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ESTIMATION OF ROCK FRAGMENTATION USING ELECTRONIC AND SHOCK TUBE DETONATORS IN LIMESTONE MINE BLASTING

R. K. Das and P. Y. Dhekne
Department of Mining Engineering, NIT, Raipur, India
E-Mail: pdhekne@nitrr.ac.in

ABSTRACT

Fragmentation has a considerable effect on the efficiency of the loading and transportation of the ore. If the fragmentation is coarse, then fragments are further required to be fragmented which involves extra time and cost. Research has proved that the rock fragmentation depends upon the delays introduced in a blast. Normally, shock tube detonators are used in Indian limestone mine blasting for providing the delay. Electronic detonators are also used in the Indian limestone mining industry, but their use is rather scanty. A little work in limestone mining is reported as regards to the assessment of the rock fragmentation distribution resulting from the blasts initiated using electronic detonators. In the present work, seven blasts have been monitored in a limestone mine to assess the effect of electronic and shock tube detonators on rock fragmentation. The blasts have been conducted in similar rockmass and with drill and blast parameters except the type of the detonators. Wipfrag image-analysis software has been used for the estimation of rock fragmentation in the muckpile. Results indicate that the blasts with electronic detonators yielded finer fragmentation than those with shock tube detonators. A reduction in oversize fragmentation in the blasts with electronic detonators can be attributed to an increased crack density, timely interference of the stress waves, and entry of gaseous products of blasting in the cracks generated in the rockmass. The result is corroborated by a reduction in the rock breaker operation time. The results indicate that the electronic detonators may pose a technical alternative to shock tube detonators in the investigated rockmass.

Keywords: rock fragmentation, shock tube detonators, electronic detonators, wipfrag.

1. INTRODUCTION

Minimization of oversize fragments is always one of the objectives in any production blasting. Oversize fragments adversely affect the efficiency of the downstream operations. Secondary breakage operation is required to be planned for handling such fragments. This operation involves the requirement of extra time and money. Sometimes, secondary blasting techniques are adopted for the breakage of such fragments. Such blasting has safety issues in addition to the issues of time and cost. It, therefore, becomes imperative that the percentage of oversize fragments in a muck pile must be as less as possible. Effect of delay detonators on rock fragmentation has been studied by many researchers (Katsabanis *et al.* 2006 and 2014, Johansson and Ouchterlony, 2013). Previously, electric delay blasting was being used in opencast mines. The electric detonators had some safety issues, especially during thunderstorms. This led to the development of Nonel systems for the detonation of the explosive charge. Earlier, detonating fuse in conjunction with cord relays were being used. But due to the problems faced during bottom initiation with detonating fuse and increased sound pressure level during blasting, shock tube detonators have become popular. Nevertheless, this system also uses the pyrotechnique delay elements that are used in electric delay detonators, also. In a pyrotechnic delay element, the heat-sensitive powder in delay element is ignited by heat. The delay element initiates primer charge and subsequently the base charge. Verma and Thote (2013) state that the delay time is governed by the powder composition, grain size, and loading density of the powder. Any variation in the powder constitution in the delay element changes the delay time causing a scatter in the delay time. Verma and Thote (2013) have also found that there is a scatter in the detonators having delay no from 3 to 6 and maximum number of detonators having delay no 5 and 6 exhibited considerable scatter. Winzer (1978) has also reported the scatter in delay detonators. Roy *et al.* 2016 found that the scatter in Nonel delay detonator is up to 45% depending upon the shelf life. Chiappetta *et al.* (1986) have found that the accuracy in delay time leads to control of ground vibration and airblast and an improvement in fragmentation. They also say that the measured delay times of delay detonators should be within a defined range of their nominal values to avoid overlapping possibilities and improved blast results. Many field trials have indicated that the implementation of proper delays has significantly improved the rock fragmentation (Mishra *et al*. 2017, Petropoulos *et al*. 2013, Yang *et al.* 2011,). This has prompted the advancement of delay detonators having precise delay and, in the process, electronic detonators have been developed. The electronic detonators are said to have a scatter as low as 1 Ms. Chiappetta *et al.* (1986) reported an improvement in fragmentation in several mines when the blasts are initiated by electronic detonators. It is said that the improvement in the scatter results in the firing of all the holes in-sequence (Stagg *et al.* 1989). The other reason is that a favourable interaction in stress waves takes place with an increase in initiating accuracy of detonators leading to an improvement in, rock fragmentation (Chiappetta *et al*., 1986, Liu and Katsabanis, 1995, Silva *et al.*, 2018). Sharma and Rai (2015) have reported a reduction in k_{50} size by nearly 25% when shock tube detonators were replaced by electronic detonators while blasting in strong garnet biotite sillimanite gneiss formations. Despite the advantages of the electronic detonators to improve upon the blast results, they have

