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Study on Impact of Velocity of Detonation of Bulk Explosive on Rock Fragmentation

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Abstract: *In surface mining, blasting in hard rock required high strength of explosives for performing the better operations of loading, transportation and crushing with good fragmentation result. Performance of explosive mainly depends on the velocity of detonation of explosive for effectively break the rock mass. More the velocity of detonation: higher the degree of good fragmentation.*

This paper analysis the result of systematic study on the impact of velocity of detonation of bulk explosive on rock fragmentation at the Pachhwara North Coal Mining Project, Pakur, Jharkhand (West Bengal Power Development Corporation Limited). Experiments were conducted to measure the velocity of detonation in blast holes which were loaded with bulk explosive and post-blast rock fragmentation analysis.

Key words: *velocity of detonation, rock fragmentation, bulk explosive, microtrap and wipfrag software.*

I. INTRODUCTION

In surface mining, explosive manufacturer supplies the Bulk explosive at site as per standard norms given by PESO. Bulk explosive is booster sensitive emulsion designed for surface mining. Once the bulk explosive initiated by detonator-booster, it produces the high-pressure gases and heat. Bulk explosive leading to significantly improved blasting by the creation of crushing zone around the blast hole. Faster the reaction take place in explosive column, generates the more cracks in rockmass so it's provided the high degree of rock fragmentation. slower the reaction take place in explosive column, generates the less amount cracks in rockmass it's provided the high degree of boulder percentages.

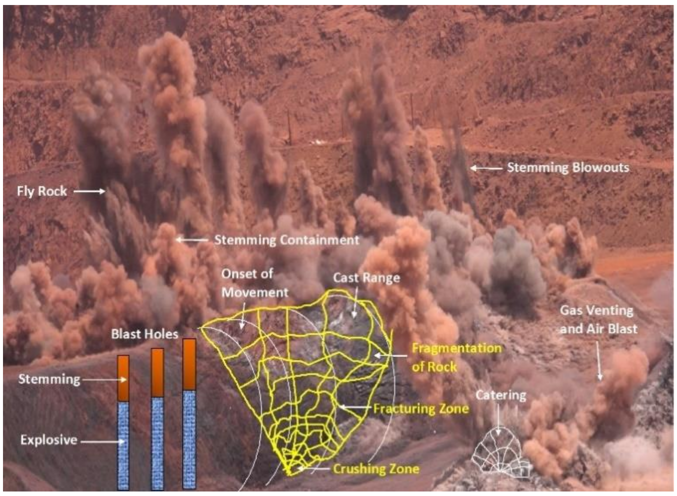

Figure 1: rock- breaking mechanism

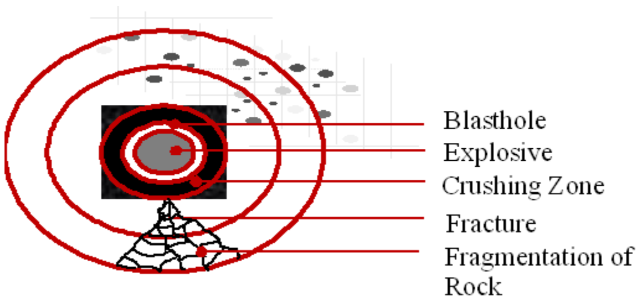

Figure 2: showing the blasting theory.

In this study, Microtrap^{TM} VOD/Data recorder and wipfrag photo analysis software were used to evaluate the quality, consistency and reliability of explosives, which helps in improving the efficiency of material -loading of shovel-dumpers.

1.1 Velocity of detonation measurement

Explosives with low VOD will have low impact on rock fragmentation than the ones with high VOD (Chiappetta, 1988, Heit, 2011). According to Cooper (1996), the explosive VOD is commonly used to approximate the detonation pressure and subsequently the explosive shock energy contained in an ideal explosive. The detonation pressure (Pd) of an explosive from the unreacted explosive density and VOD is given by

