	100.00
50.00	82.71	76.14	100.00
45.00	78.68	71.18	100.00
25.00	61.43	50.42	96.96
15.00	51.91	40.91	86.96
10.00	44.66	34.06	77.80
8.00	41.22	30.69	74.24
6.00	37.11	26.82	69.42
4.00	32.04	22.18	63.14
2.00	24.99	16.00	53.66
1.00	19.56	11.53	45.58
0.75	17.69	10.06	42.59
0.50	15.37	8.29	38.71
0.38	13.93	7.23	36.18
0.25	12.14	5.96	32.91
0.19	11.02	5.19	30.76
0.08	8.36	3.47	25.34

% Passing	Combined Size[cm]	Center Size[cm]	North Size[cm]
F10	0.14	0.74	0.01
F20	1.07	3.21	0.02
F30	3.33	7.62	0.17
F40	7.37	14.11	0.57
F50	13.48	24.57	1.48
F60	23.41	34.35	3.22
F70	34.65	43.82	6.22
F80	46.64	53.84	11.17
F90	59.90	65.61	17.04
Topsize (99.95%)	98.70	99.30	35.63

	Combined	Center	North
Fines Cutoff[cm]	8.30	14.50	8.30
Fines Factor	50.00	50.00	50.00

Figure 7. Cumulative Size Curve View of Fragmented BPM Material of Martabe Project

3. Result

Each material blasted was analyzed using split-desktop 3.1 software. All blast design used 127 mm bit, explosive emulsion Trojan 2870HV, stemming with gravel size 1.2-2.2 mm.

Table 2. Calculated Average % Passing For Blasting Results

Rock Type	B x S (m^2)	UCS (MPa)	PF (kg/m^3)	% Passing				Over target size $\leq$45cm
				25 cm	45 cm	50 cm	75 cm	
BPM	16.34	16.50	0.64	72.17	94.44	98.22	100.00	9.44
SBPM	11.85	70.50	0.92	73.92	92.47	94.69	99.03	7.47
VAN	9.45	81.60	0.96	66.95	88.65	94.57	99.18	3.65
VANh	12.54	51.10	0.86	70.07	86.32	88.54	96.28	1.32
VBX	12.19	74.00	0.94	65.83	86.31	89.42	97.97	1.31

Based on target that fragmentation size for crushing $\leq$ 45cm. Blast category succes if over size distribution $\leq$ 15% of average size target. Table of % passing $\leq$ 45cm. The next analysis focuses on materials with fragmentation below 45 cm with a distribution of over 85% (BPM, SBPM, VAN, VANh and VBX).

The analysis results are put in histogram and graph.

3.1. Histogram Distribution Fragmentation of Various Rock Types

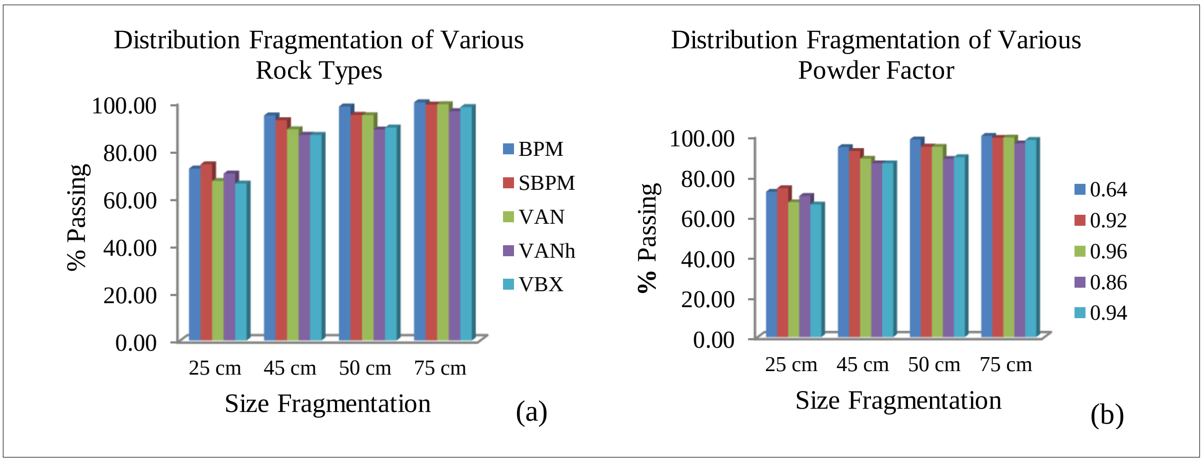


Figure 8. Histogram distribution fragmentation of various rock types (a) and various pf (b)

