Quality Assurance in Construction Blasting

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Abstract

Rapid urbanisation, scarcity of energy and higher growth rate in the country such as India has necessitated creation of large underground spaces for development of transport system, hydroelectric power projects, and nuclear repositories etc. leading to heightened construction activities. In India, in most of the construction projects, excavation is carried out using conventional drilling and blasting method due to it's distinguished advantage of being cheaper, flexible than mechanical excavation techniques such as TBM, Reapers, Road headers and it requires initial low capital investment.

The installed production capacity of explosive and accessories is more than the demand in India leading to a fierce competitive market. Absence of regulatory bodies such as DGMS for mining industry and poor awareness about the application techniques of explosives and accessories amongst construction engineers has earned bad reputation to the blasting in the construction industry. Monitoring of the supply of explosive and accessories at site, greater level of training to construction engineers about blasting techniques, its environmental effects and impact on surrounding structures will lead to improved public acceptance and reduced adverse effect of the construction blasting operations.

A study was conducted to evaluate impact of shelf life of explosive cartridges since date of manufacturing, in velocity of detonation (VOD), density and continuity of detonation (COD) in blast performance. Deterioration in all such performance parameters are reflected in number of misfires, length of pull, fragmentation, fumes in underground environment etc. It is found that ageing deteriorates all the performance parameters. It is observed that VOD reduces to 15% after two month and more than 30% after four months of shelf life. The density of explosive also approaches out of the range values (0.8 gm/cc -1.25 gm/cc) with shelf life beyond two months. Large variation in density values from the above suggested range may lead to misfire and less pull.

In case of detonators, delay time scatter is important parameter and higher scatter adversely affect the overall blast results. The lesser pull, increased vibration intensity and strata and roof control problem can be accounted to scatter in delay time of the detonators. An experiment was conducted with millisecond delay detonator series 0 to 6 to evaluate the scatter in delay time of the supplied detonators. All together 700 detonators, 100 detonators from each series 0 to 6 was measured using dual channel oscilloscope.

In study of the delay time scatter it was observed that problem of delay time scatter is more pronounced with increasing delay time on account of manufacturing capability and also inherent scatter in pyrotechnic composition. Standard deviation in case of delay series 0 is found to be 0.82 and 6.83 in case of delay series 6. The deviation from the nominal delay time is in both higher as well as lower series of the detonators. As the delay time increases, more number of the detonators in a series recorded delay time out side their nominal range. In this experiment, 28% of the measured detonator in case of delay series 0 recorded values out side their nominal range and 86% in case of delay series 6. All the delay series has recorded values out their declared nominal average delay time except delay series 1. Surprisingly, all the detonators of delay series 1 recorded values with in the nominal range.

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It is evident from the graphical and statistical analysis that the measured delay time for the each delay detonator is higher than their declared nominal value. Further, none of the detonator in any of the delay period recorded deviation in the negative direction.

Although, significant number of detonators particularly of delay no. 4 to 6 were found to be having their delay time more than the declared nominal range, highest overlapping possibilities between two consecutive delays were observed with delay period 5 & 6 detonators. Winzer index also corroborates the highest overlapping possibility between delay period 5 & 6. The index is found to be 3.56, being very close to value 3, the threshold value for overlapping between any two periods. Therefore, evaluation of permitted detonators with respect to their delay accuracy shall be made mandatory before granting approval for use underground coal mines to eliminate danger of firedamp or coal dust explosion in underground coal mines.

It reveals from the above that in addition to the blast geometry, monitoring on the explosive and accessories supply at site by the user industry will improve blast performance and as well as public acceptance. Damage inflicted to the surrounding rock mass can also be reduced. The full length paper will cover in details of various experiments carried out on quality check at site, their results and also proposes a mechanism for quality check of explosive supply at site.

Introduction

Most of the excavation from underground works in India is obtained using explosives due to its advantages such as low capital requirement, flexibile system suiting to all types of rock mass conditions. The trend is likely to continue in near future, as mechanical cutting has not taken off to the extent anticipated. More efficient and safer explosive system with stricter quality control concepts and efficient application techniques are to be adopted from strategic point of view for augmenting production and productivity from underground works. Periodic check of the quality and performance of the explosives of different manufacturers collected from the users' magazines may serve as a useful mechanism towards ensuring safety and quality of such products.