$$\mathbf{P_d = \rho e Cd2\gamma+1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, P_d is the detonation pressure (GPa), ρe is the explosive density (g/cm3), Cd is the VOD (m/s) and γ is the ratio of specific heats of detonation product gases (γ≈3). According to Cunningham (2002), γ may be approximately 2.6 for Ammonium Nitrate Fuel Oil (ANFO) to 3.2 for emulsion. Reduction in the VOD will produce a decrease in the Pd value as well as the shock energy of the explosive (Tete et al., 2013). VOD measurements indicate the performance of an explosive in real time. There are two common VOD measurement systems, i.e. the point-to-point system and continuous system. The former has limitation as compared to the latter used in this study (Crosby et al., 1991, Mishra and Sinha, 2003, Harsh et al.,2005). Pradhan and Jade (2012) carried out a study to investigate the performance of bulk emulsion explosive in a watery blast hole by measuring its in-hole VOD. The performance was found to be unsatisfactory due to reduction in VOD and failure of explosive column to detonate fully. Mendes et al. (2014) compared the VOD for emulsion explosive sensitized with hollow glass micro-balloons and emulsion explosive sensitized with hollow polymer micro-balloons. They concluded that the nature of the sensitizing agent had no significant impact on the explosive's detonation behaviour. The velocity of detonation is very important detonation parameter of explosive. The methods used for detonation velocity measurement can be divided into Optical (point to point system) and Electrical Type (continuous system, fig.3). The microTrap™ VOD recorder (electrical type) is an instrument for continuous explosive VOD measurement. It is a single channel capable of a recording rate of two million data points per second. To measure VOD, it uses the proven continuous resistance wire technique. A precise measuring probe of known linear resistance (i.e., Ω/m) is placed axially in the explosive column. As the detonation front of the explosive consumes the prove cable, the resistance of the circuit drops in proportion to the reduction in the length of the probe cable. As this is happening, a decrease in probe cable voltage versus time is recorded. When the recorder is operating it outputs a low voltage (less than 5 V DC) and an extremely low current (less than 50 mA), which ensures that the recorder will not prematurely initiate the explosive.

Data acquisition software (MREL) used to download and analyses the data from the microtrap.

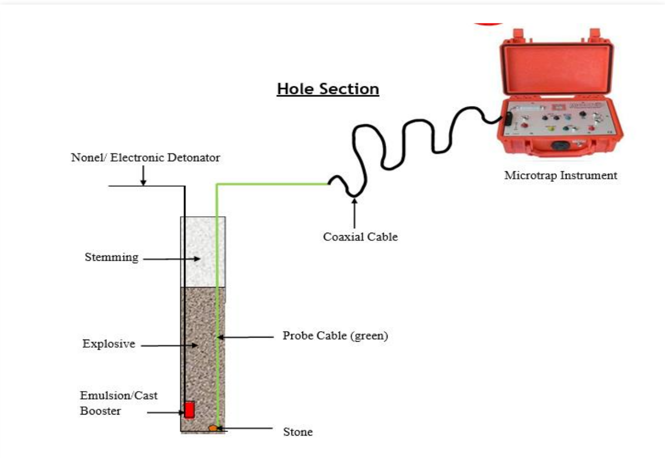

Figure 3: showing the typical model of VOD measurement

1.2 Fragmentation

Fragmentation must be very uniformly distributed and well sizes because rock fragmentation affects all the downstream surface mining operations. Post Fragmentation analysis was conducted by using image analysis software. We are used wipfrag software for measure the performance of explosive against the rock fragmentation in blast.

Following empirical equation to predict the mean fragmentation size resulting from rock blasting.

a) Kuz- Ram Model: 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.

Kuz-ram model is an empirical fragmentation model based on the Kuznestove (1973) and Rosin and Rammler (1933) equation modified by Cunningham (1983), Cunninggham (1987) which derives the uniformity index in the Rosin-Rammler equation from blasting parameters.

$$X_{50} = A * \frac{Q^{1/6}}{K^{0.8}} * \left(\frac{115}{REE}\right)^{0.633} \quad \text{.............................(2)}$$

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/m3 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

b) Rosin- Rammler Model (1933): The Rosin- Rammler equation describes the relationship between particle size x and cumulative mass oversize R.

One of these equations was developed in 1933 by Rosin and Rammler, and because of its relatively good fit with shredded refuse has become widely used in the resource recovery field.

$$Y = 1 - \exp\left(-x/x_0\right)^n \quad \text{.................................(3)}$$

Where, Y = cumulative fraction of material by weight less than size x; n= constant describing the material uniformity and hence called the "uniformity constant"; and x_0 = the "characteristic particle size", defined as the at which 63.2% (1-1/e=0.632) of the particles (by weight) are smaller.

c) Kuznetsov Model: The Kuznetsov equation relates the mean fragment size to the quantity of explosives needed to blast for a given volume of rock. The Kuznetsov equation is

$$\mathbf{Xm=A(V/Q)^{0.8}\, Q^{1/6}} \quad \text{.................................(4)}$$

Xm= Mean fragment size, A= The rock factor, V= The rock volume broken per blast hole, Q= The mass of explosive.

