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Investigation into the Effect of Stemming on Blast Performance in Underground Excavations- A Model Study

*[1]M. Devendar, [2]Manish D. Uttarwar

[1]Department of Mining Engineering, Govt. Polytechnic, Bellampally, 504251, Mancherial District, Telangana, India

[2]Department of Mining Engineering, Rajiv Gandhi College of Engineering, Research and Technology, Chandrapur 442 403 (M.S.)

Email: maram.devendar@gmail.com, udmanish1@rediffmail.com

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Abstract

Blasting in an underground mine produces potentially harmful elastic stress waves that propagate down the walls and back of the entry. Stemming may be used to maximize the effectiveness of an explosive at the face and minimize the magnitude of the elastic waves that propagate down the entry and also reduce unnecessary discharge. Stemming is necessary to stop the explosive energy from escaping through the upper part of blast holes in underground mines.

Keywords

Blasting, Stemming, Underground Excavation, Fly Ash Brick (FAB), Fragmentation, Air Overpressure, Ground Vibrations

Introduction

Rock fragmentation by blasting is an extensive and effective practice in the engineering of mines and quarries (Shi et al., 2016a; Jhanwar et al., 2000; Bohloli and Hoven, 2007).[7] Utilization efficiency of energy from the explosive has a profound impact on rock fragmentation and subsequent mucking and transportation. Researchers have been trying to utilize more energy released during blasting for rock breaking but less for air shock waves and ground vibration (Zhang et al., 2017; Shi et al., 2016b).[1] It is commonly agreed that energy released during blasting spreads into surrounding rock through two types of loadings: shock wave (stress wave) and explosion gas pressure (Zhu, 2009; Bhandari, 1977; Brinkman, 1989).[4] The stress wave initiates cracks around the blast hole and near free surface, and the longer duration gas pressure penetrates these initial cracks and causes their further extension, finally driving the movement of fractured rocks (Kutter, 1971; Mchugh, 1983).[9] Generally, blast holes from the explosive charge at the mouth of the hole are stemmed with inert materials to optimize the usage of explosive energy and reduce unnecessary discharge (Dobrilovi et al., 2005).[5] Due to adequate stemming, the efficiency of blasting increases nearly 50%, which has been proven by both lab and field tests (Brinkmann, 1990).[8] Missing or improper stemming, which leads to detonation gas escaping from blast holes in advance, results not only in wastage of explosive energy and poor fragmentation but also in environmental problems, such as ground vibration, noise, flying rocks, back breaks and air blasts (Floyd, 1999). Previous research showed that stemming can increase the action time of detonation gas inside the blast holes (Fig. 1) and promote the full reaction of explosives, reducing explosive consumption (Zong, 1996; Luo and Wu, 2006).[6]

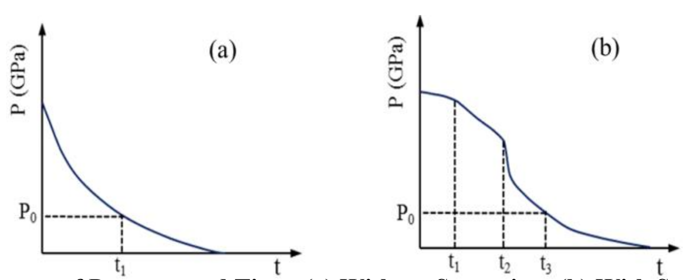

Fig.1: The Curves of Pressure and Time: (a) Without Stemming; (b) With Stemming.

In mining industries, three types of materials, including solid, liquid and colloidal materials, are used as stemming materials in blast holes. Scholars have not yet made enough progress on the selection of stemming materials. The process of ejection of stemming material from a blast hole is strongly dependent on the length and type of stemming material. Currently, there are several documents devoted to studying the effect of stemming length in blasting (Cevizci and Ozkahraman, 2012; Li and Liu, 2012; Wang et al., 2016). [3]

The composition and type of stemming material will play an important role in the blasting efficiency. This study was directed towards establishing a procedure for determining the type of stemming that would be the most effective in accomplishing the task. In the present study, model tests were carried out to investigate the effect of different stemming material on blasting performance.