Explosives being dangerous materials, minimum safety standards should be maintained as stipulated by statutory governmental organisations like BIS, CCE, DGMS, etc. and at the same time, performance characteristics of the explosives should also match the requirements of user industry. Availability of large number of explosive manufacturers in the country and various types of explosives provide flexibility in the selection of the explosives to suit various blasting applications. However, efficiency of blasting depends upon perfect quality assurance of the explosive materials used. Periodic check of quality and performance of the explosives of different manufacturers collected from the users' magazines may serve as a useful mechanism towards ensuring safety and quality of such products and has been adopted by most of the user industries in the recent past.

Quality control in performance parameters

Many researchers, scientists and academicians propose Air Gap Sensitivity (AGS), Velocity of Detonation (VOD), Cap Sensitivity and Density as the four important parameters with regard to quality of explosives. All together these four parameters help in qualitative assessment of other important performance parameter such as energy and strength. AGS of an explosive assesses its ability to transmit detonation successfully from primed cartridges to subsequent cartridges, with likely inadvertent gap between them. It is used as a control test for small diameter permitted explosives (Roy et al., 2002). Explosive samples having minimum prescribed AGS values are good enough to give satisfactory blasting performance and reduces chances of misfire during actual usage in field.

VOD is a measure of rate of release of explosive energy and detonation pressure. A reduction in the VOD will produce a corresponding reduction in the detonation pressure and availability of the shock energy of the explosive. VOD of an explosive therefore can be used as an indictor of its performance. Explosives should have VOD values within their declared range for their assured quality and consistency in the performance. Emulsion explosive usually possesses higher VOD values in comparison to NG based explosive due to very high surface contact areas between oxidiser and fuel phase in it.

Density of an explosive too is an important parameter for ascertaining the quality of explosive samples. Explosives should have density values within their declared ranges for stable detonation and optimum performance. Cap sensitivity of an explosive assesses its optimum sensitivity for complete detonation of the primed cartridge which otherwise could lead to misfires during blasting operation, threatening the safety of the personnel involved in it. Permitted explosives should be cap sensitive to approved permitted detonators only.

As all the quality parameters could not be assessed in a single test, it is important to choose some key parameters, which in turn could assess the factors governing performance of explosives in the actual field conditions. Moreover, the test chosen for ascertaining quality shall be easy to conduct in the field and needs little infrastructure. However, it is to the user industries to identify the problem area in the their blasting operation such as number of misfire cases, boulder formations, less pull and accordingly choosing the parameters to be evaluated as a part of periodic quality check.

Selection of explosive sample and its quantity is an important part of the whole quality ascertaining mechanism. The samples selected shall always be representative of the actual usage pattern of the consumer. Moreover efforts shall be made to cover samples of different manufactures from different area magazines commensurate to the proportion of the total consumption.

Although permitted explosive is not meant for use in construction blasting, the concept of ascertaining quality mechanism may be borrowed to the construction blasting industry. A case study of permitted explosives conducted in Singareni Collieries Co. Ltd, Kothagudem coal mines is described in following section. This paper presents a case study of 47 nos. of explosive samples comprising of 15 numbers of P_l and 32 numbers of P_5 explosive. Explosive samples have been encoded as A, B, C and D to maintain privacy of the sample and its manufacturer. Whereas sample A & B are emulsion explosives, samples C & D are NG based explosives. In this study all 12 numbers of Sample A, 26 numbers of sample B, 6 numbers of sample C and 3 numbers of sample D are covered (CIMFR, 2003).

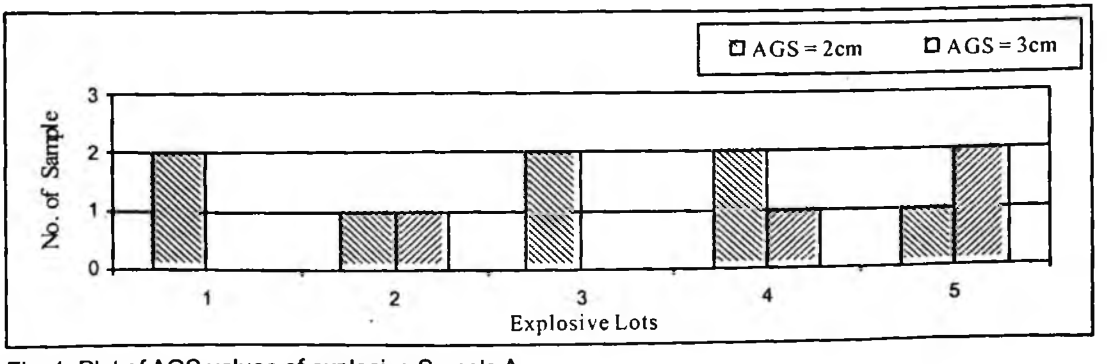

Fig. 1: Plot of AGS values of explosive Sample A

Results of various tests performed on the samples under study with respect to AGS, VOD, Density and Cap sensitivity and delay time are given below.