II. FACTORS AFFECTING THE VELOCITY OF DETONATION.

There are many factors that affects the velocity of detonation of bulk explosive. Some parameters of explosive are controllable and uncontrollable. Following factors of bulk explosive are affecting the velocity of detonation.

1) Raw material
2) Density of Explosive
3) Gassing Agent
4) Initiating System
5) Temperature

Raw Material: Velocity of Detonation of bulk explosive mainly depends on the quality of raw material used like ammonium nitrate, fuel oil etc. for making the any type of emulsion explosive. Higher the quality of raw materials; More the velocity of detonation of explosive. Raw materials can vary from manufacturer to manufacturer.

Initial Density of Explosive: Initial density of the bulk explosive can be varied in the range of 1.35 to 1.30 g/cc.

Figure 3: showing the varies density of bulk explosive

Gassing Agent: Gassing process carried out during the charging of explosive in borehole. Sodium nitrite and formaldehyde are main chemicals in gassing agent. After adding the gassing agent in matrix, density of the explosive varies from 1.25 to 1.10 g/cc.

Initiating System: Velocity of detonation also mainly depends on Initiation system. Emulsion booster and cast booster are two accessories use for initiating the bulk explosive. The velocity of detonation of the cast booster is more than the emulsion booster; provides high degree of rock fragmentation compared with emulsion booster.

Temperature: Temperature of explosive always be maintained for better chemical reaction. At manufacture level the temperature of matrix was maintained up to 65^{0}C. But during transportation, temperature of matrix decreases upto 40^{0}C.

III. TRIAL SITE

In this study, Solar BE-201 bulk explosive was used at north coal mining project, Pakur, Jharkhand. VOD tests of explosive of 7 blasts were carried out at the same rock type and surface blast design pattern.

The initial density of explosive was 1.3 gm/cc and final density of explosive was 1.13 gm/cc. The blast hole diameter was of 160 mm and burden and spacing were in the range of 4 to 5 meter. All holes were dry with good condition and proper stemming were done by the blasting crew. Cup density of bulk explosive measured in all the blasts before charging the blast holes (Figure.5). The explosive in a hole generally varied from 50 to 75 kgs depending on the hole depth.

We were used electronic detonators for better blasting result and assigned the same delay timing in all blasts for more accuracy in VOD and fragmentation analysis results. We were used cast booster of 100 gm per hole for 60 to 65 kg of explosive (Figure.4).

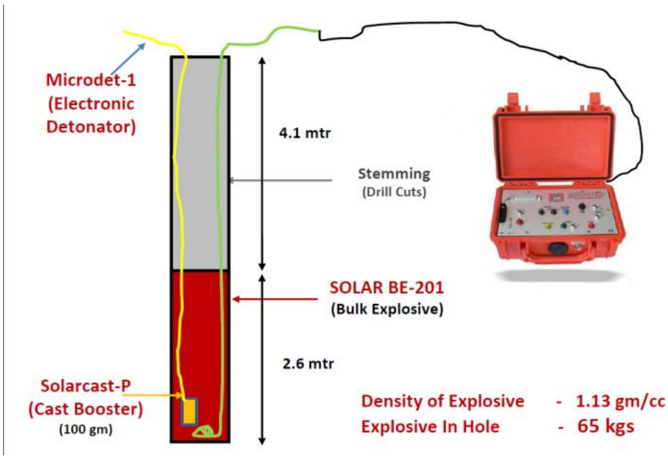

Figure 4: showing the typical model of VOD measurement.

While charging process, we were measured the temperature and cup density of bulk explosive for proper gassing in borehole (Figure.5). After finishing the charging process, we done the blasts at site. Bulk explosive is providing the energy to move the rock mass and reduce it to an optimal size.

Figure 5: showing the measurement of cup density at field.

Figure 6: showing the bulk charging at field.

