Improving Rock Fragmentation Using Airdeck Blasting Technique

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Abstract

The airdeck blasting technique has been used in the past to reduce the explosive charge and to improve the rock fragmentation. The mining and construction industry of Pakistan has always been reluctant to use airdecks in their blasting operations. This is due to the fact that researchers and practitioners have a divided opinion about the efficiency of this technique. The present research work addresses the fundamental question regarding the technical and economic efficiency of the airdeck blasting technique. A series of experiments was conducted using concrete blocks to find out the proper position and optimized length of the airdeck. It is found that an improved rock fragmentation is achieved when the airdeck is placed at the middle position of the explosive column. Moreover, it is also observed that the mean blasted rock fragment size increases with the increase of airdeck size.

Key Words: mining; quarry; concrete block; explosive; airdeck; blasting

1. Introduction

Optimization of production blasting cost is one of the factors that ensure economic feasibility of the mining projects. Various methods have been used to minimize [1] the explosive cost, for example blast design parameters such as stemming, spacing and burden are increased to economize the blasting cost. All these factors not only undermine the blasted rock fragmentation results but also make the blasting operation labor and cost intensive [1]. Thus, there is a need to develop a methodology to economize the blasting operation. Moreover, it is also desired that the blasting operation should not produce improper fragmentation, toxic gases, fly rock, air blast and blast-induced vibrations. Airdecks have been used in blasting operations to improve the fragmentation by amplifying the induced fracturing that has significant economic effect on subsequent size reduction processes. Recently, the airdeck blasting technique has been introduced to some surface mines for reducing explosive consumption without effecting the fragmentation and increasing the labor [2-6].

In 2012, Hayat and Tariq [7] introduced the airdeck blasting technique to mining industry of Pakistan. However, unfortunately, their research findings were not recognized by the mining industry because they failed to provide guidelines on the use of airdeck blasting technology. In that study the airdeck length was kept 10% of the original charge length and was not varied moreover airdeck was kept only at the top & bottom of the explosive column. In the current research work, detailed experiments were conducted to develop proper guidelines for practicing the airdeck blasting technique. This research study aims at determining the proper location and optimum length of airdecks for surface mining blasting operations.

All the experimental work was conducted at D.G. cement factory, Chakwal Pakistan. Two different series of blasting experiments were performed. The aim of the first test series was to determine the best position of the airdeck. The second set of experiment was performed to find out the optimum length of the airdeck. This paper describes the rationale for the design of experimental setup and presents the data obtained from blasting experiments on concrete blocks.

2. Literature Review

When a continuous cylindrical explosive charge in a blast hole is detonated, the blast hole enlarges by crushing walls of blast hole due to high pressure. A shock wave with a high peak pressure propagates outwards in all directions as a compressive stress wave [1]. The compressive stress wave also produces radial cracks in the strata. At the free face, this compressive stress wave reflects back as a tensile stress wave. The tensile strength of the rock is much smaller than its compressive strength, thus the rock mass breaks at the point where effective tension exceeds the tensile strength of the rock. The gas produced by explosive detonation penetrates into cracks and improves the rock fragmentation [1].

According to Mel'nikov and Marchenko, [8] the explosive column with airdecks develop additional compressional shock waves after the main compression wave produced in the rockmass due to blasting. This additional compressional wave is produced as a result of collision between the two gas streams in the center of the air gape. The collision of the gases not only generates great pressure at the meeting point, but also the gases are reflected back and penetrate in the fissures thus aiding fragmentation.

Mel'nikov and Marchenko[8] also found that when a airdeck is placed in the explosive column, the peak bore hole pressure reduces due to wave collision in the air gap. However, at the same time, multiple impacts of shock wave within the medium are produced due to collision and reflection of gases in the airdeck area. This may result in 1.5 to 1.7 times more energy transferred to the medium as compared to blasting a continuous charge. Hence, an improved rock fragmentation can be achieved by providing air gap in the explosive column of a blast hole. Experiments to study fracture network conducted by Fourney et al. [9] on Plexiglas model also supported Menikov's theory and demonstrated that a shock wave reaching the stemming is reflected back to strengthen the stress field. Jhanwar and Jethwa [10] in their work on airdeck blasting concluded that airdeck blasting results in better fragmentation and improved utilization of explosive energy. Jhanwar, et al. [5] found that the degree of fragmentation resulting from airdeck blast holes is better than that of produced by conventional blast holes in which solid decks are used. Moreover, airdeck blasting was also found to be more effective in very low to low strength moderately jointed rocks as compared to medium strength highly jointed rocks.