3.2. Correlation Between Powder Factor and Uniaxial Compressive Strength

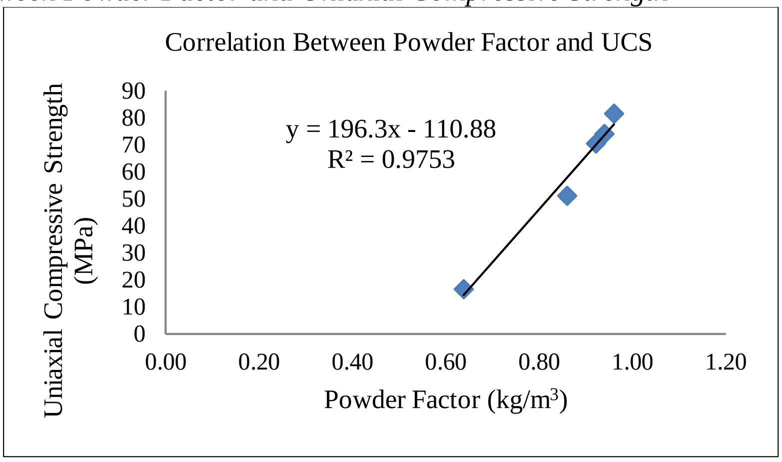


Figure 9. Correlation between powder factor and uniaxial compressive strength

3.3. Correlation Between Drill Pattern Dimension and Powder Factor

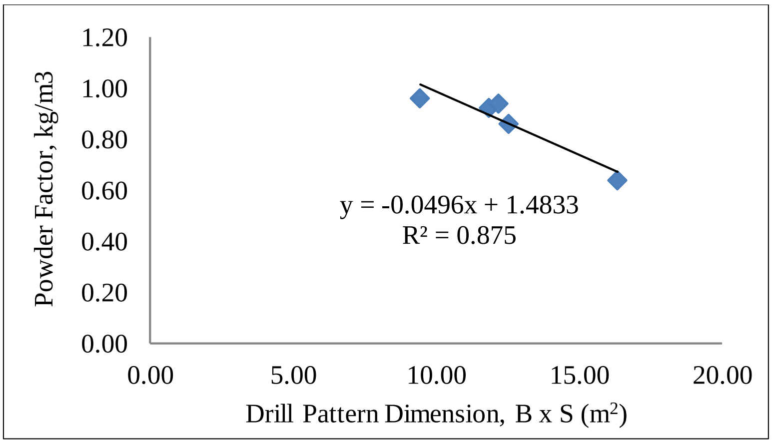


Figure 10. Correlation between drill pattern dimension and powder factor

3.4. Correlation Between Drill Pattern Dimension and Uniaxial Compressive Strength

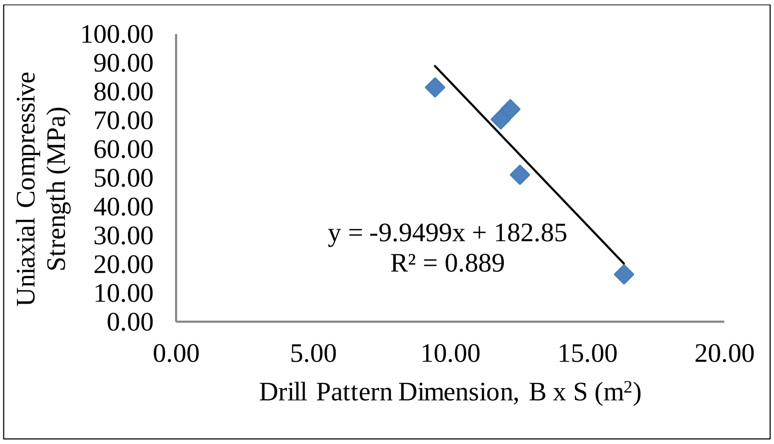


Figure 11. Correlation between drill pattern dimension and uniaxial compressive strength