Table I: showing the technical specification of Solar BE-201

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Type	Emulsion Based
Density	1.15 ± 0.05
VOD (m/s)	4000 ± 500
Related Bulk Strength	130%
Total Energy/Kg	890 Kcal/kg
Viscosity (brook field)	More than 40000 CPS
Sleeping Time	10 days

IV. VOD ANALYSIS AND ROCK FRAGMENTATION ANALYSIS

VOD analysis of explosive is done by the data acquisition suit software (MREL). We have analysed the VOD of signature hole in seven blasts for this study.

Depth of hole of blast-1 was 7.5 m and explosive column detonation was recorded of 1.82 m. The recorded VOD was 4426 mtr/sec for full explosive column length of 2.7 mtrs.

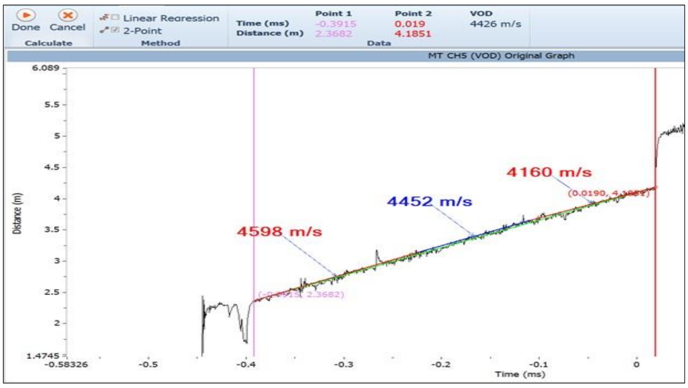

Figure 7: showing the vod analysis of blast- 1

Depth of hole of blast-2 was 7.5 mtrs and explosive column detonation was recorded of 0.76 mtrs (Fig. 8). The recorded VOD was 4403 mtr/sec for full explosive column length of 2.7 mtrs.

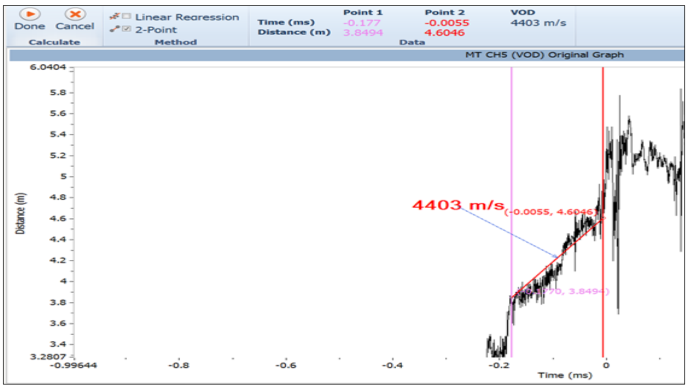

Figure 8: showing the vod analysis of blast- 2

Depth of hole of blast-3 was 7.6 mtrs and explosive column detonation was recorded of 1.71 mtrs (Fig. 9). The recorded VOD was 4414 mtr/sec for full explosive column length of 2.8 mtrs.

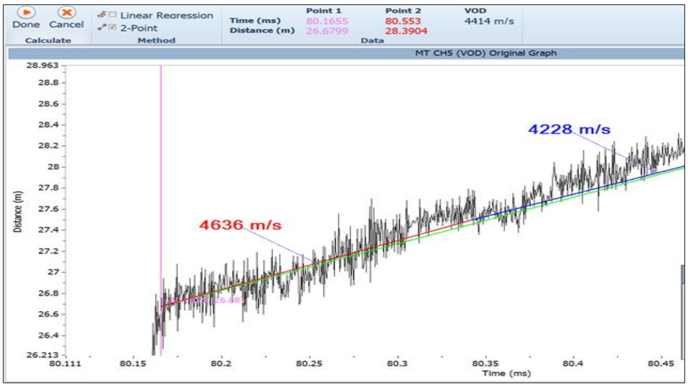

Figure 9: showing the vod analysis of blast- 3

Depth of hole of blast-4 was 6.7 mtrs and explosive column detonation was recorded of 0.8 mtr (Fig. 10). The recorded VOD was 4429 mtr/sec for full explosive column length of 2.6 mtrs.