Chiappetta R.F., [6] observed no significant difference in rock fragmentation produced by blasting a single drill hole with and without airdecking. However, the drill hole with airdeck consumed 17% less explosive than that of with a solid charge. Another series of experiments conducted by Thote N.R. and Singh D.P. showed that the powder factor increased from 7.46 t/kg to 8.96 t/kg by using airdeck blasting technique [11].

According to Moxon. et al. [12] no significant effect on the degree of fragmentation was observed with the airdecks which occupy 40% or less of the maximum volume of explosive. He concluded that maximum length of the airdeck was depending upon the structure and strength of the material to be blasted.

Three types of airdeck positions are commonly used by researchers and practitioners i.e., top, middle and bottom of the explosive column. Generally, airdeck when placed at the top of explosive column of the blast hole produced a good rock breakage in the stemming area [10]. Jhanwar et al. [13] suggested that the airdecks were most effective if placed at the middle position of an explosive column. Jhanwar [10] also observed that bottom airdeck can only be used for blasting of holes with softer bottoms. Moxon et.al., [12] also had the similar point of view and concluded that the middle position of the airdeck resulted in an improved rock fragmentation due to the interaction of two simultaneous shock wave fronts from the top and bottom of an explosive charge. Whereas, Chiappetta [6] stated that the bottom airdeck could be used more effectively than continuous cylindrical charges because it produces 2 to 7 times more pressure at the bottom of the hole when properly practiced. Contrary to that, Liu and Katsabanis [15] suggested that only the top position of airdeck improved the rock fragmentation than that of other two positions.

Bottom airdeck was successfully used by Blast Dynamics Inc. at a gold mine in Northern Nevada without effecting fragmentation and excavator productivity. Moreover, no toe problem was encountered [13].

3. Research Methodology

3.1 Model Material

Research work performed at the University of Maryland [14] and at Stiftelsen Svensk

Detonikforskning (SveDeFo) [15] demonstrated that concrete is the most suitable material for this type of research study. Thus, in the current research work, all the blasting experiments were conducted on the concrete blocks. Concrete blocks also eliminate the effects of geological uncertainties and irregularities such as fractures, folds, faults and joints on blasting results.

Concrete blocks with dimensions 350 mm × 350 mm × 300 mm were prepared. The ingredients ratio as shown in Table 1.was maintained throughout the research.

Table 1 Concrete mix composition

Ingredients	Weight(kgs)
Ordinary Portland cement	25
Sand	24
Coarse aggregate (12.7 mm)	48
Water	3.6
Chemrite NN	0.6

Chemrite NN was used in the concrete mixture to achieve an ultimate compressive strength of 40 MPa.

3.2 Experimental Setup

Airdeck in the explosive column was introduced by wooden spacers with different lengths as shown in Figure- 1.

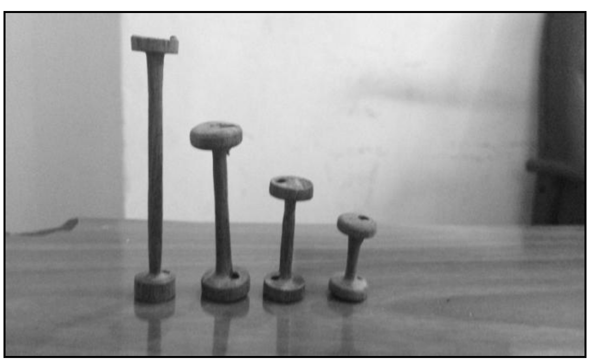


Fig. 1 Wooden spacers used during the blasting experiments

Wooden moulds with a small diameter pipe were used to prepare concrete blocks with a vertical hole. The diameter of pipe was 12.7mm and a depth of 275mm was maintained in all concrete blocks. The pipe was installed 125mm away from one of the faces of the concrete block as shown in Figure 2.

