Compressive strength and controllable blasting parameters analysis for predicting muck-pile size and heave height at Husab Uranium Mine

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Good fragmentation is a major concern for any blasting operation and makes a significant contribution to the overall production costs of the mine. Drilling and blasting must be closely monitored not to affect the downstream operations and processes for a good degree of rock fragmentation to be achieved. This study analysed the effect of explosives such as emulsion (HEF200) and ammonium nitrate and fuel oil (ANFO) on the degree of fragmentation and their heaving quality. The uniaxial compressive strength (UCS) and controllable blasting parameters to predict actual fragment size of the muck-pile using the digital image processing software Split-Desktop system and Kuz-Ram fragmentation model were considered. Heave heights were correlated with individual variables using linear, exponential, power, and logarithmic approximations to select variables that contribute more to heave heights. Cumulative size distribution curves for multiple images were used for determination of the actual mean fragment size. The UCS of the rocks varied from 100-160 MPa. The geometrical parameter of 4.8 × 5.5 m yielded mean size of 232.36 mm with heaving height of 3.26 m when emulsion was used while 7.1 × 8.1 m yielded mean fragment size of 223.22 mm with heaving height of 4.64 m when ANFO was used. From the result of analysis of variance (ANOVA) null hypothesis of no effect of the selected variables was rejected for heave height model. The models developed for actual fragment size and heave height of the muck-pile explained more than 85% and 95% variations in the model respectively.

Keywords: Heave, heights, muck-pile, geometrical, blasting, predicting, mean

INTRODUCTION

Husab uranium mine is located 45 km northeast of Walvis Bay, which is the main port of the country. The Husab ore body is the highest grade granite-hosted (alaskites) uranium deposit in Namibia. Once full production is reached, Husab will become the world's third largest uranium-only mine. The project is expected to produce 7000 tonnes of uranium each year when fully operational. Currently operations take place in two zones, pit zone 1 and pit zone 2, with measured resources of about 273 million pounds of uranium oxide (U_3O_8). The ore body is exposed by continuous drilling and blasting, and mined by conventional truck and shovel method (VBKOM Consulting Engineers, 2013). Achieving good fragmentation is the major objective of any blasting operation in the mine. Rock fragmentation is influenced by several factors which include blast design parameters (drilling pattern, blast-hole diameter, sub-grade drilling, stemming column, initiation system and delay timing; explosive parameters and rock parameters (Rout and Parida, 2007; Kalatilake *et al.,* 2010).

Selection of blast design pattern is a key task in mining activities and these patterns vary from mine to mine (Monjezi *et al.*, 2009). Blasting parameters must be determined such that the entire explosive energy is consumed for good rock fragmentation; otherwise unwanted damage such as back-break and fly-rock will occur (Monjezi *et al.*, 2011).

Fragment size distribution is mainly governed by two factors: the physico-mechanical properties of the rock which are uncontrollable, and the blasting parameters that can be changed to achieve the desired size distribution with corresponding muck-pile profile (Kilic *et al.*, 2009). There are many variables that can affect the required size distribution of fragmentation. This depends on the size required by the primary crusher as it affects the output of the crusher. Investigating blasting design parameters effects on size distribution and muck-pile profile will guarantee the safest and most economical fragment size distribution for production optimisation (Workman & Eloranta, 2005).

Although studies have been conducted on the influence of rock mass properties on blasting efficiency, depending on the geological location of the area, rock mass properties varied widely (Adebayo & Umeh, 2007; Adebayo & Opafunso, 2010). Indirect methods which are observational, empirical and digital developed over the years are feasible fragment size estimation for large excavations. Different models had been developed to describe the size distribution of fragments after blasting. According to Cunnigham these models offer equations to calculate the average size (x_{50}) as well as the entire fragment size distribution curve. Additionally, the geometric profile of the muck-pile of the blast must be established to estimate blasting performance and extraction-loading efficiency (Sharma *et al.*, 2019).

Choudhary (2013) confirmed that boulders are due to poor fragmentation which will slow down the loading process and the output of crusher. In order to solve the problem of boulders, there is a need to determine the strength of the rock and select controllable blasting parameters which will ultimately eliminate the problem of boulders as well improve the muck-pile profile. The objectives of this study are to select controllable blasting parameters (drill-hole diameter, drill-hole length, stemming, and powder factor) for blasting; determine uniaxial compressive strength of the rocks; develop models to predict actual mean fragment size and heave height of muck-pile.