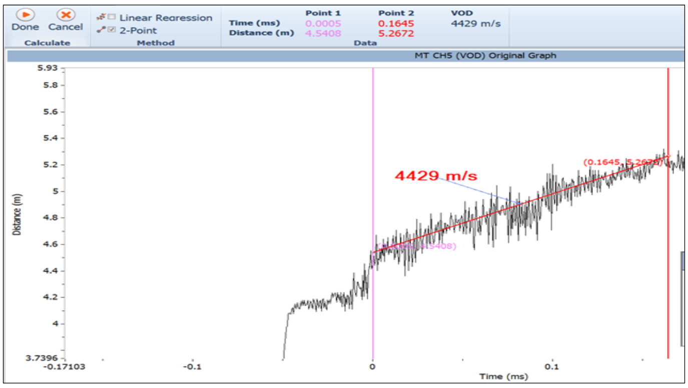

Figure 10: showing the vod analysis of blast- 4.

Depth of hole of blast-5 was 10 mtrs and explosive column detonation was recorded of 2.76 mtrs (Fig. 11). The recorded VOD was 4330 mtr/sec for full explosive column length of 4 mtrs.

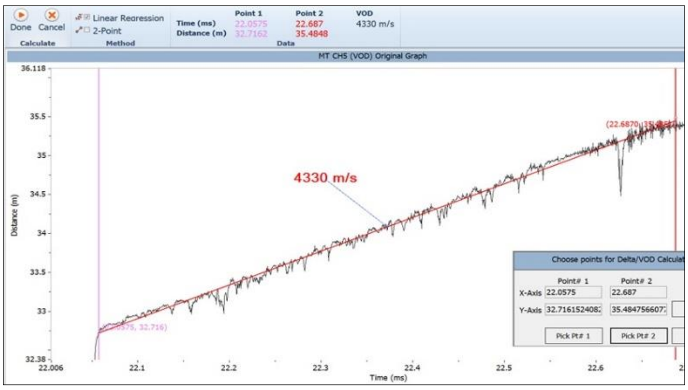

Figure 11: showing the vod analysis of blast- 5

Depth of hole of blast-6 was 7.4 mtrs and explosive column detonation was recorded of 1.45 mtrs (Fig. 12). The recorded

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VOD was 4404 mtr/sec for full explosive column length of 2.8 mtrs.

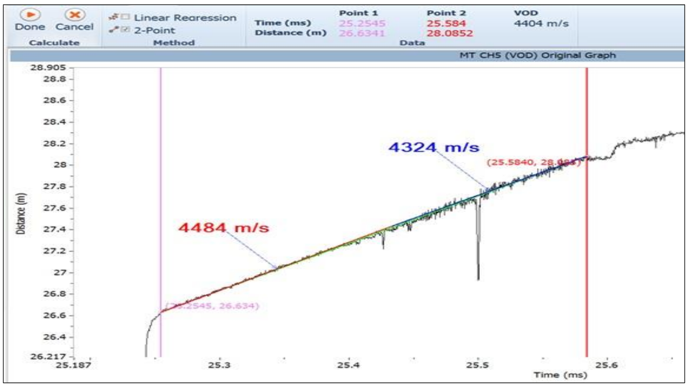

Figure 12: showing the vod analysis of blast- 6

Depth of hole of blast-7 was 6.6 mtrs and explosive column detonation was recorded of 1.65 mtrs (Fig. 13). The recorded VOD was 4341 mtr/sec for full explosive column length of 2.6 mtrs.

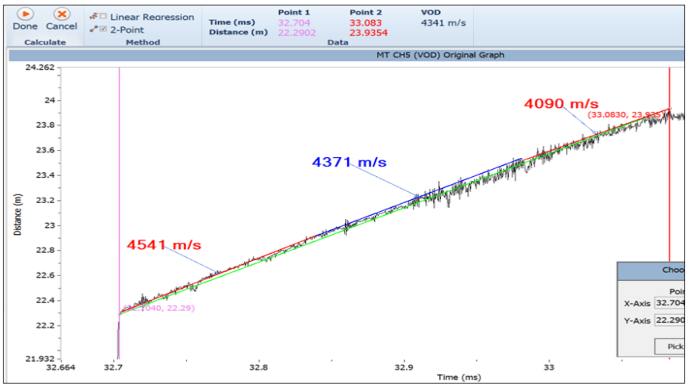

Figure13: showing the vod analysis of blast- 7

Following result of VOD of explosive (in mtr/sec), we got from the seven blasts.

Blast1	Blast2	Blast3	Blast4	Blast5	Blast6	Blast7
4426	**4403**	**4414**	**4429**	**4330**	**4404**	**4341**

FRAGMENTATION ANALYSIS

Due to some similar result in VOD of blasts, we have done the fragmentation analysis of blast no. 1, 2, 3 & 5. In study we have considered only four blasts for fragmentation analysis. The results of rock fragmentation came from the wipfrag analysis software.