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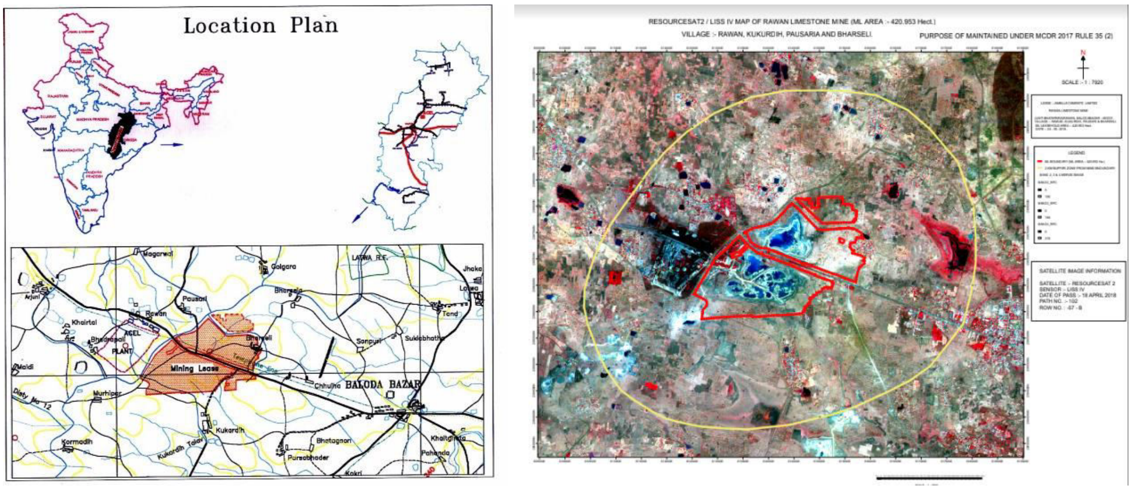
been sparsely used in the Indian limestone mines. The literature indicates that a little work is reported to quantify the benefits of electronic detonators on the rock fragmentation while blasting in limestone mines. This has been the motivation behind the present investigation.

2. SITE OF INVESTIGATION

The investigation has been conducted in Rawan limestone mine which is a captive mine of M/s Ambuja Cement Limited in Baloda Bazar district of Chhattisgarh province, India. The location detail of the mine and drone map are shown in Plate-1 (a) and (b).



(a) (b)

Plate-1. (a) Location details of Rawan limestone mine (b) Drone map.

The annual capacity of mine with all clearances in hand is 6.31 million tonnes of limestone. The mined ore is fed to the cement plant. The limestone deposit in the lease has a simple topography. The horizontal beds of limestone are mostly overlain by clay, murram etc. The thickness of the overburden is 5 m to 7 m. The limestone is fine-grained. There are two major joint sets on the property. The dip of the joints is more than 80^{O}. In addition to these joint sets, bedding joints are also observed in the deposit. The deposit is further crisscrossed by numerous fractures. The joint crevices in the top bench are filled with weathered breccias whereas they are found open in the lower benches. Water flow is not noticed in the deposit except during the rainy season. The mean geotechnical properties of the deposit, important for fragmentation, are given in Table-1.

Table-1. Mean geotechnical properties of the deposit.

Property	Mean
Uniaxial compressive strength, M Pa	42.99
Density, g/cc	2.40
Porosity, %	5.00
Young's modulus of elasticity, G Pa	49.14
Spacing between the vertical joints, m	1.50
Spacing between the horizontal joints, m	0.90

The mine is divided into two blocks viz. North and South blocks. There are four mineral benches in each of the blocks. The average height of the benches is 7.5 m. At present, there are four benches viz. 1^{st}, 2^{nd}, 3^{rd}, and 3^{rd} A. The 1^{st} bench comprises limestone boulders interlaced in clay and therefore rock fragmentation is erratic in the blasts carried out in this bench. 2^{nd}, 3^{rd} and 3^{rd} A benches comprise compact limestone. 3^{rd} A bench is submerged in water therefore production blasting is carried out only in 2^{nd} and 3^{rd} benches. Faces are so arranged that the strike of the joints is at angle of 50^{O} to the face. The layout of the mine is shown in Plate-2.