Experimental and field studies

Determination of uniaxial compressive strength

The uniaxial compressive strength of the rocks (UCS) was determined using 1100 kN compression machine. The test procedure was in accordance with ISRM (1989) and ASTM (2001) D 2938. The uniaxial compressive strength was determined using Equation 1.

$$Co = \frac{P}{A} = \frac{P}{W.D} \qquad [1]$$

Where C_o is uniaxal compressive strength (MPa), P is the applied peak load (kN), W is Width of the sample (mm), D is Height of the sample (mm)

Determination of blast parameter

Geometrical blast-hole parameters

Blast-hole diameter, depth, burden (B), stemming and spacing of the blast were measured directly after the drilling operation using a measuring tape.

Volume of blast and tonnage of rock

Volume of blast was determined using Equation 2.

$$V_b = b \times s \times l_{avg} \times n \qquad [2]$$

Where b is the burden, s is the spacing, l_{avg} is the average blast hole length (m), and n is the number of holes to be drilled. The average blast-hole length and tonnage for the blast were calculated using Equation 3 and 4.

$$l_{avg} = {}^{\sum hole\ depth}/_{n} \qquad [3]$$

$$T = \rho \times V_b \qquad [4]$$

Where T is the tonnage of the muck-pile in tons, ρ is density of rock.

Mass of charge per blast hole

After all blast holes were charged, the mass of charge per hole, m_h, in kg was then calculated using Equation 5.

$$Mass\ of\ charge\ per\ hole = {}^{m_{exp}}/_{n} \qquad [5]$$

Where m_{exp}, is the mass of explosive used for the entire blast (kg)

Determination of powder factor

Powder factor was determined using Equation 6.

$$\mathbf{Pf} = \frac{\mathbf{We}}{\mathbf{Vr}} \qquad [6]$$

Where, Pf is the powder factor, W_e is Weight of explosives (kg) and V_r is the volume of rock fragments.

Determination fragment size distribution

Digital images analysis techniques of capturing scaled images of five blasted muck-piles were used for determination of mean fragment size. The captured images were analysed by Split-Desktop software. Five pictures of each blast (before loading and after loading) where taken and analysed with Split-Desktop software.

Determination of heave height of muck-pile

The heave height was measured for each of the blasts once the blast-holes had been detonated.

RESULTS AND DISCUSSION

Uniaxial compressive strength

Table I presents the results of the uniaxial compressive strength of selected rocks. The UCS varied from 24.72 MPa for calcrete to 243.66 MPa for aplite.

Table I. Uniaxial compressive strength of selected rocks

Rock Type	UCS (MPa)
Alaskite	118.23
Aplite	243.66
Leucogranite	138.01
Pegmatite	109.56
Calsc_silicate	151.38
Calsc_silicate (b)	81.43
Cals_silicate(epidote)	140.10
Calc_silicate (garnet)	101.69
Gneiss	116.27
Quartzite	102.55
Calcrete	24.72
Marble	97.06
Smokey Quartz	157.86

Conglomerate	139.91
Sediments	150.48
Biotite Schist	123.33
Biotite Schist (diopside)	153.92
Garnet schist	100.43
Schist	119.15

Blasting parameters

Tables II and III show drilling and blasting parameters used on different blocks blasted in area of study. The blasts for these blocks were trim and production blasting as summarised in Tables II and III. The explosives used are ammonium nitrate and fuel oil (ANFO) and emulsion using non-electrical (NONEL) ignition system. The charge per hole and powder factor varied from 83.30 – 214 kg/ blast-hole and 0.420 – 0.496 kg/m^3 respectively. The explosive density ranged between 0.86 and 1.15 g/cm^3 for the blasts.