Methodology

This paper discusses the performance of the blasting with different stemming materials and the role of stemming in blasting. A series of small-scale tests were conducted with different stemming materials on Fly ash brick (FAB) with a detonator to investigate the effect of stemming material on blast performance. The types of stemming materials used were Drill cuttings, Moist clay, Fly ash-Clay Mixture, Sand -Clay Mixture and Sand. The Parameters like Fragmentation, Air overpressure, Ground Vibrations were studied and data generated for each blast model was observed. For each stemming material used, the above parameters were measured and compared with the each of the stemming material performances for all the blast trials. The performance for each stemming material is observed and analyzed for underground excavations. The study revealed that the quality and type of stemming material significantly influences the blasting performance. Hence, the quality and type of stemming material must be considered in designing blast rounds. The results indicated that the sand was the best stemming material that can be effectively improve blast performance and in turn mining efficiency for all situations.

Experimental Setup

Block Preparation: Fly ash brick (FAB) model blocks, owning to its flexibility in making with desired shape, size, and necessary strength were prepared. A total of 36 (FAB) model blocks made of Fly-ash, sand, cement mixtures at different proportions were developed.

The blocks were prepared with the sizes of 30cm X 20cm X 15cm by using FAB moulds [Fig. 3(b)]. The clay in the mould was compacted by using compaction machine. The blocks were kept in shade for drying and curing for 14 days.

Fig.2(a): Sand Used in F.A.B.

Fig.2(b). Fly Ash Used in F.A.B

Fig.3 (a): Mixing Unit

Fig. 3(b): F.A.B. Moulding Unit

Fig. 4(a): Mobile Moulding Machine

Fig. 4(b): F.A.B Models

As stated below in the Table no.1, a total of 12 models were prepared with inferior quality (Low strength), 12 models with medium and another 12 with superior quality. The models were cured for a period of 2 weeks and dried for another 2 weeks. The models were then blasted with an instantaneous detonator inserted in a 10 mm drill hole made in the models.

Model No.	Model Strength	Fly Ash	Sand	Cement
1	Low strength	60	25	15
2	Medium strength	50	30	20
3	High strength	40	35	25

Table 1: Composition of the FAB Model Mixture

Tests Conducted in the Laboratory:

The strength properties like Volumetric Shrinkage, Density, Water absorption and Compression strength tests were conducted at the laboratory and at the model preparation site on (FAB) model blocks. For each composition 3 model blocks were tested, and the average results were given in the Table 2

1. Shrinkage Test:

Volumetric shrinkage is the measure which decides the final size of mould which was to be used in the brick preparation.

$$\text{Volumetric shrinkage} = \frac{W_1 - W_2}{W_2} \times 100$$

W_1 - Volume of moulded brick (cm^3)

W_2 - Actual volume of moulded brick after drying (cm^3)

2. Density:

$$\text{Density} = \frac{M}{W} \times 100$$

M - Mass of dry block in gm

W - Volume of dry blocks (cc)

3. Percent Water Absorption: The dried brick was immersed in water for 24 hours.

$$W_3 = \frac{W_2 - W_1}{W_1} \times 100$$

W_1 - Weight of dry brick in kg.

W_2 - Weight of brick after 24 hrs immersion in water

W_3 - Percent water absorption.