Plate-2. Layout of Rawan limestone mine.

The exploitation of limestone is done by conventional drilling and blasting technique. The blast holes are drilled by pneumatically operated drills. The blast holes have a diameter of 115 mm. Blast holes are normally drilled on a staggered pattern. The average burden and spacing are 3.00 m to 3.75 m and 4.00 m to 5.75 m, respectively. The blast holes are charged with Site-Mixed-Emulsion explosive. Charged holes are primed either by cartridge boosters or by cast boosters. The holes are normally fired by the shock tube detonators whereas the use of electronic detonators is sporadic. Hole to hole delay in the front row is 17 ms and every hole is connected diagonally to the hole in the next row with a delay of 42 ms. A down-the-hole delay of 400 ms is introduced in every hole. Loading of blasted limestone is carried out by hydraulic excavators of bucket capacity of 4.2 m^3 and 6.5 m^3 onto the dumpers of 55- ton capacity. The dumpers unload their contents into the crusher. The crusher is fitted with a grizzly having the openings of the size of 1.2 m. It is, therefore, necessary that the maximum percentage of the ore fragments must be less than 1.2 m so that the secondary breakage requirements are minimum. Any fragment having a size more than 1.2 m is considered as a boulder. The boulders are not loaded by the excavators and are left in the field for further fragmentation by the rock breaker.

3. MATERIALS AND METHODS

To investigate the effect of type of the detonator on rock fragmentation, seven blasts have been conducted in the faces of 2nd and 3rd benches of the mine. The main consideration behind the selection of the faces has been the regular frequency of the blasts and loading of the blasted ore. Moreover, the orientation of joints w.r.t. the face is also the same. This has ensured that the geotechnical properties of the rockmass under investigation are similar. Out of the seven blasts, four have been conducted with shock tube detonators whereas the remaining blasts have been conducted with electronic detonators. The holes have been charged with site mixed emulsion explosive. Blast holes have been primed with cast boosters. Blast design parameters and the explosive consumption have been noted from the blaster's report. However, sample checking of the same has been done in the field to verify the authenticity of the record. Hole-to-hole and row-to-row delays have also been maintained the same in all the blasts. In concluding, the size of the blast, the blast geometry, and the charging and firing parameters has been kept similar except the type of the detonator. Effects of geotechnical properties of the rockmass, blast design, and explosive parameters have been thus annulled. The firing circuit and the section of a blast hole are shown in Figure-1. The blast geometry and charging details of the blasts are presented in Table-2.

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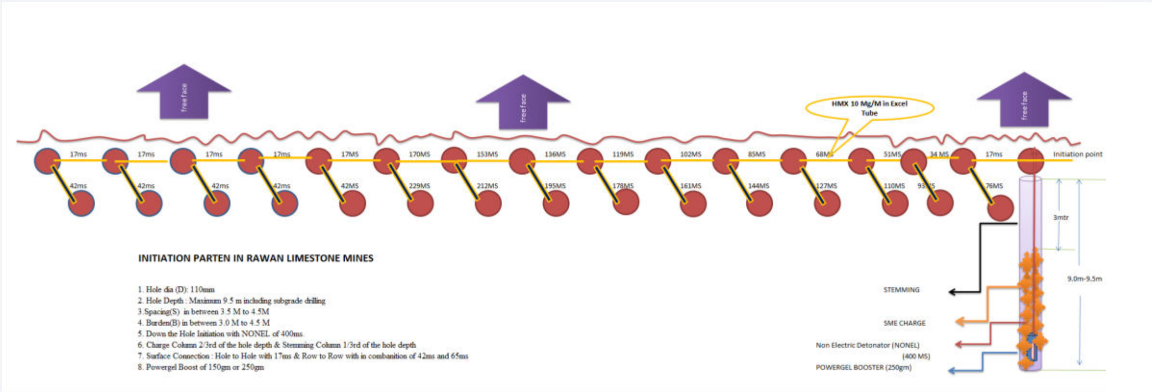

Figure-1. The firing circuit and the section of a blast hole.

Table-2. Blast geometry and the charging details of the blasts.