Table II. Drilling and blasting design parameters used

Parameters	Blast 1		Blast 2		Blast 3
Blast Type	Trim		Production		Trim
Block ID	D004	D007	D020	D022	D039
Burden (m)	5	5	7.1	4.8	4.8
Spacing (m)	5.8	5.8	8.1	5.3	5.5
Diameter (m)	0.165	0.165	0.251	0.165	0.165
Av. hole depth (m)	10.43	10.43	9.66	9.33	9.49
No. of holes	129	26	987	430	585
Volume (m^3)	39018.63	7864.22	548324.49	102062.74	146563.56
Firing pattern	Chevron	Chevron	Chevron	Chevron	Chevron
Stem. Height (m)	4.5	4.5	4.5	4.5	4.5
Sub-drill (m)	2.0	2.5	2.5	2.0	2.0
Ignition System	NONEL	NONEL	NONEL	NONEL	NONEL
Timing	25/42/75	25/42/75	25/42/75	25/42/75	25/42/75
Explosive	ANFO	ANFO	ANFO	ANFO	EMULSION
Charge/ hole (kg/hole)	91.9	95.6	214	97.6	83.3
Expl. Density (g/cm^3)	0.86	0.86	0.86	0.86	1.15
Powd. Factor (kg/m^3)	0.422	0.440	0.496	0.493	0.420

Table III. Drilling and blasting design parameters used

Parameters	Blast 3	Blast 4	Blast 4	Blast 5
Blast type	Trim	Production	Production	Production
Block ID	D040	D019	1B06D052	1B07D074
Burden (m)	4.8	7.1	7.1	7.1
Spacing (m)	5.5	8.1	8.1	8.1
Blast hole diameter (m)	0.165	0.251	0.251	0.251
Average hole depth (m)	9.45	9.43	9.35	9.59
No. of holes	163	259	231	411

Volume (m³)	40665.24	140460.70	124212.97	226675.09
Firing pattern	Chevron	Chevron	Chevron	Chevron
Stemming height (m)	4.5	4.5	4.5	4.5
Sub-drill (m)	2.0	2.0	2.0	2.0
Ignition system	NONEL	NONEL	NONEL	NONEL
Timing	25/42/75	25/42/75	25/42/75	25/42/75
Type of explosive	EMULSION	ANFO	ANFO	ANFO
Charge per hole (kg/hole)	83.3	214	214	214
Explosive density (g/cm³)	1.15	0.86	0.86	0.86
Powder factor (kg/m³)	0.420	0.496	0.496	0.496

Table IV presents the size reduction ratio of predicted to actual fragment size distribution. The top size (99.95%) varied from 1082.03 mm for blast 5 to 1678.05 mm for blast 2. Also, the fines cut-off varied from 146.35 mm for blast 5 to 201.50 mm for blast 4. Predicted and actual fragment size ranged from 239.72 for blast 2 to 367.39 mm for blast 5 and 137. 89 mm for blast 2 to 296.97 for blast 5 respectively. The size reduction ration varied from 1.15 for blast 1 to 1.74 for blast 2.

Table IV. Size reduction ratio of predicted to actual fragmentation

Blast No.	Predicted size (mm)	Actual size (mm)	Size Reduction Ratio	Top size (99.95%) (mm)	Fines Cut-off (mm)	Fines Factor
Blast 1	300.14	260.70	1.15	1172.42	200.05	50.00
Blast 2	239.72	137.89	1.74	1678.05	193.60	50.00
Blast 3	265.28	203.61	1.30	1130.98	142.75	50.00
Blast 4	309.32	234.81	1.32	1460.84	201.50	50.00
Blast 5	367.39	296.97	1.24	1082.03	146.35	50.00

Analysis of mean fragment size for the blasts

Figures 1 – 5 present actual mean fragment size against predicted fragment size distribution for blasts 1-5. Mean fragment size varied from 28.83 – 726.23 mm, 2.50 – 834.56 mm, 9.00 – 653.02 mm, 10.92 - 852.56 mm and 20.40 – 780.68 mm for blasts 1,2, 3, 4 and 5 respectively as shown in Figures 1 – 5.

Mean fragment size distribution of blast 1

Blast 1 was carried out in an area dominated by gneiss rock type having UCS of 116.27 Mpa. For blast 1, the actual and predicted mean fragment sizes are 260.70 mm and 300.00 mm respectively. The size reduction of this blast was 1.15 as presented in Table IV. The slight deviation of the actual mean fragment size distribution from the predicted mean fragment size distribution was due to collapsed blast-holes and resulted in re-drilling of the blast-holes at different positions. Furthermore, at Husab Mine anything less than 8 mm and greater than 1200 mm are considered as fines and boulders respectively. As could be observed in Figure 1 the lower and upper size bound of the actual fragment size distributions are 28.83 mm and 1172.42 mm respectively, this revealed that no fines and boulders resulted from blast 1.