4. Compression Test: Universal Testing Machine

(Vivekananda college of Polytechnic, Mancherial) was used to determine compressive strength of the brick.

$$\text{Compressive strength} = \frac{\text{Crushing load (kg)}}{\text{Surface area in contact}} \times 100$$

Fig.5 (a): Compression Testing Machine

Fig.5 (b): FAB Block

FAB Type	Weight per unit volume g/cm^3	Compressive strength (kg/cm^2)	Volumetric shrinkage (%)	Water absorption (%)
Low strength	1.10	62	5	12
Medium strength	1.16	80	7	15
High strength	1.20	93	10	19

Table 2: Average Strength Properties of FAB Specimen

Trial blasts with Fly ash brick (FAB) Models

Fly ash brick (FAB) were used for laboratory scale model studies. A series of small-scale tests were made on these model blocks by blasting with an instantaneous detonator inserted in a 10 mm drill hole made in the models. Fragmentation, Ground Vibration and Air overpressure data was generated with Fly ash brick (FAB) model blasts with various stemming material. All the other parameters are to be kept constant. The influence of Fragmentation, Ground Vibration and Air overpressure with varying stemming material was determined for various onsite trial blasts.

Maximum seismic range	254 mm/s
Resolution	0.127 mm/s
Accuracy	3% at 15 Hz
Trigger levels	0.25 to 254 mm/s

Table 3: Technical Specifications of the Geophones of Seismograph

Measurement of Ground Vibration and Air overpressure

Ground vibration monitoring is the process of recording and reporting the intensity of the vibration levels. Ground vibrations were by using seismograph. The seismograph monitor measures the Peak Particle Velocity (PPV) in millimetres per second. The PPV defined "the maximum speed of a particular particle as it oscillates about a point of equilibrium, caused by the traveling seismic wave". Air overpressure or "Airblast", is "an airborne shock wave resulting from the detonation of explosives." Air overpressure is monitored with a microphone designed to measure and record air pressure changes over time in pounds per square inch (psi), millibars (mb), or pascals, and is often reported in decibels (dB).

In this study, Minimate Plus (Instantel, Canada) was used for measurement of Ground Vibration and Air overpressure. Minimate Plus is the one of the most advanced compact seismograph developed by Instantel Inc., Canada. It is a programmable instrument with user-friendly menus with particle velocity measuring range of 0 - 2540mm/s and frequency measuring range of 28Hz to 2kHz. This instrument used in most of the experimentation sites where the near-field vibration recorded. Technical specifications of geophones of seismograph (Minimate Plus) are given in Table 3

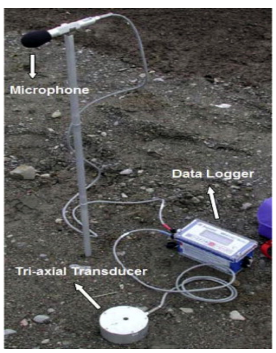

Fig.6(a): Instantel Minimate Plus and its Accessories

Fig. 6(b): Instantel Minimate Plus

Preparation of F.A.B. Model for Blasting:

The F.A.B. models were drilled by a drill rod with 10mm drill bit up to 10cm depth as shown in Fig.7 and inserted a plain detonator and then stemmed by varying the stemming material. As shown in Fig.9 other Fly Ash Bricks were covered around the F.A.B. model all sides so as act as to reduce the fly rock pieces from F.A.B. model caused by detonation.

Fig.7 (a): Drilling the Blast Hole in F.A.B

Fig.7 (b): Measurement of Depth of Drill Hole

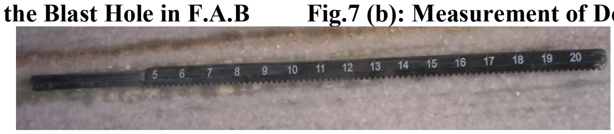

Fig.7(c): Depth Measurement Rod

Fig.8: F.A.B.Models

Fig 9: F.A.B. Model after Charging a Detonator and Stemming with Weights over F.A.B. Model

Fig 10(a): Minimate Plus Installation for Recording
Fig 10(b): F.A.B. Model after Blasting

