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Effect of layer thickness of rocks on blast fragmentation – case study in a limestone mine

The paper discusses the influence of layer thickness of limestone beds on blast fragmentation in different blasting benches of Aditya Limestone Mines of UltraTech Cements Limited. Blast fragmentation analysis was carried out using photographic method to determine the mean fragment sizes. Good correlations were obtained between average layer thicknesses and blast fragment size, power factor (t/kg) and charge factor (kg/m^3). Mean fragment sizes less than 100 cm were obtained with the average layer thickness of limestone beds less than 80 cm. The powder factor more than 14 t/kg was achieved with layer thickness less than 200 cm. However, in geologically disturbed limestone strata, blast design patterns and joint parameters had significance in achieving desired fragment size.

1. Introduction

Blast fragmentation, particle size distribution and shape of a muck profile are the essential components for effective performance of loading and hauling machinery deployed in a mine. The poor result in any of these components can greatly affect the performances of loading and hauling machinery. For blasting in ore body/minerals, the required fragment size depends mainly on screen size of the primary crusher, bucket size of the loading equipment and dumper size and capacity. In case of blasting in overburden, bucket size of the loading equipment and dumper capacity are the main factors that govern the required fragment sizes. There are several factors that influenced blast fragmentation, size distribution of fragment sizes and muck profile. Rock and rock mass properties, blast design parameters and explosive properties are the main factors to be considered in designing a blast for achieving the desired fragment sizes and size distribution. Rock and rock mass properties have been used by different researchers for the determination of charge factor (specific charge) or to define blastability of rock as given in Table 1. The property of joints are used by the different person in their blastability models.

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The influence of rock and rock mass parameters on the blastability and fragmentation summarized by Reichhof and Moser (2000) is given in Table 2. Out of several parameters listed out, few parameters have been quantified such as compressive strength, acoustic impedance, Young modulus, density, joint frequency and joint orientation to bench face. Different joint properties such as joint spacing, joint orientation with respect to bench face, joint status (open or fill), type of joint filling materials and their properties, joint frequency etc. have maximum influence on the degree of rock fragmentation by blasting. Dhar et al. (1993) recommended charge factors for different rock quality designation (RQD) based on the different experimental blasts in Indian geo-mining conditions as shown in Table 3. The charge factor value of 0.30 kg/m^3 was recommended for RQD value is less than 30.

In the present study, the influence of layer thickness (bed thickness) on blast fragmentation was investigated. The other joint parameters such as orientation, frequency, nature of joints etc. were not considered. An attempt is made to correlate layer thickness of limestone beds with average fragment size, powder factor and charge factor.

2. Case study

The study was conducted in Aditya Limestone Mines of UltraTech Cements Limited, Aditya Cement Works, Shambhupura, Chittorgarh, Rajasthan. The limestone deposit in the mine belongs to Nimbahera limestone formation where limestone, shale and clay are the major rock type (Parihar and Bhandari, 2013). The limestone deposit is heavily jointed, fine grained, thinly-laminated to massive in structures. The specific gravity of limestone varied from 2.60 to 2.70 and the uniaxial compressive strength varied from 430 to 690 kg/cm^2. Tensile strength varied from 60 to 120 kg/cm^2. The joints are multi-directional wherein joints in the top benches are filled with overburden soil and clay occasionally. The amount of dip varies from 0^o to 20^o and dip direction changes from east to west due to folding. Mining is carried out by fully mechanised open pit mining method. At present, there are four working pits in the mine and bench height varied from 6.0 to 9.0 m. Drilling is done with ROC L6 and IBH-10 drill machines of

TABLE 1: DIFFERENT ROCK AND ROCK MASS PROPERTIES USED BY DIFFERENT RESEARCHERS FOR DETERMINATION OF SPECIFIC CHARGE OR BLASTABILITY