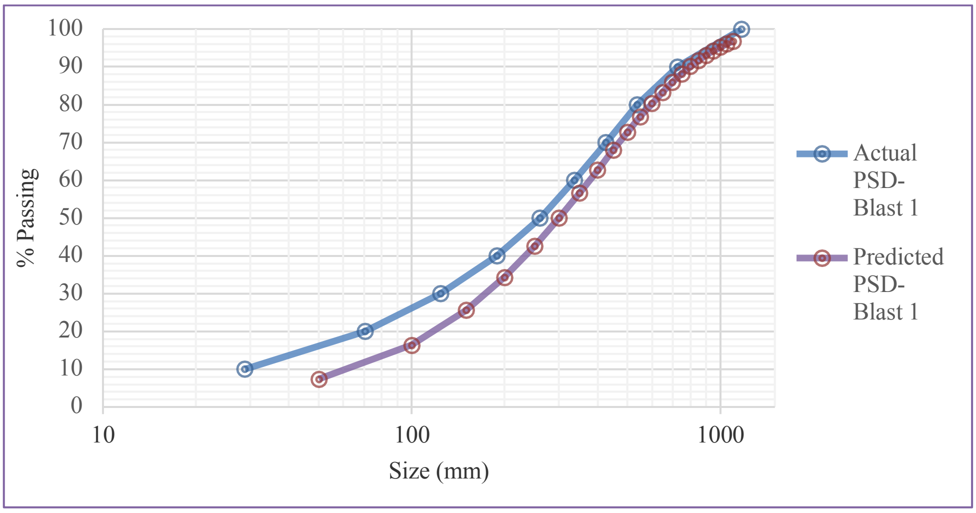

Figure 1. Actual against predicted fragment size distribution for blast 1.

Mean fragment size distribution of blast 2

Blast 2 was carried out in an area dominated by Calsc-silicate rock type with UCS of 81.43 Mpa. The mean fragment size reduction ratio for blast 2 is 1.74. This is a slightly higher size reduction ratio than Blast 1 due to the weaker rock formation which can result in the explosive coverage being able to absorb more, rather than actually fragmenting the rock. Blast 2 consisted of two blocks with different drilling and blasting parameters, which could have been the major contribution to the deviation between the curves as illustrated in Figure 2. Blast 2 resulted in formation of fines reaching up to 2.50 mm in size and top size of 1678.05 mm in size. All these may be attributed to the rock types and blasting parameters.

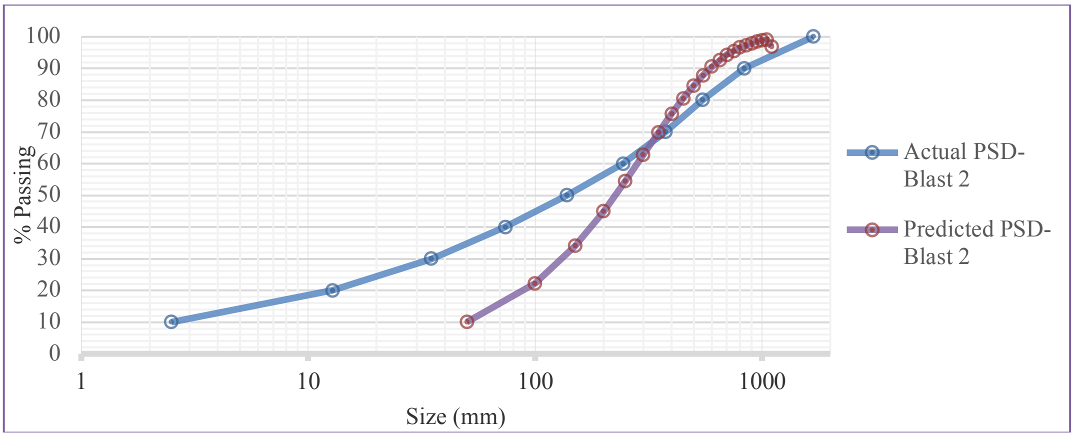

Figure 2. Actual against predicted fragment size distribution for blast 2.