a) Air Gap Sensitivity (AGS)

Lot-wise air gap sensitivity values of sample A are shown in Fig. 1. In case of sample A (P_1 type), all samples met 2 cm air gap sensitivity criterion under Full Cartridge (SS) Test conditions (IS: 6609). Fig. 1 shows that whereas most of the explosive sample A covered in the first lots were having only 2cm AGS value, in subsequent lots approx. 40% (four nos.) of the sample possessed 3cm air gap sensitivity. Thus, with subsequent lot of explosive samples, AGS values improved.

All the twenty six samples of explosive B were found to possess minimum 2 cm air in full cartridges test conditions excepting six samples, four samples in 1st lot and two samples in 5th lot. These six samples could meet 2 cm AGS in Cut Face Test conditions only. Figure 2 shows plot of AGS values of explosive Sample B. Plot shows that the AGS values of samples improved in subsequent lots.

Air gap sensitivity values of NG-based explosive samples C & D were found to be substantially higher than the minimum requirement of 5 cm. Figure 3 shows the plot of air gap sensitivity of NG-based explosive sample C & D. Whereas, AGS values of these samples covered in the first two lots varied from 7 to 11 cm, in the subsequent lots values improved to more than 15 cm. Two of the three samples of explosive C evaluated in 4th & 5th lots were having 20 cm AGS value. An obvious trend as depicted from the figure is shift in central tendency of the AGS values towards the higher side with the subsequent lots.

b) Velocity of Detonation (VOD)

VOD values of the sample A varied from 3382 m/s to 4077 m/s compared to their declared range of 3500 ± 400 m/s. As shown in figure 4, ten out of twelve sample of explosive A were found to have VOD values above declared nominal average value of 3500 m/s