Name of the researchers	Parameters used for determination of specific charge or blastability index
Hino (1958)	Defined blastability index as ratio of compressive strength to tensile strength. Higher the value, easier will be fragmentation.
Broadbent (1974) Heinen & Dimock (1976)	Used in-situ seismic wave velocities for determination of specific charge in open pit copper mines.
Ashby (Hoek & Bray, 1977)	Developed for the Bougainville Copper Mine based on fracture frequency and Joint shear strength.
Langefors and Kihlstrom (1978)	Used rock constant 'c' to determine specific charge.
Kutuzov (1979)	Used joint spacing, rock density and uniaxial compressive strength for determination of charge factor for general bench blasting.
Borquez (1981)	Used RQD, joint alteration factor and joint strength to determine blastability factor (K_v) = 1.96 - 0.27 ln (ERQD) ERQD = RQD×alteration factor.
Rustan et al., 1983 Rustan and Nie, 1987	Determined fragmentation gradient (n), K_{50} and critical burden based on impedance (density, P-wave velocity) and rock structures and friction properties of the discontinuity.
Lilly (1986)	Defined blastability from rock mass description (RMD), joint plane spacing (JPS), joint plane orientation (JPO), specific gravity influence (SGI) and hardness. BI = 0.5 (RMD + JPS + JPO + SGI + H)
Ghose (1988)	Developed blastability model for selection of specific charge for coal measure rocks in open pit blasting based on density, spacing of discontinuity, point load strength index, joint plane orientation.
Berta (1990)	Used impedance factor to explain the transfer of explosive energy to rock fragmentation for the selection of specific charge.
Mutluoglu et al. (1991)	Used seismic wave velocity for optimization of specific charge in coal and lignite mines.
Adhikari (1994)	Used density (ρ), rock types and degree of jointing to determine specific charge for bench blasting: q = a + bρ, a and b are rock coefficients.
Scott (1996)	Used dynamic compressive strength, density, Young's Modulus, block size, structures, target fragment size, heave, confine scale, water for blastability model to select charge factor for dragline bench, cast blasting in dragline bench and shovel operation in coal measure strata.

TABLE 2: INFLUENCING ROCK AND ROCK MASS PARAMETERS ON BLASTABILITY AND FRAGMENTATION (REICHHOF & MOSER, 2000)

Influencing parameters	Influence on		Quantified
	Blastability	Fragmentation	
Rock material			
Compressive strength	Yes/No	Yes/No	Yes
Tensile strength	Yes	No	No
Shear strength	Yes	No	No
Acoustic impedance	Yes	Yes	Yes
Young Modulus	Yes	Yes	Yes
Poisson's ratio	Yes	No	No
Mineral content	Yes	Yes	No
Angle of internal friction	Yes	Yes	No
Density	Yes	Yes	Yes
Porosity	Yes	Yes	No
Joint parameters			
Joint status (open or close)	Yes	Yes	No
Joint width	Yes	Yes	No
Joint frequency	Yes	Yes	Yes
Type of filling materials	Yes	Yes	No
Shear strength of filling materials	Yes	Yes	No
Friction properties of filling materials	Yes	Yes	No
Joint distance to a borehole	Yes	Yes	No
Angle of incident – stress wave to joint face	Yes	Yes	No
Joint orientation			
Joint orientation with respect to bench face	Yes	Yes	Yes

100-115mm diameter. The bucket capacity of the loading equipment deployed at the mine is 6.5 m^3 (PC 1250). Transportation of limestone from the working face to the crusher hopper is carried out by 35/60 tonne capacity dumpers.

2.1 MEASUREMENT OF LAYER THICKNESS

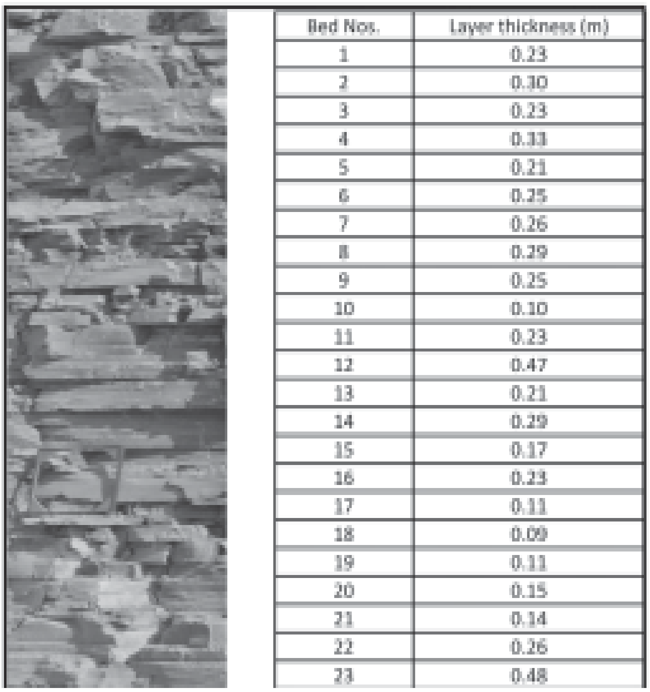
It is difficult to measure layer thickness of different limestone beds manually in a blasting bench. In order to assess the different layer thicknesses of limestone beds in the blasting faces, image photos of the bench faces were taken by keeping a reference scale using digital camera as shown in Fig.1. The images of the bench faces were uploaded in image analysis software. In the present study, Fragalyst-4.0 Software, developed by CSIR-CIMFR was used to measure the different layer thicknesses. The number of limestone layers/beds along with their respective thicknesses were identified and measured from top to

TABLE 3: RECOMMENDED CHARGE FACTOR IN ROCK BLASTING BASED ON RQD VALUES (DHAR ET. AL, 1993)

RQD	Charge factor (kg/m^3)
10-50	0.30
50-70	0.60-0.70
70-100	0.80-0.90

bottom of the entire blasting faces as shown in Fig.2. The lamination plane could not be identified from the images. Therefore, the bedding planes of the limestone strata were measured and considered as layer thicknesses. No joint planes were taken into consideration during such measurements.