Mean fragment size distribution of blast 3

Blast 3 was carried out in an area dominated by alaskite rock type with UCS of 118.23 MPa. P50 of actual mean fragment size of 203.61 mm and a predicted value of 265.28 mm resulted in a size reduction ratio of 1.30. Blast 3 was a trim blast and the actual fragment size reached a top size of 1130.98 mm, coming close to the boundary of boulder size of 1200 mm.

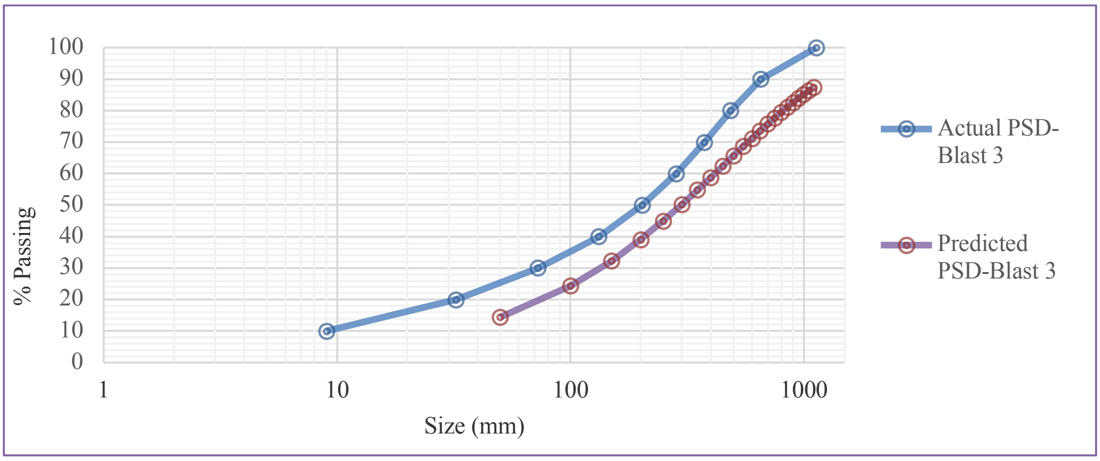

Figure 3. Actual against predicted fragment size distribution for blast 3.

Mean fragment size distribution of blast 4

Blast 4 was carried out in an area dominated by alaskite rock type with UCS of 118.23 MPa. Actual and predicted mean sizes are 309.32 mm and 232.81 mm respectively with a reduction ratio of 1.32. Blast 4 experienced minimum blast-holes collapse, this means that the explosive energy coverage was maintained as planned and resulted in the curves following a similar trend as presented in Figure 4.

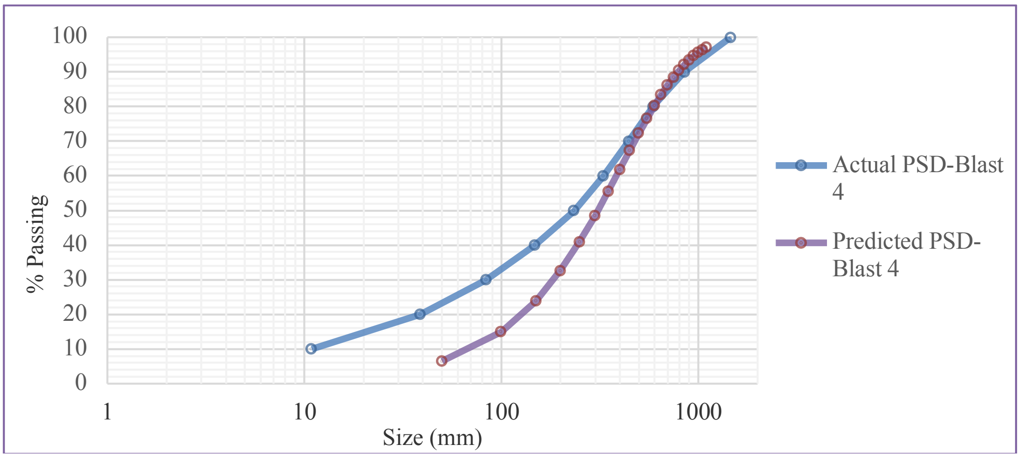

Figure 4. Actual against predicted fragment size distribution for blast 4.