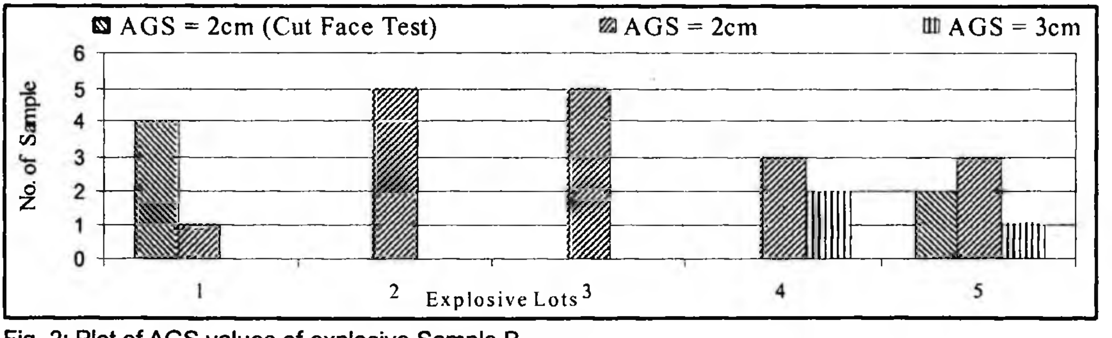

Fig. 2: Plot of AGS values of explosive Sample B

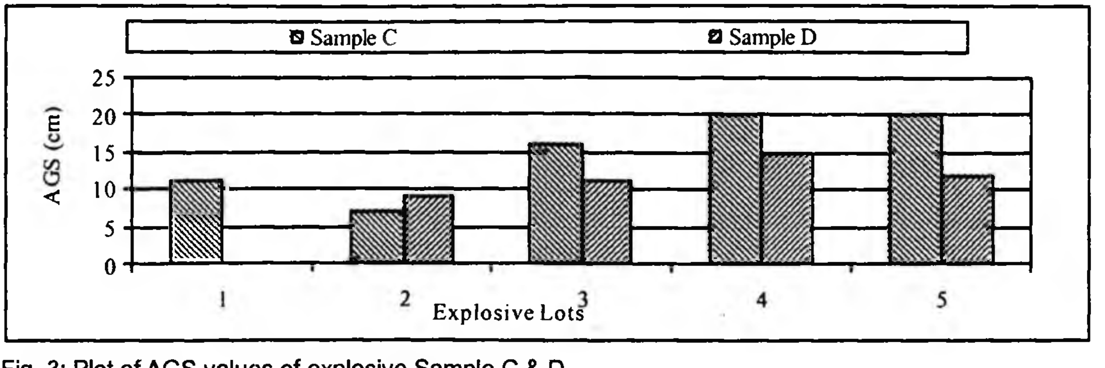

Fig. 3: Plot of AGS values of explosive Sample C & D

with three of them even higher than the declared upper limit of 3900 m/s. Moreover, average VOD values of sample A studied in subsequent lots were higher than that of two samples covered in the initial lots.

VOD values within declared ranges. Samples having VOD values lower than their declared ranges were encountered only in the first two lots. Improvement was noticed from third lot onwards and fifteen out of sixteen samples