Fig.1 Image of the basting face



Bed Nos.	Layer thickness (m)
1	0.23
2	0.30
3	0.23
4	0.33
5	0.21
6	0.25
7	0.26
8	0.29
9	0.25
10	0.10
11	0.23
12	0.47
13	0.21
14	0.29
15	0.17
16	0.23
17	0.11
18	0.09
19	0.11
20	0.15
21	0.14
22	0.26
23	0.48

Fig.2 Identification of different layer and bed thickness

The layer thicknesses of limestone beds varied from few centimetre to a metre in a bench. Similarly, the thicknesses varied from one bench to other. The average layer thickness for each bench was determined by summing all the identified layers and then divided by the number of beds.

2.2 BLAST DESIGN PARAMETERS

The blasthole diameter used in the mine was 110 mm. Depending upon the bench height, the depth of holes varied from 6.0 to 9.0 m. In all the blasts, ammonium nitrate fuel oil (ANFO) explosive was used. Shock tube (Nonel) initiation system was used for in-hole explosive initiation as well as surface hole-to-hole initiation. The burden and spacing values were 4.0 and 6.0 - 6.5 m respectively for blasthole depth of 9.0 m. Depending on the nature of the limestone strata, the explosive charge per hole varied from 45.0 to 52.0 kg. In case of 6 m hole depth, burden and spacing used were 4.0 m and 5.5 - 6.0 m respectively and the explosive charge per hole varied from 26.50 to 28.00 kg. The different working pits are surrounded by villages. Therefore, the total number of holes in a blasting round varied from only four to ten depend on the location of the villages from the blasting locations. Single column explosive charge was used in most of the cases. However, air decking using wooden spacers and solid decking with in-hole delay were also used to reduce ground vibration. Depend on the nature of the limestone strata, charge factor used varied from 0.18 to 0.25 kg/m^3 and the in-situ powder factor varied from 10.5 to 14.2 m^3/kg.

2.3 BLAST FRAGMENTATION ANALYSIS

The blast fragmentations obtained from different benches using different design patterns were analyzed using image analysis technique for the determination of mean fragment sizes. Fragalyst-4.0 software was used for obtaining fragment size distribution (Rosin-Rammler Distribution) and mean fragment size (K_{50}) of the blasted materials as shown in Figs.3 to 5. Depending on the layer thickness of limestone strata and charge factor used, the average fragment sizes (K50) varied from 0.08 to 0.42 m.

Fig.3 Image of the blast fragmentation obtained

3. Discussions and observations

The average layer thicknesses obtained at different blasting benches were correlated with mean fragment sizes, charge factors and powder factors as shown in Figs.6 to 8. Good correlations were obtained between layer thickness of limestone beds and mean fragment size, powder factor and charge factor. Powder factor of more than 14 t/kg was obtained for average layer thickness of less than 200 cm with mean

