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Performance Analysis of Using Discarded Water Bottles in Explosive Column for Surface Mine Blasts

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The explosive cost is among the biggest contributors of day to day expenses of any mine. Many researchers have worked on explosive consumption reduction techniques. Attempts are being made to utilise waste bottles for providing air gaps in the explosive column, but no detailed study of the resulted blast performance were made. This paper presents performance analysis of use of discarded water bottles in rock blasting. Five experimental blasts were conducted in a limestone mine by inserting plastic bottles in the explosive columns for creating air gaps. The aspects that were used for assessing the blast performance were powder factor, fragmentation, ground vibration, air blast etc. Moreover for assessing the explosive performance the rock confined in-hole velocity of detonation was also measured. It was found that after replacement of 20% of explosive by volume with plastic bottles there was significant improvement in actual powder factor. Though there was minor fall in velocity of detonation of the explosive but it was sufficient to generate decent fragmentation. The ground vibration levels were also reduced significantly when compared with the general practice of the mine. The findings of this study may help the mine operators to improve powder factor.

1. Introduction

Blasting is an essential part of the mining cycle as most of the mines use drilling and blasting for primary rock breakage. India consumed around 1,211,427,000 kg of ammonium nitrate based explosive in year 2016-17 (PESO, 2017). The explosive cost is among the biggest contributors of day to day expenses of any mine. Explosives provide energy and the efficient use of this energy is a major factor in keeping the rock blasting costs under control. Blasting follows drilling and precedes loading, hauling, and crushing. It is important that blasting operations be carried out in an efficient manner as results of blasting influence subsequent operations (Bhandari, 1997). The aspects that are generally looked for assessing the blast performance are powder factor, fragmentation, ground vibration, air blast, fly rock etc. (Konya and Walter, 1991).

Powder factor is an important parameter which is used to analyse the blast performance. It is the amount of rock broken per unit of explosive consumed. It indicates the explosive consumption of the blast which is associated with mine economy (Mohamed et al., 2015).

Another important measure of blast performance is fragmentation. It is single most important objective of blasting (Cunningham, 2005). There has been no accepted measure of fragmentation (Sanchidrián et al., 2007). It has been measured and expressed in numerous ways, most important among these are; screen sizing, average size, crusher monitoring, boulder count and secondary breakage, muck assessment and image analysis etc. (Faramarzi et al., 2013). The image analysis method can provide accuracy with less equipment cost. In this method, photographs of the blasted muck pile with scaling objects are analysed using image analysis software which gives size distribution of the entire muck pile.

Ground vibration and noise are other important parameters used to analyse the side effect of blasting. These parameters are important as they indicate the waste energy component of the total energy generated by explosives.

Moreover, the performance of explosive must also be measured in the hole so that it may be known whether the explosive is doing the desired tasks. Primarily it is measured through velocity of detonation (VOD) measurement in the borehole (Crosby et al., 1996). There are number of methods for measuring VOD but in general the methods can be split into two categories: point to point and continuous systems (Chiappetta,

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1998; Mishra and Sinha, 2003). Point to point system relies on detecting the detonation front at discreet points using fibre optic targets or metal plates etc. Such systems are generally suitable for quality control checks but often lack the resolution required to assess detailed explosives performance. Continuous systems employ a probe which is consumed by the detonation front which is monitored as a voltage drop or by an electronic pulse system. The advantage of such an accurate yet practical field system is that it can be used not only for VOD measurement, but the data produced give a full time history of explosive detonation inside the borehole allowing many detailed analysis.

ANFO, slurry and emulsion explosives are being used in India in commercial blasting. Among these explosives, bulk emulsion explosives are dominating the market because of their excellent detonation characteristics, good water resistance, swift charging rate and exceptionally good safety characteristics. The only demerit of emulsion explosive is its high density. Because of high density, when emulsion explosives are used in soft to medium hard and easy to blast rocks, more explosive is consumed. Various methods such as decking (Melnikov et al., 1978; Jhanwar, 2011), use of air tubes in explosive column (Sang-Wook et al., 2005) etc. are tried to reduce the explosive consumption. Attempts are being made to utilise waste bottles for providing deck in between the explosive column or in stemming regions, but no detailed study of the resulted blast performance were made. Pradhan & Pradhan (2013) reported better explosive energy distribution through placement of plastic bottles in emulsion explosive column. Raman Sundar et al. (2013) conducted some trial blasts in an iron ore mine and studied explosive energy distribution through placement plastic bottles in emulsion explosive column. Pradhan et al. (2015) found that the total explosive costs were reduced by 7-16 % when discarded water bottles were used as air gaps in between the emulsion explosive column. This paper tries to analyse the effect of use of plastic bottles on blast performance. Various parameters such as powder factor, fragmentation, ground vibration, rock confined Velocity of Detonation etc. are used to evaluate the blast performance.