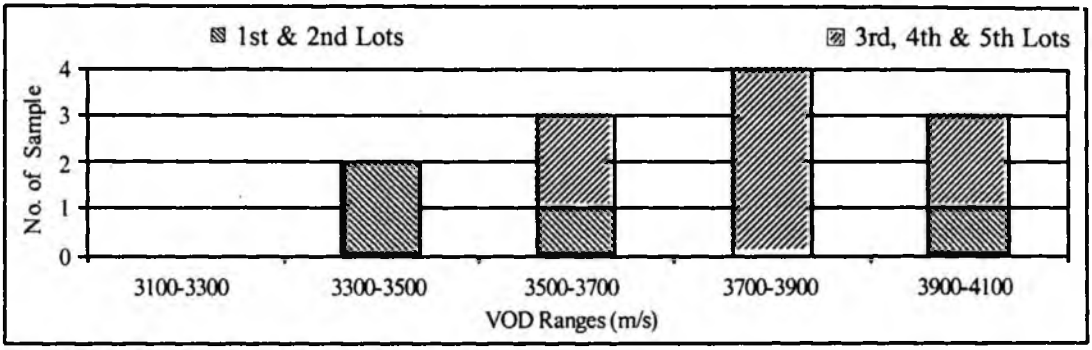

Fig. 4: Plot of VOD values of explosive Sample A

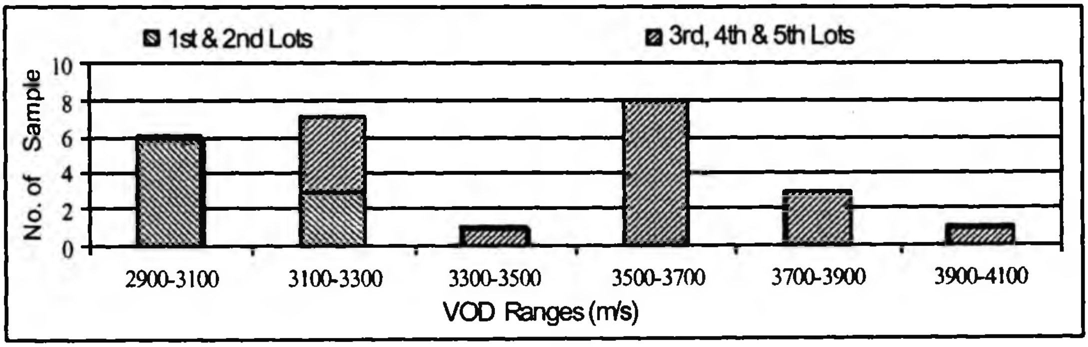

Fig. 5: Plot of VOD values of explosive Sample B

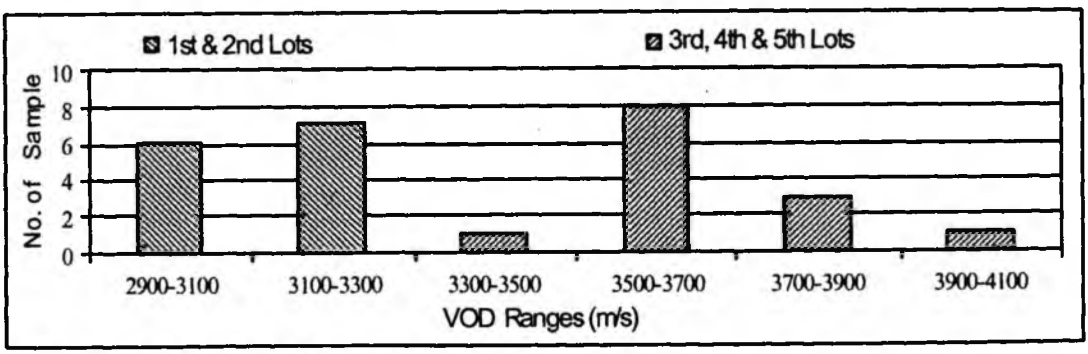

Fig. 6: Plot of VOD values of explosive sample C

Figure 5 is a plot of VOD values of explosive sample B. VOD values of sample B varied over a wide range of 2902 m/s to 4110 m/s compared to their declared range of 3500 ± 400 m/s. It is obvious from figure that nineteen out of twenty six B samples were having their recorded VOD values within their declared ranges. One sample tested during 4th lot was found to have VOD value of 4110 m/s which is higher than their declared range and may be considered to be better to achieve overall average blasting results.

Figure 6 shows plot of VOD values of explosives sample C. As shown in the figure 6, VOD values of all six samples of explosive C were found to be higher than their declared nominal average of 2100 m/s. Overall average VOD value of all the samples is 2361 m/s. Similarly, average VOD values of all three samples of explosives D were measured to be 2418 m/s which are within the declared range of 2110 - 2500 m/s but towards the upper limit. Usually higher VOD values of NG-based explosives were associated with their higher AGS values. Improvement towards the upper limit of VOD was observed with the subsequent lots of the samples.

c) Density

Density values of sample A is shown graphically in Figure 7. It shows that all samples of explosive A were having density values within their declared range of 1.15 ± 0.08 g/cc (ranging between 1.07 to 1.23 g/cc). Average density value of explosive A is calculated to be 1.125 g/cc which is close to its declared nominal average value of 1.15 g/cc. It is quite clear from the plot that the consistence and within the range density values are found in last two lots showing stricter quality control at the manufacturing end.

Figure 8 shows plot of density values of all the twenty six samples of explosive B. Density values of explosive B were found to be varying between 1.122 to 1.236 g/cc which is well within their declared range of 1.20 ± 0.08. From the figure, it is also evident that the average density value of sample B evaluated in five different lots has gradually improved towards their declared nominal average value of 1.20 g/cc, which is an indication of improvement in the quality of explosive sample.

Density values of five out of six samples of explosive C were found to be varying between 1.204 to 1.235 g/cc which are close to its declared value of 1.20 g/cc. One sample of explosive C covered in the first lot was found to be having higher density of 1.347 g/cc. Density values of 1.138, 1.077 and 1.170 g/