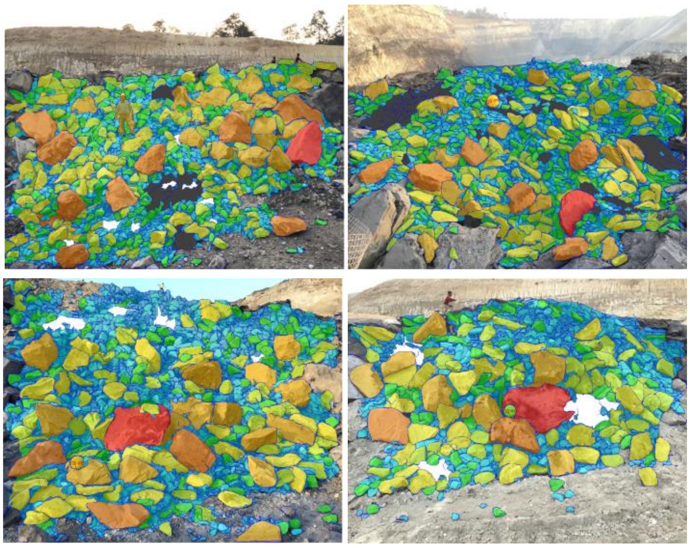

Figure 14: Fragment size analysis at pachhwara north coal block with the help of wipfrag software.

Below graphs showing the accumulated passing area vs rock size distributions. Analysis is shown in the form of netting, countering, histogram (red) and cumulative curve (Blue). Where, N= rosin-rammler uniformity coefficient, Xmax = gaudin- schuhmann characteristic size & Xc = characteristic size.

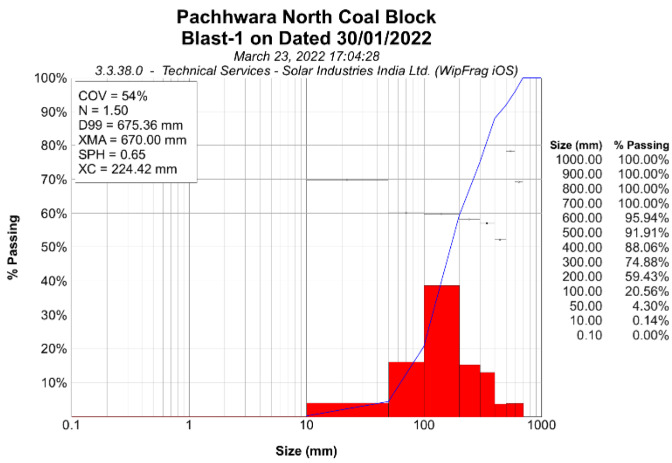

Figure 15: showing the fragmentation analysis of blast-1 (velocity of detonation is 4426 mtr/sec)

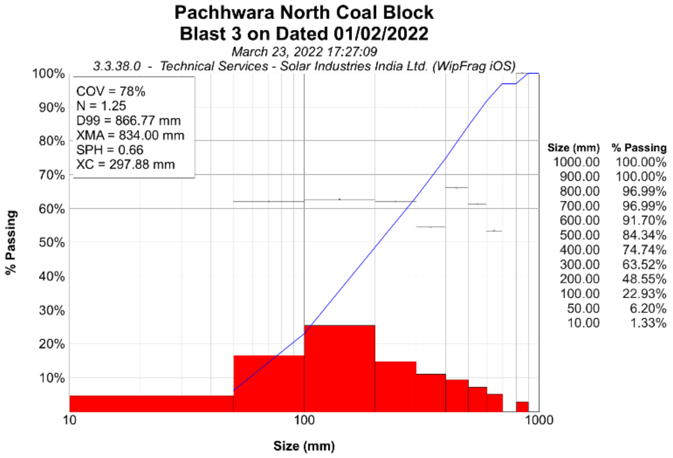

Figure 16: showing the fragmentation analysis of blast-3 (velocity of detonation is 4414 mtr/sec)