2. Experimentation

The study was conducted at Century cements limestone mine, Baikunth in Chhattisgarh state of India. The deposit is worked in two pits, namely Block ‘B’ and ‘MF2’. In each of the pit, besides the overburden bench there are three benches of varying height. The height of benches varies from 6.0-9.5 m. The conventional drilling and blasting method is used for excavation. The blasted muck is removed by using 3.2 m^3 hydraulic shovel and 35 t dumpers. The dumpers unload their content in the crusher. The size of crusher feed size is controlled through a grizzly of 1 m opening. For secondary blasting rock breaker is used.

The general practice of the mine was to charge the holes with site mixed emulsions (SME) of matrix density between 1300 kg/m^3 and rated VOD between 3500 m/s to 4500 m/s. Shock tubes with cartridge booster were used to initiate the explosive. By following this practice the actual powder factor of the mine was near 6.0 t/ kg and the loading density was around 12 kg/m. The mine considers fragments of size more than 1 m as boulders and the desirable range of fragmentation is between 0.2 m to 0.8 m. 17 milliseconds hole to hole delay, 42 milliseconds row to row delay, and 250 milliseconds down the hole delay were used in all the blasts. The hole diameter, average hole depth, average spacing and average burden were 0.115 m, 8.5-9.5 m, 5.0 m and 4.0 m respectively. Usually by following this practice about 60-70 % of blasted particles were in the optimum range.

Five trial blasts with plastic bottles inserted with explosive in charge column were conducted in the mine. All other blast parameters were kept similar as the general practice of the mine. The faces were so selected that they have a similar geology. The physico-mechanical properties of rock sample collected from Century cements limestone mine are presented in Table 1(A).

For all the trial blasts the explosive used was double salt emulsion, which was blackish in colour and greasy in appearance. The oxidizer blend (OB) comprised of aqueous solution of ammonium nitrate, sodium nitrate, thio-urea and water. The fuel blend (FB) comprised of light diesel oil, furnace oil and sorbitol mono oleate. Aqueous sodium nitrate solution with formaldehyde solution was used as gassing agent. The density of matrix was between 1350-1380 kg/m^3 and the viscosity was about 10.4 Nsm^{-2}. The initial matrix temperature was between 333.15- 338.15 K. The rock confined in-hole VOD of the explosive under these conditions was between 4511 m/s and 4150 m/s (Pradhan, 2007).

Discarded plastic water bottles were used to introduce air gaps in the explosive column. These plastic bottles were available in local market. The physical properties of the bottles are summarized in Table 1(B). The snapshot of the bottles used for the trial blasts is shown in Figure 1(A). In all trial blasts, plastic bottles were inserted manually in the explosive column while charging to save about 20 % explosive by volume. 15-17 bottles were inserted in a constant pace so that uniformity of the air gaps in the explosive column can be maintained. Figure 1 (B) shows the cross section of the blast hole charged with plastic bottles as air gaps. For analysing the blast results, various parameters such as loading density, actual powder factor, fragmentation, ground vibration and noise etc. were measured. For analysing the effect of plastic bottles in explosive column the in-hole VOD was measured.

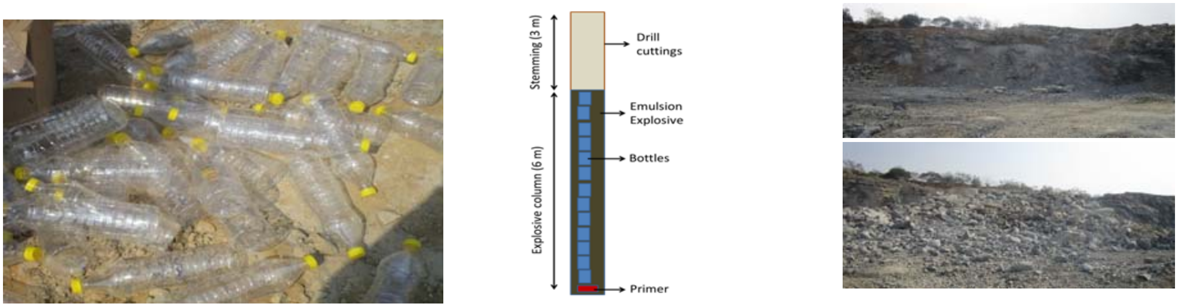
Table 1(A): The physico-mechanical properties of rock collected from the mine; (B): Physical properties of plastic bottles used in the trial blasts