4. Discussion

4.1. Uniaxial Compressive Strength

Uniaxial compressive strength tests were carried out on the selected rock types. At the martabe site the tests were performed on five different rock types, corresponding to the rock lithology to be mined. Rock UCS values vary from 16.5 MPa to 81.6 MPa due to differences in constituent material and the process of formation.

4.2. Correlation Between Powder Factor and Uniaxial Compressive Strength

The correlation between the uniaxial compressive strength and Powder Factor for different rock type were critically investigated from the research work. Figure 9 shows the correlation between uniaxial compressive strength and powder factor, the equation of the graph is as written in Equation 3:

$$y = 196.3x - 110.88 \qquad (3)$$

where y is the unaxial compressive strength in MPa and x is powder factor in kg/m^3. The coefficient of correlation (R^2) is 0.975 indicating very strong correlation between them.

4.3. Correlation Between Drill Pattern Dimension and Powder Factor

Figure 10 shows the correlation between powder factor and drill pattern dimension when using emulsion explosive, the equation of the graph is as written in Equation 4:

$$y = -0.0496x + 1.4833 \qquad (4)$$

where y is the powder factor in kg/m^3 and x is drill pattern dimension in m^2 (burden x spacing). The coefficient of correlation (R^2) is 0.875 indicating strong correlation between them.

4.4. Correlation Between Drill Pattern Dimension and Uniaxial Compressive Strength

Figure 11 shows the correlation between uniaxial compressive strength and drill pattern dimension when using emulsion explosive, the equation of the graph is as written in Equation 5:

$$y = -9.9499x + 182.85 \qquad (5)$$

where y uniaxial compressive strength in MPa and x is drill pattern dimension in m^2 (burden x spacing). The coefficient of correlation (R^2) is 0.889 indicating strong correlation between them.

It can be observed that there is a very strong correlation between powder factor and uniaxial compressive strength of the rock under consideration. It can be observed that, for all the rock type consideration, the higher the uniaxial compressive strength, the higher powder factor to achieved blast fragmentation average. On this case, the targe of blast fragmentation size is <45cm more than 85%. This study can also be used for planning the efficiency of materials in rocks with uniaxial compressive strength.

5. Conclusion

The results of the uniaxial compressive strength and blast fragmentation using emulsion with various powder factor and drill pattern dimension. For each rock type BPM 16.5 MPa using PF 0.64 kg/m^3 and drill pattern dimension is 16.34 m^2 retrieved blast fragmentation size $\leq$ 45 cm sebesar 94.44% ; SBPM is 70.5 MPa using PF 0.92 kg/m^3 and drill pattern dimension is 11.85 m^2 has distribution of fragmentation size $\leq$ 45cm of 92.47%; VAN is 81.6 MPa using PF 0.96 kg/m^3 and drill pattern dimension is 9.45 m^2 has distribution of fragmentation size $\leq$ 45 cm of 88.65%, VANh is 51.1 MPa using PF 0.86 kg/m^3 and drill pattern dimension is 12.54 m^2 has distribution of fragmentation size $\leq$ 45 cm of 86.32%and VBX is 74.0MPa using PF 0.94 kg/m^3 and drill pattern dimension is 12.19 m^2 has distribution of fragmentation size $\leq$ 45 cm of 86.31%.

From the correlation of measured variables, it was observed that there is a good correlation between powder factor and uniaxial compressive strength. It was observed that powder factor increases with increase in uniaxial compressive strength, likewise between the drill pattern dimension and PF has a proportional relationship, the last relationship between drill pattern dimension and uniaxial compressive strength is also directly proportional. Equations 3 to 5 can be used to plan the efficiency of explosives at the same rock type with this study.

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