Fig. 2 Concrete block inside the wooden mould with a built-in hole assembly

The concrete blocks were casted using facilities of the Concrete lab at Civil Engineering Department, University of Engineering and Technology Lahore. In order to achieve a uniform mixing all the ingredients were mixed in a mechanical mixer for 5 minutes. After mixing, the concrete mixture was poured into the wooden moulds. The wooden mould was placed on mechanical vibrating platform to reduce any entrapped air. For every concrete block, a small concrete block (152× 152 × 152 mm) was alsocasted to check its designed strength as shown in Figure3.The blocks were left in the moulds for 48 hours before being removed and placed in curing water tank for 28 days. Theuniaxial compressive strength (UCS) of the smaller blocks constructed from the same mixture was determined by direct compressive strength testing and was found to be almost 40 MPa.

Fig. 3 Smaller concrete blocks along with model blocks for UCS testing.

3.3 Experimental Program

Several field visits were made to select the suitable site for blasting. With the co-operation of Inspectorate of Mines, the permission was granted to perform experiments at D.G. Cement Pvt. Ltd. near Kallar Kahar area of Chakwal District in Punjab province of Pakistan. The concrete blocks were blasted in a reinforced rubber walled blasting chamber. The blasting chamber was used for protection and collection of blasted fragments as shown in Figure 4. The rubber walls of the chamber provided cushioning effect and reduced the further fragmentation by impact.

Fig. 4 Metallic blasting chamber with reinforced rubber walls

The stemming, explosive and airdeck length of the blocks were painted with different colors as shown in Figure5. Water-gelexplosive (blaster) manufactured by Biafo Industries was used in all the experiments. Density of blaster was 1.32g/cc and a velocity of detonation 43000 m/s.Nonel initiation system was used for all experiments.

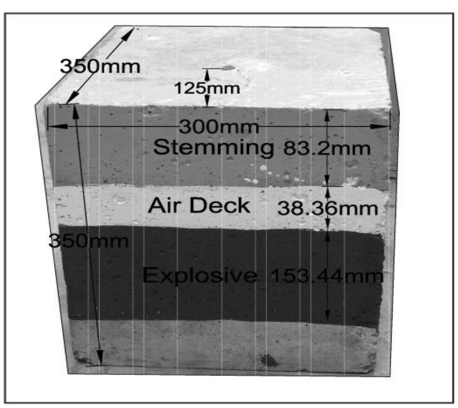


Fig. 5 Dimensions of concrete block, location of hole, stemming, air deck and explosive

3.4 Blasting Testing

Two series of blasting experiments were performed. First series consisted of baseline blasting experiments. During baseline testing, three concrete blocks were blasted individually with full column charge without any airdecking.

Second test series was performed to find out the most appropriate position of airdeck. In this series of experiments, airdecks were introduced at three different positions: top, middle, and bottom of the blast hole. The airdeck proportion used in the current research study was defined by Moxon et.al., [9] and was calculated using equation 1.

$$AP(\%) = \frac{Air\ deck\ length}{(Explosive\ length + Airdeck\ length} \times 100 \qquad (1)$$

Where; AP(%) is the airdeck proportion (%)

Nine concrete blocks were blasted during this series of experiments. Out of nine blocks, three were blasted with 20% airdeck length located at the top of the blast hole. The next three were blasted with 20% airdeck length located at the middle portion and the last three blocks were blasted with 20% airdeck length located at the bottom position. Table 2 shows the different experimental parameters used in this research work. After blasting, concrete block fragments were collected for sieve analysis. The sieves used for size analysis (in mm) are 128, 64, 32, 16, 8, 4, 2, and 1.