(A)

Rock type	Uniaxial compressive strength (MPa)	Young's Modulus (GPa)	Porosity (%)	Density (kg/m3)
Dolomitic Limestone	39.01	45.62	5.90	2270

(B)

Properties of bulking agent	Measurements
Maximum Diameter	0.076 m
Length	0.270 m
Mass	21.0×10^{-3} kg
Volume	1.07×10^{-3} m^3
Density	19.62 kg/m^3



(A) *(B)* *(C)*

Figure 1(A): The snapshot of the plastic bottles used in trial blasts; (B): Cross section of blast hole charged by inserting plastic bottles in the explosive column; (C): Snapshot showing face of the trial blast and muck pile resulted after the trial blast.

For determining the cup density, emulsion was taken to a cup of 0.405 L volume and 0.127 kg mass immediately after mixing the gassing agents. The cup was filled mouthful. The matrix was allowed for gassing in the cup. As the gassing progressed, the explosive column rose in the cup. The rise in the explosive column was slashed to keep the volume of the explosive in the cup constant. The mass of the explosive in the cup was measured and explosive density was calculated. The measured cup densities of the emulsion explosive used in various trial blasts is summarized in Table 2(A).

Rock confined VOD (in hole) was measured in the fourth trial blast in single hole by using HandiTrap-II VOD recorder of MREL Special Explosive Products Limited, Canada. The HandiTrap-II is a portable, 1 channel, and high resolution explosives continuous VOD recorder. It uses continuous resistance wire technique for monitoring VOD. An MREL manufactured probecable-HT of known linear resistance is placed axially in the or explosive column. As the detonation front of the explosive consumes the probecable, the resistance of the circuit will decrease in proportion to the reduction in length of the probecable. The HandiTrap-II records the resulting decrease in voltage across the probecable versus time. For measuring the in-hole VOD, the probecable, 30 m long and shorted out at one end is used. The short circuit end of the cable is attached to the primer and lowered into the hole. About 6.2 m length of the cable was in explosive column. The hole was then loaded with explosives and plastic bottles were inserted in the explosive column while charging. The blast holes were later stemmed as per usual procedure. For connecting the Handitrap-II with probe cable, connections were made shielding to shielding and centre conductor to centre conductor. The HandiTrap-II was later placed in a protective shelter near the blast area (Figure 2).

The visual inspections were made immediately after each blast. Actual powder factor was estimated by counting the number of dumper trips required for transportation of the muck generated due to blasting. Later, detailed fragmentation analyses were performed using Wipfrag 3.1.13.0 software for each trial blast. This software is used for digital image analysis of blasted fragments for finding size distribution. 18-25 scaled digital photographs throughout the complete mucking of the fragmented rock pile were taken for each blast. Blast induced ground vibrations and the noise levels were measured using two numbers of seismographs of Instantel Inc. Canada. These seismographs are microprocessor based units having three transducers which are mutually perpendicular to each other. It measures the Peak Particle Velocity (PPV) in all three directions i.e. vertical, longitudinal and transverse with respective amplitudes and frequencies. For all the trial blasts, the first seismograph was placed at distances 100-120 m, the second seismograph was placed between 180-200 m. The details of the experimental blasts are summarized in Table 2(A). The snapshots of the face and the muck pile resulted after the blast is shown in the Figure 1(C).

Figure 2: Snapshot of VOD measurement using Handitrap-II.

Table 2(A): Various details of the experimental blasts; (B): Summary of various blast analysis parameters observed for the trial blasts.