Location	Bench RL, m	D, m	*n*	*S*, m	*B*, m	*d, mm*	Type of the detonator	*C,* kg	*T*, m
NB III	249	7.7	33	4.0	3.5	115	Electronic	54	3.2
NB III	249	7.0	38	4.0	3.5	115	Electronic	45	2.7
NB II	258	7.0	42	4.0	3.5	115	Electronic	45	2.7
NB III	249	7.7	37	4.0	3.5	115	Shock tube	54	3.2
NB III	249	7.0	37	4.0	3.5	115	Shock tube	45	2.7
NB II	258	7.0	36	4.0	3.5	115	Shock tube	45	2.7
NB II	258	6.5	43	4.0	3.5	115	Shock tube	46	2.4

Where Location denotes the section in a bench and the bench is designated in roman numeral, D is the average depth of the holes, n is the number of holes in a blast, S is average spacing, B is the average burden, d is blast hole diameter, C is the column charge, T is average stemming column,.

Plate-3 (a) and (b) shows the charging of the holes and the electronic detonators used in the blasts.

(a) (b)

Plate-3. (a) Charging of blast holes; (b) Electronic detonator.

Literature mentions a number of methods for the fragmentation analysis. Out of these methods, sieve analysis and the image analysis software are widely used for fragmentation analysis for the research purpose. Although sieve analysis is the most accurate method, it suffers from the disadvantage of non-feasibility in the fragmentation analysis of the muckpile of a normal production blast. The image analysis software gives the fragmentation analysis report with sufficient accuracy. Hence, in the present investigation Wipfrag image analysis software has been used for the fragmentation analysis of the muckpile. The image processing using image analysis software is quick, does not disrupt production, inexpensive and fast and has less significant sampling errors (Maerz *et al.*, 1996). A digital camera was used to capture the image such that every fragment was clearly visible in the photograph. Every section of the muckpile has been photographed using two scaling objects of 2.3 m length as

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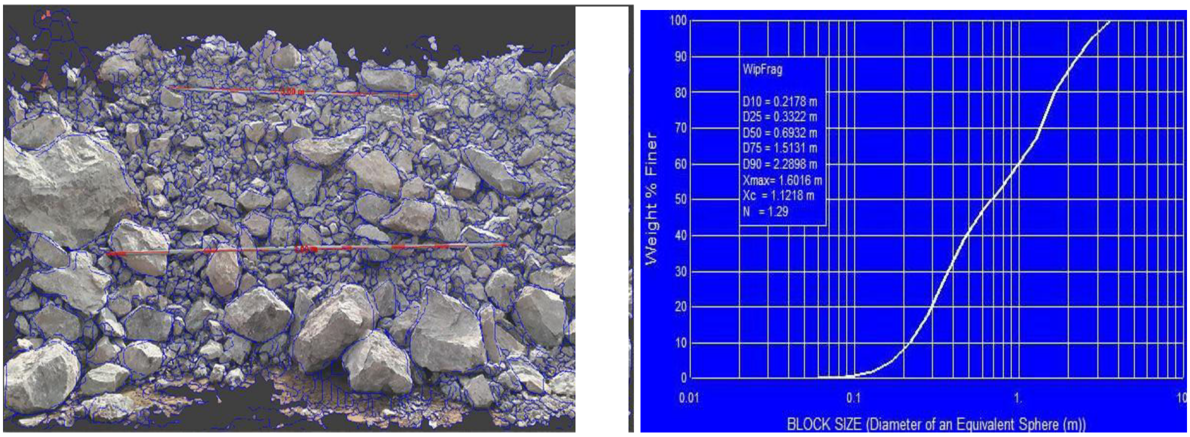
the line of sight is not perpendicular to the muckpile surface. Care has been taken that every part of the muckpile is covered during photography. It has also been ensured that digital images are having good clarity. After capturing the digital images of the muckpile surface, the loading commenced across the length of the muckpile. After 40% of the loading of the muckpile, the loader has been pulled out of the face and the fresh surface of the muckpile has been photographed. The procedure has been repeated after 80 % of the loading. The total number of digital images captured from a muckpile is around 25. The muckpile generated in all the seven blasts has been photographed by adopting this procedure. Each of the photographs has been analyzed for the estimation of fragmentation distribution. The fragmentation analysis reports of all the photographs of a muckpile have been merged to arrive at an overall fragmentation distribution in the muckpile. A muckpile where are the fragments are delineated for further processing in the software and the fragmentation distribution obtained from the software are shown in Figure-2 (a) and (b) respectively.