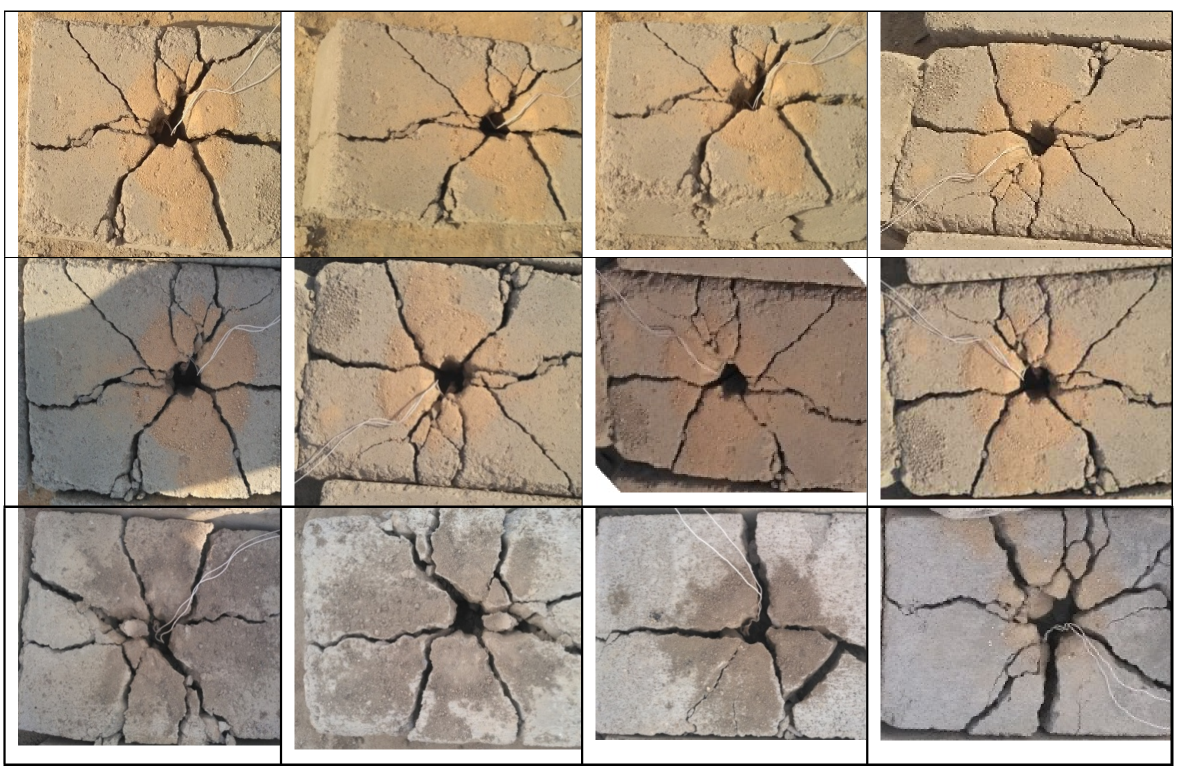

Fig.11: Blasted Models with Different Stemming Material

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Result & Discussion

As stated in the preceding sections, a series of experimental trial blasts were conducted using FAB model blocks with different type of stemming materials. In- blast monitoring using seismograph was done in respect of air over-pressure and ground vibrations and that the post-blast monitoring was done in respect of fragmentation achieved. Table 4.1 through 4.3 depicts performance of drill cuttings, fly ash red clay and sand as stemming materials based on parameters like fragmentation, air over-pressure and ground vibrations as applied to varying strength of FAB model blocks. Table 4.4 shows the average results of all the trial blasts with different stemming materials and varying strength of FAB model blocks.

Figure 12.1 is the graphical representation of average performance of various stemming materials using varying strength of FAB model blocks. Figure 12.2 through 12.4 depicts performance of various stemming materials in based on fragmentation, air over-pressure and ground vibrations respectively using bar chart.