(A)

Serial No. of Blast	No. of holes	Density of emulsion explosive (kg/m^3)	Total no. of plastic bottles used	Total amount of explosive consumed (kg)	Explosive saved (compared to usual practice of the mine)
1.	30	1.15	483	1750	19.0%
2.	32	1.12	514	1804	19.7%
3.	26	1.15	416	1493	20.2%
4.	25	1.15	398	1434	20.3%
5.	25	1.13	385	1420	19.3%

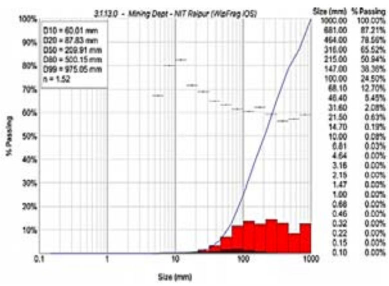
(B)

Serial no. of the trial blast	Actual powder factor (t/kg)	No. of boulders observed	Average loading density achieved (kg/m)
1.	6.83	4	9.7
2.	6.90	2	9.4
3.	6.85	3	9.6
4.	6.91	2	9.5
5.	7.01	1	9.4
Average	6.90	--	9.52

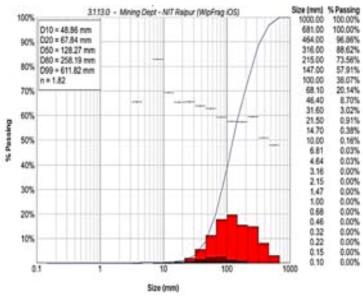
3. Observations and results

In all trial blasts, about 20% of explosives by volume were replaced by using discarded water bottles. The fragmentation achieved for each blast is shown in Figure 3(A to E). The distance time graph generated by the Handitrap-II is shown in Figure 4(A).

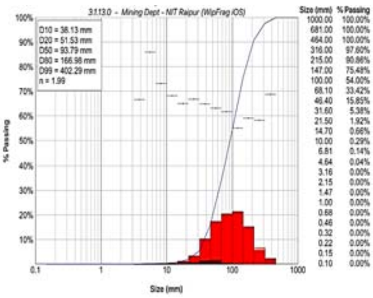
The actual powder factor, boulder count, loading densities for trial blast conducted by introducing the bottles are presented in Table 2(B). The peak particle velocity and peak sound level with corresponding maximum charge per delay, scaled distance and the distance of the seismograph from the face for each blast is summarized in Table 3.