(a) (b)

Figure-2. (a) Delineated fragments in a muckpile (b) Software output.

During the loading, the encountered boulders are kept aside for their further breakage by the rock breaker. After the loading is over, the rock breaker is pressed into the service of breakage of the boulders and the time taken by the rock breaker to break all the boulders in a blast has been recorded to cross-check the results of fragmentation distribution obtained after analysis through the software.

4. RESULTS AND DISCUSSIONS

Photographs of the muckpile resulting from the blasts have been analyzed using the Wipfrag software. The results of the fragmentation analysis and the time required for the rock breaker operations are presented in Table-3. The blasts from Sr. No. 1 to 3 have been carried out with electronic detonators whereas the blasts from Sr. No. 4 to 7 have been carried out with shock tube detonators.

Table-3. Analysis of fragmentation and rock breaker operation time in each blast.

S. No.	D10, m	D25, m	D50, m	D75, m	D90, m	Uniformity Index	Rock breaker operation time, min
1	0.1223	0.1854	0.3079	0.6011	1.0424	1.33	45
2	0.1139	0.1863	0.3544	0.6962	1.1091	1.41	48
3	0.1109	0.1810	0.3523	0.7430	1.5275	1.38	62
4	0.2230	0.3382	0.6494	1.4883	2.7388	1.29	90
5	0.2364	0.3731	0.6748	1.3717	2.1321	1.32	78
6	0.2178	0.3322	0.6932	1.5131	2.2898	1.29	82
7	0.2497	0.3862	0.6810	1.3328	2.1234	1.36	80

The mean D10, D25, D50, D75 and D90 sizes and uniformity index of the blasts are given in Table-4.

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Table-4. Mean D10, D25, D50, D75 and D90 sizes and uniformity index of the blasts.

S. No.	Type of the detonator	D10	D25	D50	D75	D90	Uniformity Index
1	Electronic	0.1157	0.1842	0.3382	0.6801	1.2263	1.37
2	Shock-tube	0.2317	0.3574	0.6746	1.4265	2.3210	1.31

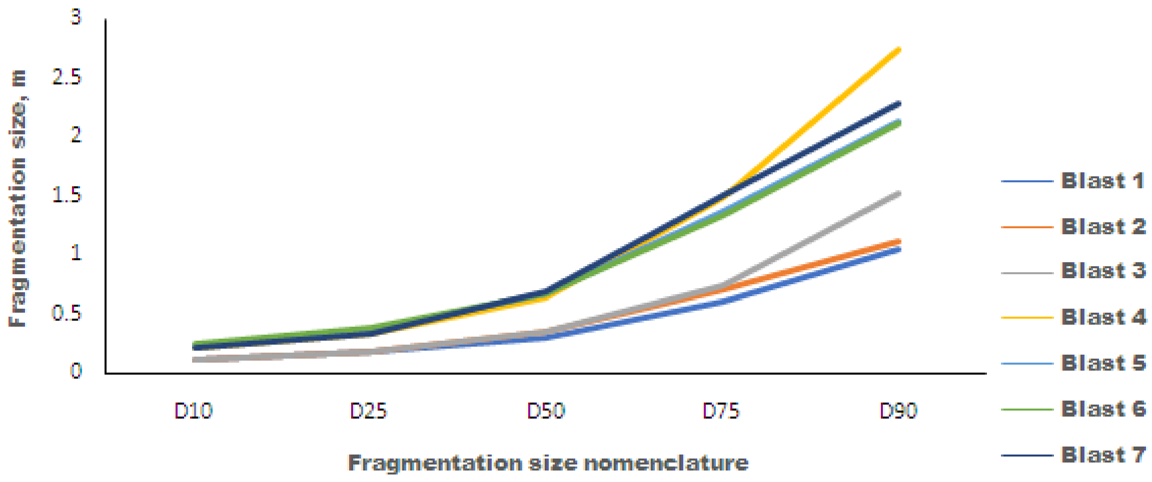

Fig 3 Fragmentation sizes for various blasts (Blast no. 1-3 have been conducted using electronic detonators and Blast no. 4-7 have been conducted using shock tube detonators