Parameter	**Drill cuttings as stemming**				**Fly ash –Red Clay as stemming**				**Sand as stemming**			
	Trial 1	Tri al 2	Tri al 3	Tri al 4	Tri al 1	Tria l 2	Tria l 3	Trial 4	Tria l 1	Tria l 2	Trial 3	Trial 4
1.Fragmentation (No. of Major Cracks)	7	8	7	7	7	8	9	8	9	8	9	9
2.Air over pressure (dB) (2m from the source)	83	84	83	84	81	82	81	80	73	74	75	74
3. Ground Vibrations (mm/s) (2m from the face)	4.5	4	4	4.5	3.5	3.2	3.5	3.5	2	2	2.5	2.5

Table 4.1: Results of Experimental blast trials with different stemming on Low Strength F.A.B. Models

Parameter	**Drill cuttings as stemming**				**Fly ash –Red Clay as stemming**				**Sand as stemming**			
	Tria l 1	Tria l 2	Tria l 3	Tria l 4	Tria l 1	Tria l 2	Tria l 3	Trial 4	Tria l 1	Tri al 2	Trial 3	Trial 4
1.Fragmentation (No. of Major Cracks)	5	6	6	5	6	6	7	6	7	7	8	6
2.Air over pressure (dB) (2m from the source)	84	86	84	84	83	81	82	82	75	75	73	74
3. Ground Vibrations (m/s) (2m from the face)	5.5	4.5	5	5.5	4	4	4.5	4	2.5	2	2.5	3

Table 4.2: Results of Experimental Blast Trials with Different Stemming on Medium Strength F.A.B. Models

Parameter	**Drill cuttings as stemming**				**Fly ash –Red Clay as stemming**				**Sand as stemming**			
	Trial 1	Trial 2	Tria l 3	Trial 4	Trial 1	Tria l 2	Trial 3	Tria l 4	Tria l 1	Tria l 2	Trial 3	Tri al 4
1.Fragmentation (No. of Major Cracks)	5	4	5	4	4	6	6	5	6	7	6	6
2.Air over pressure (dB) (2m from the source)	88	87	84	85	85	85	83	82	78	78	77	75
3. Ground Vibrations (mm/s) (2m from the face)	6	4.5	4	4.5	4.5	4	5	5	3.8	3.9	3.5	3

Table 4.3: Results of Experimental Blast Trials with Different Stemming on High Strength F.A.B. Models

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Parameter	Drill cuttings as stemming				Fly ash –Red Clay as stemming				Sand as stemming			
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4
1.Fragmentation (No. of Major Cracks)	7.2	8.0	8.7	5.5	6.8	7.0	4.5	5.2	6.2	7.2	8.0	8.7
2. Air over pressure (dB) (2m from the source)	83.5	81	74	84.5	82	74.4	86	83.8	7.7	83.5	81	74
3. Ground Vibrations (mm/s) (2m from the face)	4.25	3.4	2.2	5.3	4.1	2.5	4.7	4.6	3.6	4.25	3.4	2.2

Table 4.4: shows the average Results of Experimental blast trials with different stemming on different strength F.A.B. Models

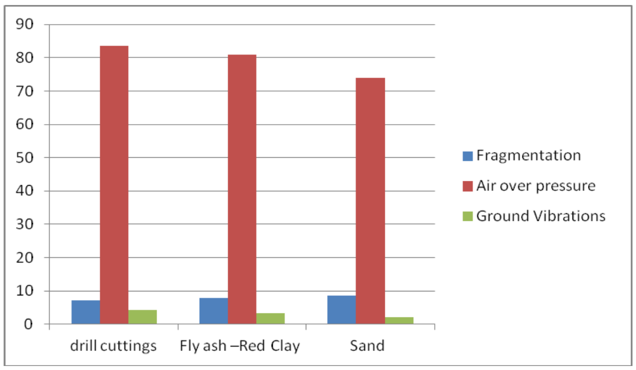

Fig.12.1: Bar Chart Showing the Graphical Representation of Different Stemming for Different Parameters