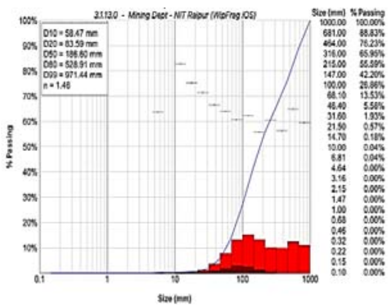
A. First trial blast



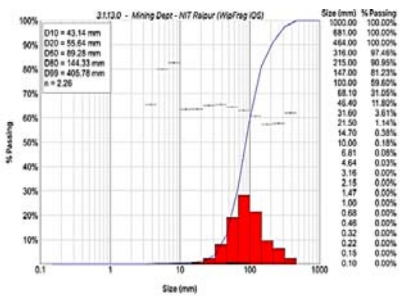
B. Second trial blast



C. Third trial blast



D. Fourth trial blast

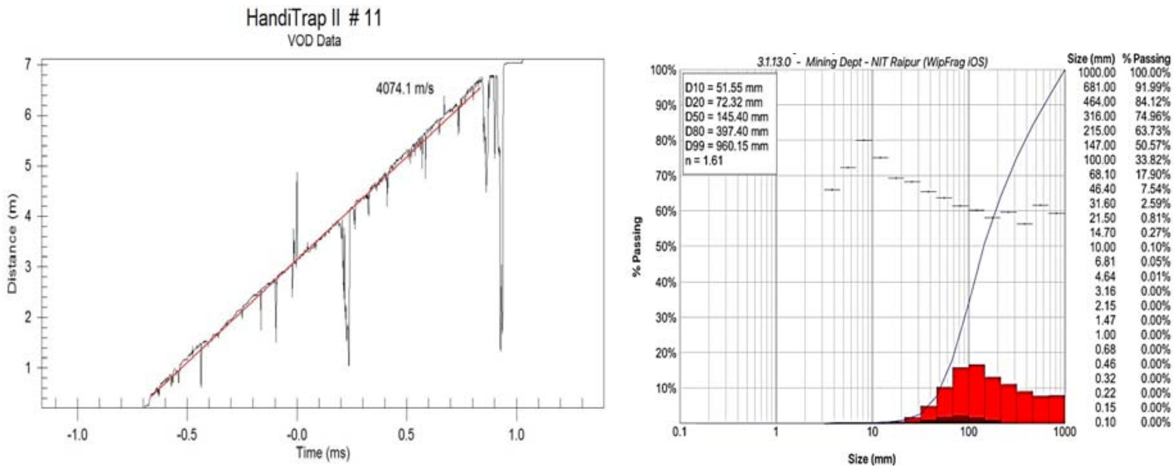


E. Fifth trial blast

Figure 3 (A to E): The fragmentation achieved for various trial blasts.

Table 3: Summary of various blast induced ground vibration parameters observed for the trial blasts.

Serial no. of the trial blast	Distance of seismograph from face (m)	Maximum charge per delay (kg)	Peak particle velocity (mm/s)	Scaled distance ($m/kg^{1/2}$)	Peak sound level (dB)
1.	100-120 m	60	12.51	14.46	134.5L
	180-200 m	60	7.36	24.52	112.0L
2.	100-120 m	62	13.47	13.97	135.0L
	180-200 m	62	6.27	24.13	108.4L
3.	100-120 m	57	12.76	14.57	143.5L
	180-200 m	57	7.01	25.16	100.0L
4.	100-120 m	58	14.62	14.44	137.7L
	180-200 m	58	6.58	24.94	109.5L
5.	100-120 m	55	9.65	14.83	134.3L
	180-200 m	55	6.73	25.61	110.2L



(A) (B)

Figure 4(A): The Distance-Time graph generated by Handitrap II; (B): Average fragmentation achieved from five trial blasts.

4. Discussion

By using discarded plastic bottles in the explosive column the loading density has been decreased from 12 kg/m to an average value of 9.52 kg/m. The average actual powder factor has increased to 6.90 t/kg from 6.0 t/kg, which indicates significant reduction (about 15 %) in explosive consumption (Table 2 (B)).

The sole objective of rock blasting is fragmentation. The fragmentations achieved from all the five trial blasts were merged together using the software to generate the average size distribution. The average fragmentation achieved from all the five trial blasts is shown in Figure 4 (B). About 61% of particles were in the between 0.1 m – 0.8 m which is considered as the optimum range of the mine. From the rest 39 % particles 34 % particles were less than 0.1 m and only 5% particles were above 0.8 m. Overall, the fragmentations achieved was found to be satisfying for the mines.

The in-hole VOD observed was around 4074 m/s which is significantly more than ANFO and is found sufficient to break the strata present in the mine. There may be some fall in VOD when plastic bottles were used in the explosive column. Also there were some downward spikes in the graph which may indicate the presence of bottle in the explosive column.

By using discarded water bottles in the explosive column, there were significant decreases in charge per delay. The usual charge per delay of the mine was around 70-75 kg which was decreased to 55-62 kg due to introduction of plastic bottles in the explosive column. Due to the decrease in charge per delay, the scaled distance has increased from 12.70 $m/kg^{1/2}$ to 13.97 $m/kg^{1/2}$ at 100-120 m distance and from 21.94 $m/kg^{1/2}$ to 24.13 $m/kg^{1/2}$ at 180-200 m distance. This increase in scaled distance indicates decrease in the ground vibration when compared to general practice of the mine.

5. Conclusion

The use of plastic bottles in explosive column can be a prominent solution for explosive consumption reduction as after replacing about 20 % of explosive with plastic bottles; there was no significant impact on the blast performance. Although due to presence of plastic bottles in explosive column there was 5-10 % fall in rock confined in-hole VOD but still the VOD was enough to cause good fragmentation of the rock mass. About 61 % of rock fragmented were in the between 0.1 m – 0.8 m which was considered as the optimum range by the mine. Moreover, due to the decrease in charge per delay, the scaled distance has increased from 12.70 $m/kg^{1/2}$ to 13.97 $m/kg^{1/2}$ at 100-120 m distance and from 21.94 $m/kg^{1/2}$ to 24.13 $m/kg^{1/2}$ at 180-200 m distance. Though, due to the size of bottles, it is difficult to engineer a mechanical process of controlling loading density precisely and this makes this process more site specific and manual.

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