Mean fragment size distribution of blast 5

Blast 5 was carried out in an area dominated gneiss rock type with UCS of 116.27 MPa. Furthermore, out of all five blasts, blast 5's size distribution curve (actual and predicted) had the lowest deviation. Resulting in size reduction ratio of 1.24 from actual mean fragment size and predicted mean fragment size of 367.39 mm and 296.97 mm respectively as shown in Figure 5. Blast 5 experienced minimum blast-holes collapse, meaning that the explosive energy coverage was maintained as planned. The tie up for blast movement had a major role in distributing explosive coverage evenly over the block.

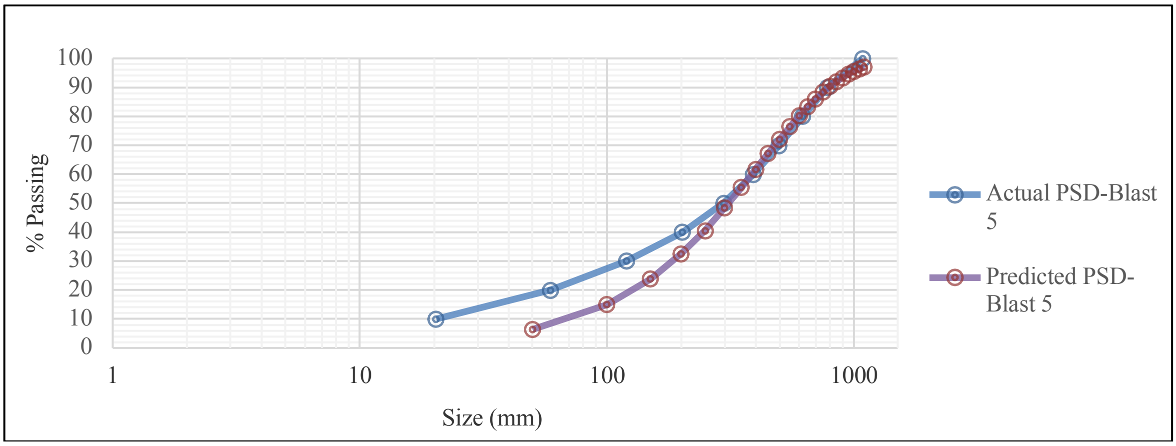

Figure 5. Actual against predicted fragment size distribution for blast 5.

Effect of explosives on resultant muck-pile

After the blasting operation, the resultant heights of the highest points of the muck-pile were taken to establish the effect of the type of explosives used. This is presented in Table V. The highest heights of muck-pile were recorded from the blasts that used analysis of variance (ANFO), with a value of 5.79 m from Blast 5. The lowest height was 3.26 m recorded from Blast 3 which used emulsion. It could be observed that ANFO has better heaving quality than emulsion while emulsion has better fragmenting quality than ANFO.

Table V. Explosives used, tie up and resultant muck-pile heave height

Blast No.	Explosives Used	Tie up pattern	Mean Fragment Size (mm)	Heaved Height (m)
Blast 1	ANFO	Chevron	260.70	4.69
Blast 2	ANFO	Chevron	137.89	3.37
Blast 3	Emulsion	Chevron	203.61	3.26
Blast 4	ANFO	Chevron	234.81	4.71
Blast 5	ANFO	Chevron	296.97	5.79

Statistical Modelling

Hypothesis testing

If F $<F_{crit}$ and P > 0.05 then the null hypothesis is accepted. From Tables VI it can be observed that the above conditions are satisfied for geometrical parameters. The blast-hole geometrical parameters values are 0.07008< 3.47805 and 0.98< 0.05. Therefore, the null hypothesis is accepted that geometrical parameters have effect on muck-pile profile and size distribution.

Table VI. ANOVA single factor test for geometrical parameter

ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	***F crit***
Between Groups	4885.40	4	1221.35	0.07008	0.98963	**3.47805**
Within Groups	174282	10	17428.2			
Total	179167	14				

Multiple linear regression analysis for actual mean fragment size

A multiple linear regression analysis was carried out between PF, ED, and S as independent variables as well as actual mean fragment size (AF) as dependent variable using statistical package for social sciences (SPSS) but burden (B) was excluded from the model. Based on the analysis of the predictive model for AF and it is expressed in Equation 7.