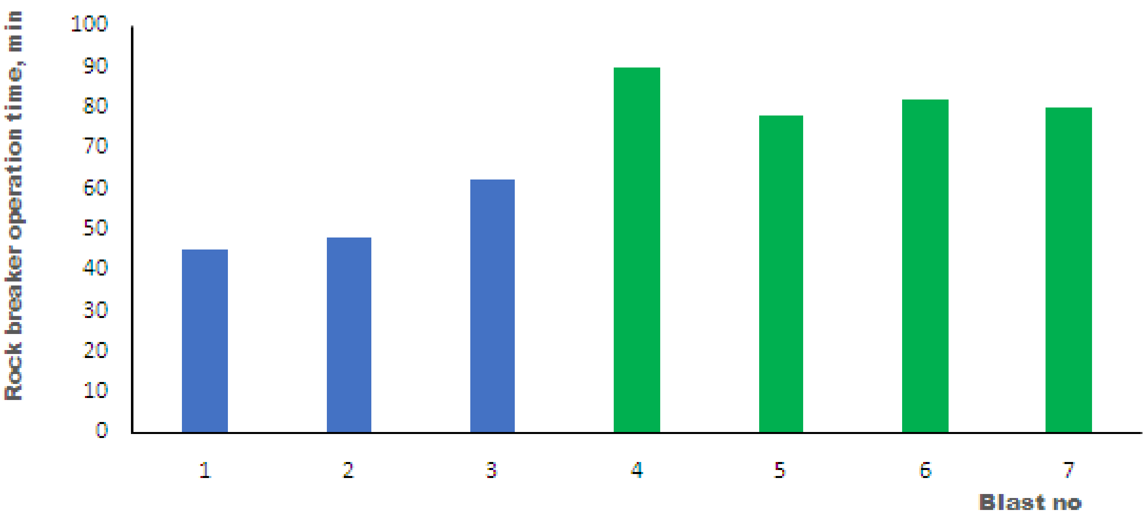

Fig 4 Rock breaker operation time in respect of various blasts (Blast no. 1-3 have been conducted using electronic detonators and Blast no. 4-7 have been conducted using shock tube detonators

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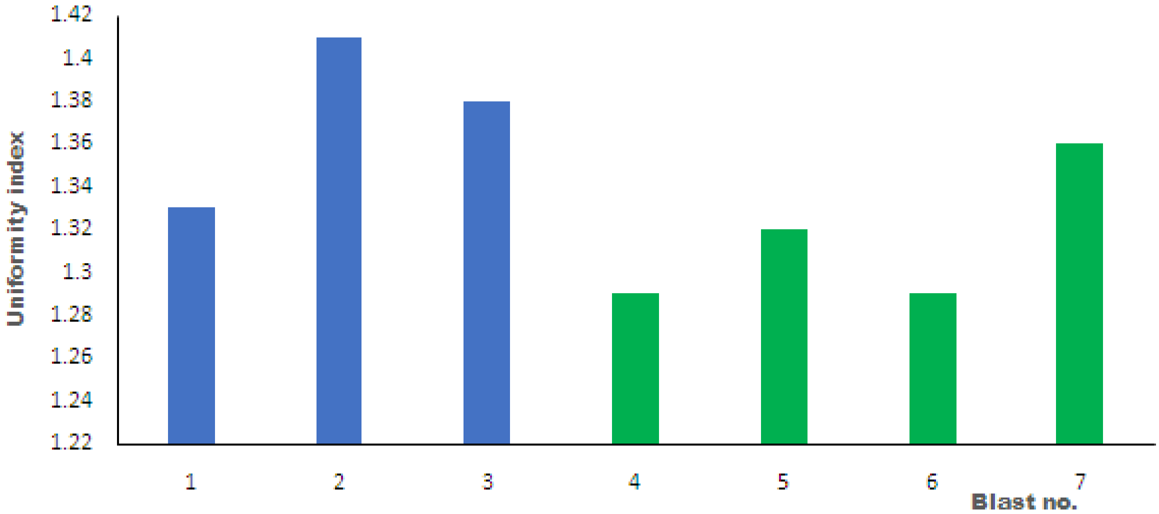

Fig 5 Uniformity index of the muckpiles resulting from various blasts (Blast no. 1-3 have been conducted with electronic detonators and Blast no. 4-7 have been conducted with shock tube detonators)

It is evident from the Tables 3 and 4 and Figures 3, 4, and 5 that:

a) The sizes viz. D10, D25, D50, D75 and D90 in the blasts using electronic detonators are similar in all such blasts. The same trend is observed in the blasts using shock tube detonators.

b) The mean D10, D25, D50, D75, and D90 sizes in the blasts with electronic detonators are around 50% smaller than those with shock tube detonators.