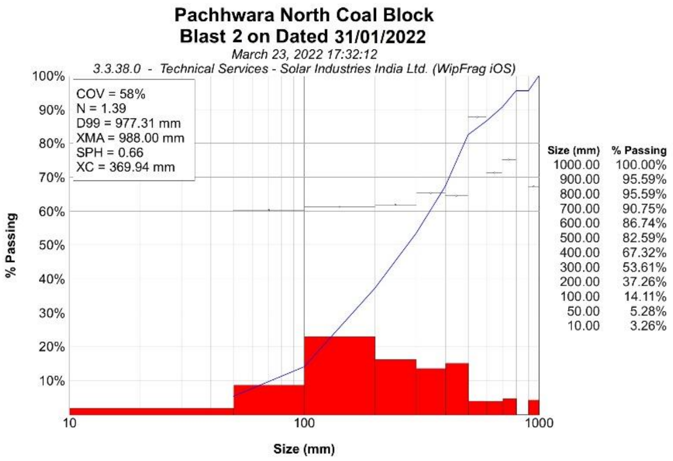

Figure 17: showing the fragmentation analysis of blast-2 (velocity of detonation is 4403 mtr/sec)

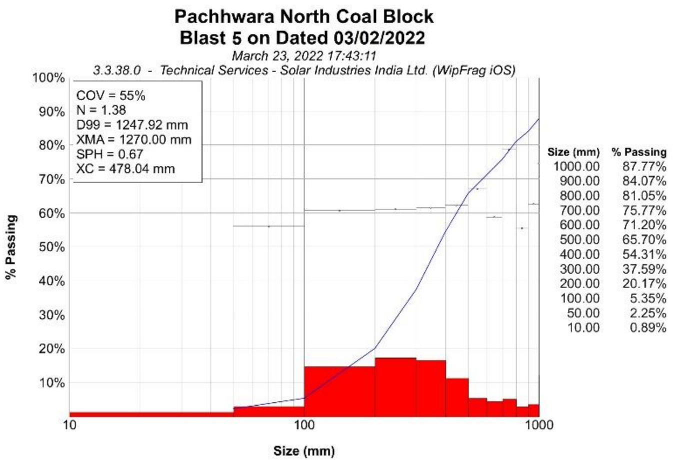

Figure 18: showing the fragmentation analysis of blast-5 (velocity of detonation is 4330 mtr/sec)

V. RESULTS

The VOD values recorded from the field ranged between 4200 meter/sec to 4800 meter/sec and the analysed fragmentation size distribution indicates that Ref. Table II, provided good fragmentation in blasts 1,3,2 compared to blast 5 due to higher velocity of detonation of explosive.

Table II: showing the results of VOD and rock fragmentation measurement

Blast Nos.	**Dated**	**VOD** (mtr/sec)	**XC** (mm)	**XMA** (mm)	**D99** (mm)
Blast-1	30/01/22	**4426**	224	670	675
Blast-3	01/02/22	**4414**	297	834	866
Blast-2	31/01/22	**4403**	370	988	977
Blast-5	03/02/22	**4330**	478	1270	1247

Maximum size of rock of blasts 1, 3, 2 & 5 were measured 670 mm, 834 mm, 988 mm & 1270 mm.

Oversize can have many implications for a mining operation such as time needed to remove oversize from muckpiles, inefficient loading operations, more wear on load & haul equipment and secondary blasting. So more the VOD, giving better fragmentation.

Table III: showing the results of rock size distributions.

Blast Nos.	**>500 (mm)**	**500 – 300 (mm)**	**300 – 100 (mm)**	**100 – 50 (mm)**	**< 50 (mm)**
Blast -1	8 %	17 %	54 %	16 %	4.5 %
Blast -3	16 %	24 %	38 %	10 %	7 %
Blast -2	18 %	27 %	39 %	9 %	5.5 %
Blast -5	29 %	29 %	34 %	15 %	5.5 %

Rock size distribution analysis shows that blast-1 provided good result of rock fragmentation compared to other blasts. hence Blast 5, which having the low VOD, provided 29% of above 500 mm coarser size of rock, which is on higher side.

VI. CONCLUSION

In this context, it is observed that the velocity of detonation (Vod) recorded in blasts 5 & 7 is lower and degree of fragmentation is also poor as compared to blasts 1, 2, 3, 4 & 6. Based on the rock fragmentation analysis, it can be concluded that velocity of detonation of bulk explosive is directly proportional to the rock fragmentation. It means higher the VOD of bulk explosive, higher the degree rock fragmentation.

Following conclusion are drawn in this work

1) Due to difference in vod of explosive, we got the different results of rock fragmentation. Blast -1, which having the more VOD (ref. table II & III) provided the good degree of rock fragmentation.