Table VII. Coefficients for prediction of actual mean fragment size

Model		**Unstandardised Coefficients**		**Standardise Coefficients**	**T**	**Sig.**	**95.0% Confidence Interval for B**	
		B	Std. Error	Beta			Lower Bound	**Upper Bound**
1	(Constant)	1303.85	597.99		2.180	.27	-6294.45	**8902.152**
	PF	-3237.65	1371.0	-2.071	-2.361	.25	-20658.16	**14182.854**
	ED	-222.68	233.78	-.478	-.953	.51	-3193.196	**2747.834**
	S	93.75	39.250	1.913	2.389	.25	-404.969	**592.480**

a. Dependent variable: AF
b. Predictors: (Constant), PF, ED, S)

$$AF = 1303.85 - 3237.65PF - 222.68ED - 93.75S \qquad [7]$$

The model summary and ANOVA for Equation 7 are presented in Tables VIII and IX respectively. The model summary shows that 86.8% of the variations are accounted for by the model as shown in Table VIII. The model statistics values F and significance (sig) were used to provide sufficient evidence to accept the hypothesis that the inputs have effect. From Table IX F of (2.183) and sig 0.453 (greater than 0.05) were obtained these show that the null hypothesis can be accepted. This revealed that at least one of the input parameters significantly affect the value of actual mean fragment size.

Table VIII. Model summary actual mean fragment size

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of Estimate**	**Changes Statistics**				
					R Square Change	F change	df1	df2	**Sig. F Change**
1	0.931	0.868	0.470	43.95	0.866	3.269	2	1	**0.364**

a. Predictors: (Constant), PF, ED, S
b. Dependent Variable: AF

Table IX. ANOVA for predicting actual mean fragment size

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	12651.58	3	4217.19	2.183	**0.453**
	Residual	1931.93	1	1931.93		
	Total	14583.52	4			

a. Dependent variable: AF
b. Predictors: (Constant), PF, ED, S

The stemming height was removed from the analysis since it is constant for all the blast. The significance of other parameters for the modelling was investigated by establishing correlation between individual variables and the heave heights of the muck-pile obtained after blasting. Coefficient of determination (R^2) was used as an indicator of correlation strength and (R^2) values for individual variables against heave heights are presented in Table X. It was found that only length of holes (LH) has negligible effect on heave height of muck-pile. In order to further analyse statistical and develop the prediction model for heave height the remaining five variables were select for the model.

Table X. Relation between individual variables and heave height for the blasts

Independent Variables	Regression Line	R^2
B (Burden)	$HH= 0.606B + 0.724$	**0.400**
S (Spacing)	$HH= 0.578S + 0.407$	**0.454**
LH (Length of holes)	$HH= 0.128LH^{1.541}$	**0.071**
ED (Explosives density)	$HH = 12.29e^{-1.15ED}$	**0.373**
NH (Number of holes)	$HH = 5.109e^{-5E-0NH}$	**0.226**
CH (Charge per hole)	$HH = 0.921CH^{0.309}$	**0.519**

Multiple linear regression analysis for heave heights

A multiple linear regression analysis was carried out between B, S, ED, NH and CH as independent variables as well as heave height (HH) as dependent variable using SPSS. Based on the analysis the predictive model for heave height is expressed in Equation 8.

Table XI. Coefficients for heave heights

Model		Unstandardised Coefficients		Standardise Coefficients	T	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	**Upper Bound**
1	(Constant)	-57.910	.000		.	.	-57.910	**-57.910**
	S	16.997	.000	19.818	.	.	16.997	**16.997**
	ED	-6.023	.000	-.739	.	.	-6.023	**-6.023**
	NH	.007	.000	1.435	.	.	.007	**.007**
	CH	-.334	.000	-19.873	.	.	-.334	**-.334**

$$HH = -57.91 + 16.997S - 6.023ED + 0.007NH - 0.334CH \quad [8]$$

The model summary and ANOVA for Equation 8 are presented in Tables XII and XIII respectively. The model summary shows that all variations are accounted for by the model as shown in Table XII. The model statistics values F and significance (sig) were used to provide sufficient evidence to reject the hypothesis of no effect. From Table XII F of (0.001) and sig 0.001 less than 0.05 were obtained this shows that the null hypothesis can be rejected. This revealed that at least one of the input parameters significantly affect the value of heave height.