c) It is further evident that in the blasts carried out with shock tube detonators, more than 25% (by weight) of the muckpile is oversize whereas, in the blasts with electronic detonators, this percentage is around 10%.

d) It is also observed that rock breaker operating time is more in the blasts with shock tube detonators than in those with electronic detonators. The increase in the time indicates that the number of boulders has increased in the muckpile resulting from blasts with shock tube detonators.

e) A high value of uniformity index in case of blasts with electronic detonators vis-a-vis those with shock tube detonators indicates that fragmentation is more uniform in the former case than in the latter case. With the application of electronic detonators, the improvement in the mean uniformity index is around 5%.

When an explosive charge is detonated, a shock wave is radiated along with the gaseous products. The propagation velocity of the shock wave produced at the moment of the detonation of the explosive is considerably more than the speed at which the gaseous products expand. This causes the shock wave to act on the surface of the blast hole before the gaseous products could exert the pressure thereon. The action of the shock wave on the walls of the blast holes creates a stress wave which exerts a compressive stress. The stress wave causes the compressive failure of the surrounding rock leading to the generation of exceptionally fine ore therefrom. The wave after causing the compressive failure proceeds further in the rockmass. As the distance travelled by the wave increases, the wave attenuates due to the dissipation of its energy. As a result, tensile failure takes place at fractures, joints, and other weak planes since the wave does not have sufficient energy to cause the compressive failure. However, when the wave encounters a free face, it gets reflected. The reflected wave causes the spalling at the bench face. Gaseous products from the detonation of the explosive enter the radial fractures generated by the wave and expand them thereby breaking the rock. These fragments are displaced at a remarkably high speed and their mid-air collision takes place thereby further fragmenting them. The majority of the fragment size distribution depends upon the crack density in the zone of tensile failure and the in-flight collisions of the fragments. The crack density in the zone of tensile failure, in turn, depends upon the energy of the stress wave reaching thereat whereas the in-flight collisions depend upon the appropriateness of the burden relief and the timely entry of the gaseous products in the cracks. Hongxian *et al*. (2013) have reported that the P wave velocity reduces up to 36 % in the blasts conducted with shock tube detonators whereas the reduction was up to 18 % in the blasts conducted with electronic detonators. This implies that the stress waves have more energy to develop more cracks in the blasts with electronic detonator than those generated from the blasts with shock tube detonators. Therefore, the fragmentation is finer in the blasts conducted with electronic detonators than those conducted with shock tube detonators. Moreover, down-the-hole (DTH) delay of 400 ms has been used in the blasts with shock tube detonators.

The shock tube detonator introduces uncertainty of around 10% in the scatter (Persson *et al*., 1994) causing a scatter of ± 40 ms in DTH. The scatter causes the explosive charge in the adjacent holes to detonate either in close succession or asynchronously thereby adversely affecting the rock fragmentation (Liu and Katsabanis, 1997). The reason behind the adverse effect on the fragmentation is an inappropriate burden relief with minimum opportunities for in-flight collisions caused by the premature release of the gas pressure in the cracks and crevices already present in the rockmass. Large fragments are therefore not broken down and it is observed that size at D75 and beyond increases tremendously in the blasts with shock tube detonators. This has resulted in the generation of gigantic boulders being handled by rock breaker. The electronic detonators exhibit a scatter not more than 1 ms in the delay. This improves upon the precision in the detonation time thereby ensuring a proper burden relief, improved in-flight collisions as well as the timely entry of the gaseous products the cracks induced by the stress waves. The difference in the generation of boulders in two types of the blast is corroborated by the rock breaker operation time.

5. CONCLUSIONS

Seven blasts have been monitored in Rawan limestone mine for the assessment of the effect of electronic and shock tube detonators on rock fragmentation. The digital photographs of the muck pile have been analyzed using Wipfrag image analysis software. The results indicate that fragmentation is finer in the blasts detonated with electronic detonators than those with shock tube detonators because the precision in detonation time resulted in an improvement in the utilisation of explosive energy. This slashes the requirement of secondary breakage operations which is indicated by the rock breaker operation time. This finding is in consonance to the reported research findings. Reduction in boulders resulting from the blasts initiated with electronic detonators obviously enhances the efficiency of the downstream operations. It can, therefore, be concluded that the application of electronic detonators for blasting exhibited an advantage in the oversize fragmentation distribution in the given geotechnical set-up.

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