2) For better fragmentation of rock, we required good degree of velocity of detonation of explosive. In blast -1, coarser size of rock above 500 mm is only 8 %. It is showed that the chances of boulders are less when the VOD is on higher side.
3) Mean fragment particle size increases with the decreases in the velocity of detonation of explosive.

This study can also assist to improve in velocity of detonation of bulk explosive and rock fragmentation.

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REFERENCES

1. A. G. Anshits, N. N. Anshits, A. A. Deribas, S. M. Karakhanov, N. S. Kasatkina, A.V. Plastinin, A. Yu. Reshetnyak & V. V. Sil'vestrov (2005), Detonation velocity of emulsion explosives containing cenospheres.

2. Abiodun Ismail lawal (2021), A new modification to the kuz-ram model using the fragment size predicted by image analysis.

3. AI Lawal (2021), A new modification to the Kuz-Ram model using the fragment size predicted by image analysis.

4. Aruna D. Tete, Amol Deshmukh, Rajendra Yerpude (2014), Design and implementation of sensor for velocity of detonation measurement.

5. Binay Kumar Singh, Debjeet Mondal, Paresh Nath Singha Roy (2019), Application of digital image analysis for monitoring the behavior of factors that control the rock fragmentation in opencast bench blasting: A case study conducted over four opencast coal mines of the Talcher Coalfields, India..

6. E Kabwe,(2018), Velocity of detonation measurement and fragmentation analysis to evaluate blasting efficiency, Journal of rock mechanics and geotechnical engineering, volume 10, issue 3, pp. 523-533 – elsevier.

7. F. Ouchterlony (2016), The case for the median fragment size as a better fragment size descriptor than the mean.

8. H.T. Ozkahraman (2006), Fragmentation assessment and design of blast pattern at Goltas Limestone Quarry, Turkey, International journal of rock mechanics and mining sciences, 43 (4), pp. 628-633.

9. J Mesec, S Zganec, I Kovac (2015), In-hole velocity of detonation (VOD) measurements as a framework for the selection type of explosive, In International journal of mining science and technology, volume 25, issue 4, pp. 675-680, elsevier.

10. M. M. Chaudhri, L.-A. Almgren, and A. Persson (1993), "Detonation behaviour of a water-in-oil type emulsion explosive containing glass microballoons of selected sizes," in: Proc. 10th Int. Symp. on Detonation, pp. 741–748.

11. M. Pradhan, R.K. Jade (2012), Detonation behavior of bulk emulsion explosive in water filled blast holes performance of explosives and new developments, pp. 65-70.

12. MA Morin, F Ficarazzo (2006), Monte carlo simulation as a tool to predict blasting fragmentation based on the kuz–ram model.

13. Manoj Pradhan.(2009), Effect of charge temperature on the detonation velocity of bulk emulsion explosives.

14. Michael Scott Shattuck (2015), Determination of detonation velocity of explosive compounds using optical techniques.

15. P Mertuszka, B Kramarczyk (2018), The impact of time on the detonation capacity of bulk emulsion explosives based on emulinit 8L.

16. P. Mertuszka, M. Pytlik (2019), Analysis and comparison of the continuous detonation velocity measurement method with the standard method.

17. Piotr Mertuszka, Krzysztof Fuławka, Mateusz Pytlik, Michal Szastok (2019), The influence of temperature on the detonation velocity of selected emulsion explosives.

18. Piotr Mertuszka, Bartłomiej Kramarczyk (2018), The impact of time on the detonation capacity of bulk emulsion explosives based on emulinit 8l.

19. Qi Zhang And Yan Chang (2012), Prediction of detonation pressure and velocity of explosives with micrometer aluminium powders.

20. R.F. Chiappetta (1988), Blast monitoring instruments and analysis techniques with an emphasis on field application.

21. S Prasad, BS Choudhary (2017), Effect of stemming to burden ratio and powder factor on blast induced rock fragmentation–a case study, IOP conference series - iopscience.iop.org.

22. Silva, R. F. (2006), Fragmentation model and its application to global mine cost. Proceedings of the 8th int. symp. on rock frag. by blast. 223-225.

23. Singh, P. K., Roy, M. P., Paswan R K, Md. Sarim, Kumar S, Jha R R. (2015), Rock fragmentation control in opencast blasting. Journal of rock mechanics and geotechnical engineering.