Table 2 Different parameters used in the experimentation

Explosive weight (gm)	Airdeck length (mm)	Airdeck proportion (%)	Explosive length (mm)	Stemming length (mm)
27.94	0.00	0.00	191.80	83.20
25.29	19.18	10.00	172.62	83.20
22.36	38.36	20.00	153.44	83.20
19.60	57.60	30.00	134.20	83.20
16.85	76.40	40.00	115.40	83.20

4. Results and Discussion

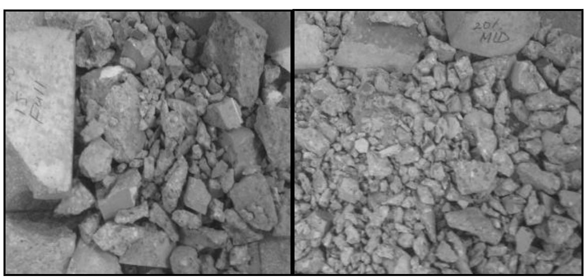
4.1 Airdeck Location

Concrete blocks were placed in the blasting chamber for experiments. After blasting the blocks, blasted material for each block was collected and sieve analysis was performed on each collected fraction. The results of sieve analysis are shown in Table 3.

Table 3 Experimental results with respect to location of airdeck

Fraction Size (mm)	Solid Charge mean values	20% Airdeck – mean values		
	(Kg)	Top (kg)	Middle (kg)	Bottom (kg)
+128	29.10	40.50	19.33	54.35
-128+64	24.77	29.40	22.76	19.20
-64+32	17.01	8.00	21.80	7.50
-32+16	7.53	4.20	12.10	2.23
-16+8	4.07	1.35	5.95	0.85
-8+4	1.27	0.50	1.57	0.26
-4+2	0.47	0.45	0.65	0.14
-2+1	0.41	0.17	0.45	0.10
Total	84.62	84.57	84.60	84.63

It may be inferred that the size distribution of blasted block fragments for airdeck located at the middle position are more uniform as compared to that of solid charge and airdeck at top and bottom positions as shown in Figure6.



a) Full-length charge b) 20% middle airdeck

Fig. 6 Fragmentation of concrete blocks due to blasting

The mean size of the blasted block fragments is tabulated in Table 4.

Table 4 Experimental results in terms of mean fragment size

Fraction	Solid Charge	20% Airdeck		
		Top	Middle	Bottom
Mean Fragment Size(mm)	97.00	117.90	80.10	132.10

It is evident from the results that mid column airdeck produced smaller mean fragment size when compared to full column explosive charge and airdeck at top and bottom. The mean size of the blasted block fragments was calculated by using the following formula [9].

$$MFS(mm) = \frac{\sum Mass\,\%age \times mean\ sieve\ size}{100} \quad (2)$$

Where MFS(mm) is the mean fragment size in mm.

Figure 7 shows the cumulative percent-passing plot for the blasted block fragments for all the experiments in this phase.

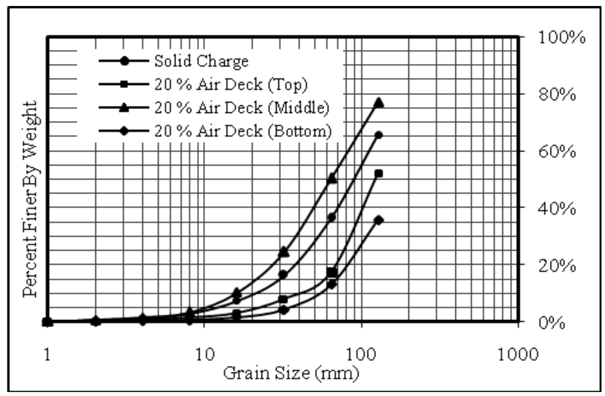


Fig. 7 Comparison between full charges versus 20% airdeck at different positions

It may be observed from the Figure 7 that airdeck, when placed at the middle position of explosive charge, produces a small size distribution compared to full column explosive charge and airdeck at top and bottom positions. It may also be observed that the size distribution of fragments produced by airdeck placed at middle position is closest to the same produced by solid explosive charge. These results are in accordance with the findings of Mel'nikov and Marchenko [5].Moreover, full column explosive charge produced a coarser fragment size distribution compared to airdeck at middle and a finer size distribution than airdeck at top and bottom positions respectively. Thus overall a better fragmentation was produced with airdeck at middle position when compared with that of full column charge and airdecks placed at the top and bottom of an explosive charge.