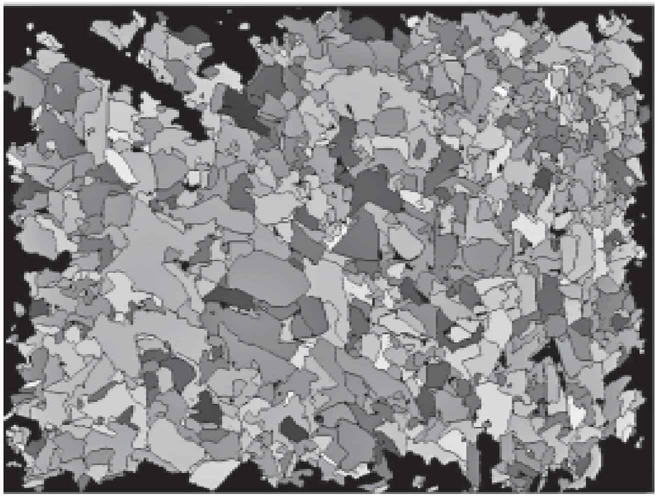


Fig.4 Segment of the rock fragments after the edge edition

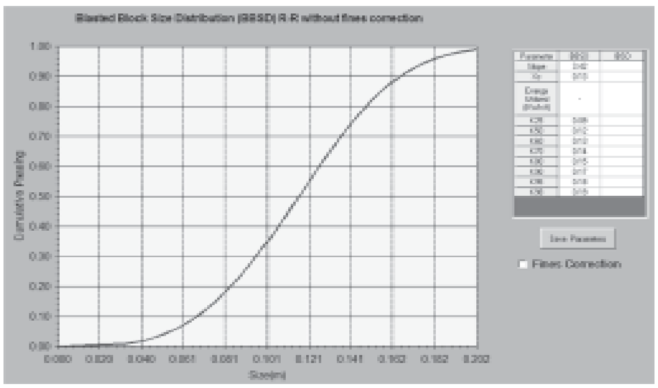


Fig.5 Fragment size distributions curve of the blasted muck

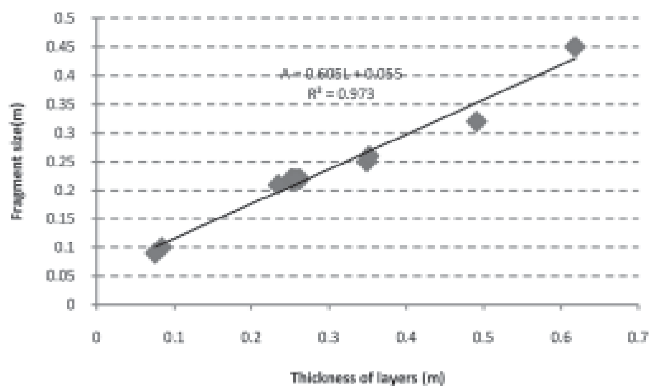


Fig.6 Plot of average layer thickness v/s mean fragment size

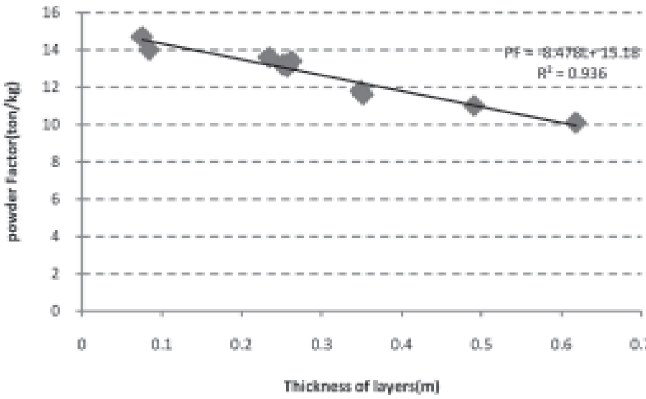


Fig.7 Plot of average layer thickness v/s powder factor in tonne/kg

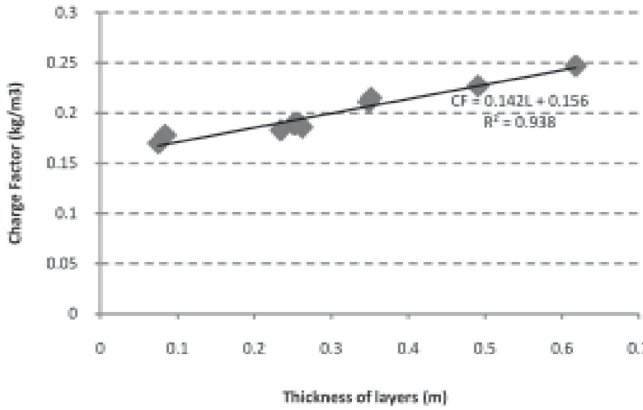


Fig.8 Plot of average layer thickness v/s charge factor in kg/m^3

Fig.9 Boulder formed with layer thickness of 35 cm and other joint spacing more than 1.5 m in top stemming column portion

fragment size of 0.1 to 0.2 m. As the deposits all along the mine are thinly laminated, the charge factor of 0.17 to 0.25 kg/ m^3 generally produces good blast fragmentation. Whenever the average layer thickness of limestone strata was more than 30 cm, higher charge factor was required to obtain finer degree of fragmentation.

Apart from the layer thickness of the bedding planes, other joint parameters and blast design parameters also play important role in blast fragmentation. It was observed that layer thickness of limestone bed less than 35 cm can result in boulder generation from the uncharged, top stemming column portion of a hole if joint spacing are more than 1.5 m and higher burden and spacing of drill hole pattern are used as shown in Fig.9. Oversize boulders were observed in the top bench portion where joints were filled with clay/soil and layer thickness of limestone beds were more than 35 cm.

4. Conclusions

The blast fragmentation was found to be strongly influenced by layer thickness of the beds irrespective of other joint parameters. The average layer thickness of limestone beds less than 200 cm required lesser charge factor for obtaining the desired fragmentation. Higher value of powder factor can also be achieved with lesser thickness of limestone beds. However, oversize boulders can be generated from the top stemming portion of a hole if other joints with opened or filled with clay/soil are present even when the thicknesses of limestone beds are 35 cm. It is difficult to eliminate boulder formations in the top, disturbed limestone strata. However, the formation of boulders can be reduced significantly with reduced drilling geometry and modified explosive charge.

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