Table XII. Model summary for prediction of heave height

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df 1	df2	**Sig. F Change**
1	1.000	1.000	.	.	1.000	0.0001	4	0	**.**

Predictors: (Constant), CH, NH, ED, S

Table XIII. ANOVA for heave height model

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	4.466	4	1.117	0.001	**0.001**
	Residual	.000	0	.		
	Total	4.466	4			

Predictors: (Constant), CH, NH, ED, S

CONCLUSION

This paper analysed the different blocks where rock blasting was conducted for trim and production respectively. It was found that aplite has the highest UCS. Also, using burden, spacing, length of hole, and explosive 4.8 m, 5.5 m, 9.5 m and emulsion (HEF 200) respectively resulted in mean fragment size of 232.26 mm with heaving height of 3.26 m. Also, burden, spacing, length of hole and explosive of 7.1 m, 8.1 m, 9.5 m and ANFO respectively resulted in mean fragment size of 223.22 mm with heaving height of 4.64 m.

ANFO has a better heaving quality than emulsion while emulsion produces smaller fragment size than ANFO ranging between 9.00 - 1130.98 mm as compared to ANFO ranging between 28.83 – 1678.05 mm. The models developed for both actual mean fragment size and heave height based on the statistical analysis accounted for more than 85% of the variations.

In addition, powder factor, explosive density, and spacing were used to establish the relation between actual mean fragment size and controllable blasting parameters. It was found that all parameters affect actual mean fragment size. Also, burden, spacing, length of hole, explosive, density, number of holes and charge per hole were used to establish the relation between heave height of muck-pile and controllable blasting parameters. It was found that all the parameters have contributed to HH of muck-pile except length of holes.

Although the research established which of the two explosives have a better heaving and fragmentation quality, further research can be conducted on how these qualities affect downstream process such as cycle times and crushing efficiency.

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REFERENCES

Adebayo, B. and Umeh E. C. (2007). Influence of some rock properties on blasting performance - a case study. *Intern Journal of Engineering and Applied Sciences,* 2 (1) 41-44.

Adebayo, B. and Opafunso, Z.O. (2010). Analysis of variability of rock properties influencing wear of bit. *Daffordil International University Journal of Science and Technology*, 5 (2), 1-7.

ASTM (2001). Standard test method for determination of compressive strength of rock, Designation D 2938, *America Standard Test International,* West Conshohocken, PA, USA.

Choudhary, S.B. (2013). Firing patterns and its effect on muckpile shape parameters and fragmentation in quarry blasts, *International Journal of Research in Engineering and Technology,* 2 (9), 32-45.

Cunnigham, C.V. (1983). The Kuz-Ram model for prediction of fragmentation from blasting. *Proceedings of the 1st Symposinm for fragmentation by blasting*, Lulea.

ISRM (1989). in *Rock Characterization testing and monitoring: International Society for Rock Mechanics Commission,* edited by E.T. Brown, (Pergamon press), 75-105.

Kilic, M., Yasar, E., Erdogan, Y. and Ranjith, P.G. (2009) Influence of rock mass properties on blasting efficiency, *Academic Journals,* 4 (11) ,1213-1224.

Kulatilake, P.W., Hudaverdi, T. and Kuzu, C. (2010). Mean particle size prediction in rock fragmentation using neural networks, *Engineering Geology,* 114 (4), 298- 311.

Monjezi, M., Khoshalan, H.A. and Varjani, A.Y. (2011). Optimization of open pit blast parameters using genetic algorithm, *Internationl Journal of Rock Mechanics and Mining Sciences,* 48 (5), 864-869.

Monjezi, M., Rezaei, M. and Yazdian, V.A. (2009). Prediction of rock fragmentation due to blasting in Gol-E-Gohar mine using fuzzy logic, *International Journal of Rock Mechanics and Mining Sciences,* 46 (8) 1273-1280.

Rout, M. and Parida, C. K. (2007) Optimization of blasting parameters in opencast mines, *National Institute of Technology, Rourkela,* 1-150.

Sharma, A. Kumar, A. and Choudhary, S.B. (2019). Impact of Blast Design Parameters on Blasted Muckpile Profile in Building Stone Quarrie, *International Information and Engineering Technology Association,* 43 (1), 29-36.

VBKOM Consulting Engineers (2013). Swakop Uranium - Husab Uranium Project - Life of Mine Technical Report, Swakopmund.

Workman, L and Eloranta, J. (2205) , The Effect of blasting on Crushing and Grinding Efficiency and Energy Consumption, unpublished, 1-20.

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