4.2 Optimum Airdeck Length

Third phase of this research, aims at finding the optimum length of the airdeck. For this purpose, another series of experiments wasconducted at the already determined middle position of explosive column but with varying lengths of airdeck. Experiments were conducted at four different airdeck lengths of 10 %, 20 %, 30%, and 40% of the total column charge. The results are shown in Table 5. These results suggested that airdeck length equivalent to 20% of total column charge produced the best fragmentation. Figure 8 shows the cumulative percentage plot for the blasted block fragments for all the experiments in this phase. The mean fragment size for the blasted block was calculated and presented in Table 6.The mean fragment size decreases gradually with increase of airdeck size from 0 to 20% and then increases with increasing airdeck size. The Figure 9 shows that 20% airdeck produces the smallest mean fragment size, which has significant economic effect on subsequent size reduction processes, and then mean fragment size increases with increasing airdeck size.

Table 5 Experimental results with the varying lengths of the airdecks at middle position

Fraction Size (mm)	Middle Position – mean values (Wt, kg)			
	10% Airdeck	20 % Airdeck	30 % Airdeck	40 % Airdeck
+128	23.15	19.33	42.88	49.08
-128+64	23.25	22.76	23.80	25.15
-64+32	17.50	21.80	11.45	7.25
-32+16	10.60	12.10	4.06	1.50
-16+8	6.50	5.95	1.63	0.85
-8+4	2.20	1.57	0.63	0.40
-4+2	0.74	0.65	0.22	0.15
-2+1	0.47	0.45	0.14	0.10
Total	84.41	84.60	84.80	84.48

Table 6 Mean fragmentation size for varying length of airdeck at middle position

Fraction	Middle Position			
	10% Airdeck	20 % Airdeck	30 % Airdeck	40 % Airdeck
Mean fragment Size(mm)	85.50	80.10	117.80	128.60

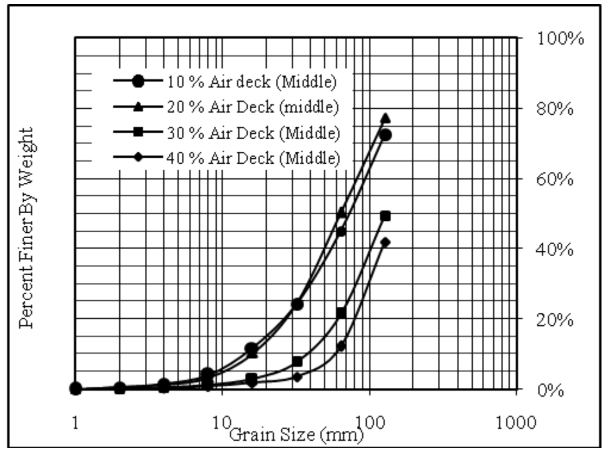


Fig. 8 Percentage passing plot – comparing different airdeck lengths at middle position

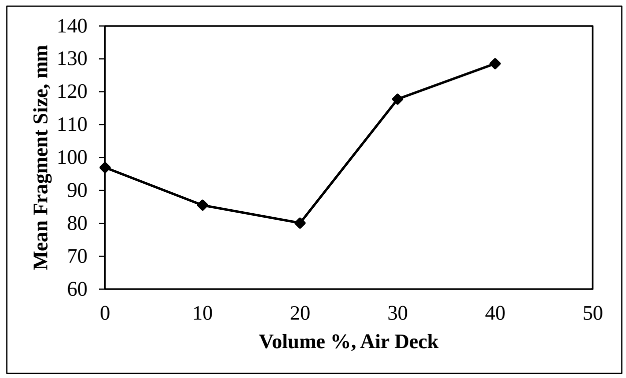


Fig. 9 Effect of increasing airdeck size on mean fragment size

5. Conclusion

After detailed experimentation and analysis of blasted fragmentation results, following conclusions can be drawn.

Air deck technique is proved significantly effective in homogeneous concrete block blasting because it produces more uniform fragmentation with minimum fines and over size blasted material. Sieve analysis of blasted fragmentation indicates that blasted rock fragmentation produced by airdeck is as good as produced by full column charge.

Airdecks, when placed at middle position of an explosive column produce more uniform blasted rock size distribution compared to that at other positions. It is because, the airdeck at middle position results in multiple impacts of shock wave that leads to an efficient transfer of explosive energy in the surrounding rocks. The results of this work also indicate that the optimum length of airdeck is 20% of the total length of explosive column.

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