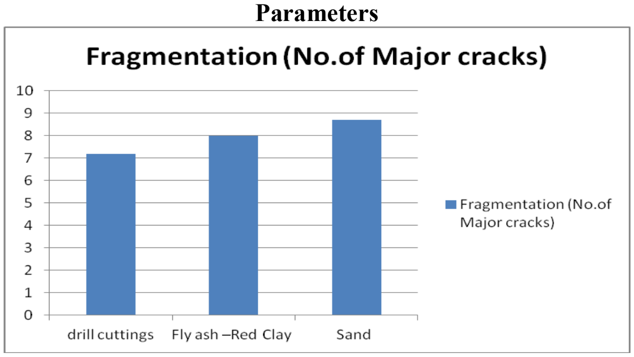

Fig.12.2: Bar Chart Showing the Graphical Representation of Effect of Different Stemming on Blast Fragmentation

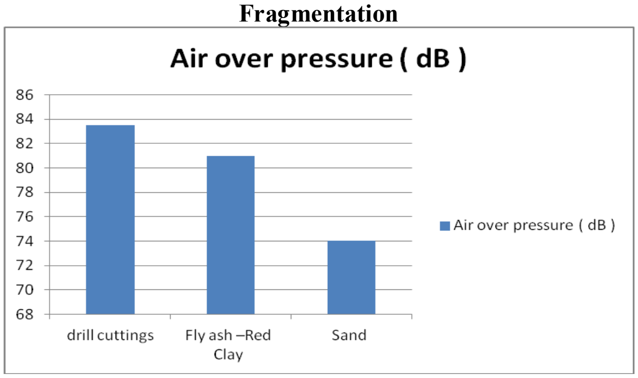

Fig.12.3: Bar Chart Showing the Graphical Representation of Effect of Different Stemming on Air Over Pressure

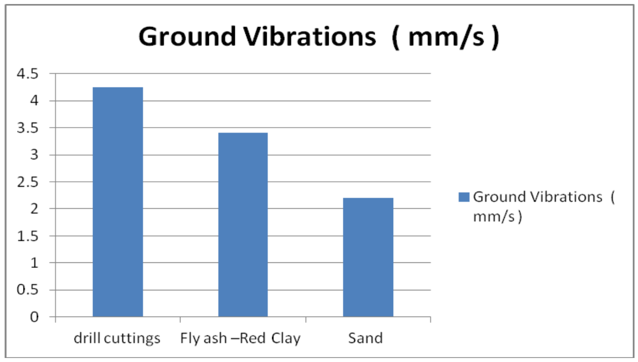

Fig.12.4: Bar Chart Showing the Graphical Representation of Effect of Different Stemming on Ground Vibrations

Comparative Analysis of Stemming Materials

a. Fragmentation is more with sand stemming compared to the Fly ash-red clay and drill cuttings.

b. Ground Vibrations with Sand stemming is less compared to other stemming materials.

c. Air-overpressure is also less with sand stemming as compared to Fly ash-red clay and drill cuttings as stemming materials.

Conclusions

1. The performance of models blasted with the stemming Fly ash-Red clay composition is more as compared with that of drill cuttings.
2. The performance of models blasted with the sand stemming is more as compared with that of Fly ash-Red clay composition.
3. The Average fragmentation with the sand as stemming material increased by 12% as compared with Fly ash-Red clay composition and increases by 20% as compared with the drill cuttings.
4. The Average Air over pressure of the blast reduces with the sand as stemming material by 9% as compared with Fly ash-Red clay composition and by 12% as compared with the drill cuttings.
5. The Average Ground vibrations of the blast reduces with the sand as stemming material by 20% as compared with Fly ash-Red clay composition and by 30% compare with the drill cuttings.
6. Sand is the best stemming material among all other compositions of stemming. Sand is found to effectively confine the high-pressure stress produced by the blasting.

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