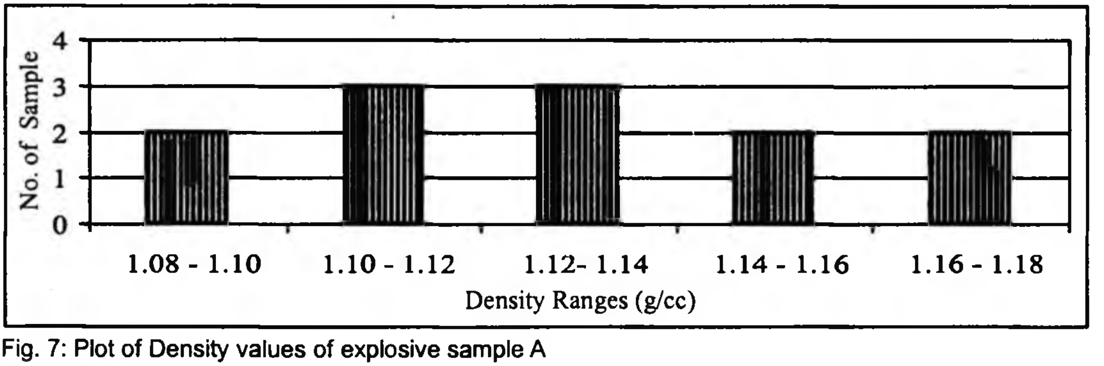

Fig. 7: Plot of Density values of explosive sample A

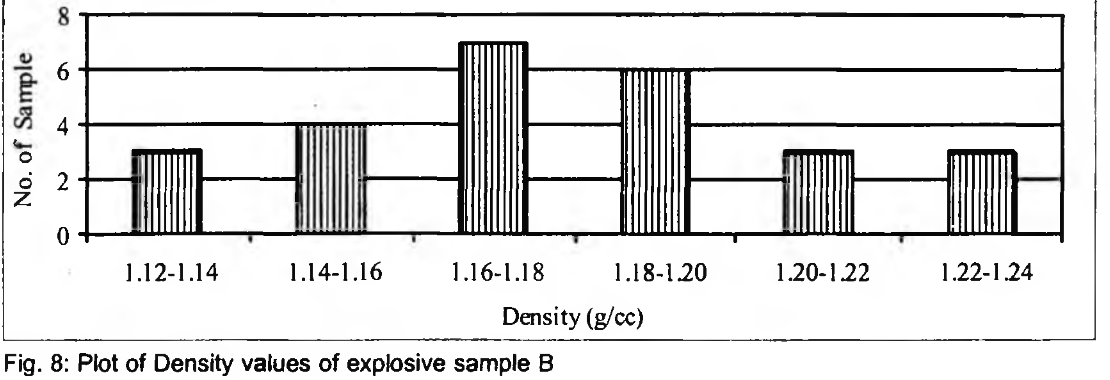

Fig. 8: Plot of Density values of explosive sample B

cc of sample D of 2nd, 3rd & 4th lots indicate that only one out of three samples were found to be within their declared range of 1.05 ± 0.05 g/cc, the other two values being higher than the declared range.

d) Cap Sensitivity

All samples of permitted explosives under the study have exhibited satisfactory cap sensitivity in all the trials. Satisfactory cap sensitivity is also corroborated in all trials for air gap sensitivity and velocity of detonation without exhibiting any misfire of primed cartridges.

e) Delay Time Accuracy in Pyrotechnic Detonator

In order to assess delay accuracy of permitted detonators of a domestic manufacturer, randomly selected hundred units from each delay period (0 to 6) from the same batch of detonators that were found suitable for use in underground coal mines in respect of their incendivity, handling & electrical safety, performance and water resistance characteristics were evaluated. Overlapping possibilities amongst delay periods were evaluated by calculating Winzer index and graphical methods (Verma and Roy, 2003). Table 1 summarises maximum, minimum, nominal and average value of measured delay time with standard deviation for each delay period.

It is evident from the graphical and statistical analysis of measured delay timing of these detonators as given in Figure 9 and 10 & Table -1 respectively that the measured delay time of all delay detonators are higher than their respective nominal value. There is no deviation in the negative side of delay timing in any delay period. The delay timing of significant number of delay detonators (particularly of delay no. 4 to 6) are found to be out side the declared range. Measured average value of delay time for each delay detonators is plotted against respective nominal average declared delay time and is shown in Fig. 9. It is found that for all delay detonators (delay no. 0-6) the measured average value of delay time is higher than that of the nominal declared value.

The findings reveal that significant scattering exist in all the delay periods. Scattering increases with higher delay periods. Overlapping possibilities between delay period 5 and 6 is found to be significantly high. Winzer index (Winzer, 1978) for the pair of delay period 5 & 6 is found to be very close to the threshold value for overlapping (Fig. 10).

Conclusions

1. The study was conducted on 47 nos. of explosive samples. Air gap sensitivity (AGS), Velocity of detonation (VOD), Density and Cap sensitivity are the four parameters chosen for evaluation with regard to the quality and performance of all the samples. These tests were carried out in the light of relevant recommendations and guidelines of statutory bodies.

Table 1: Results of statistical analysis of measured delay time

Delay no.	Nominal declared delay interval (ms)	Statistical analysis of measured delay timing				No. of detonators outside the nominal declared range
		Minimum (ms)	Maximum (ms)	Average (ms)	Std. Deviation	
0	5-8	4.0	8.2	5.63	0.82	Nil
1	25 ± 10	26	33.2	29.75	1.92	Nil
2	50 ± 10	50.8	68.8	56.88	3.87	8
3	75 ± 10	75.2	93.6	80.95	3.88	6
4	100 ± 10	100.8	120.0	113.17	3.78	37
5	125 ± 10	128	154.0	137.38	4.57	37
6	150 ± 10	152	188.0	166.65	6.83	43

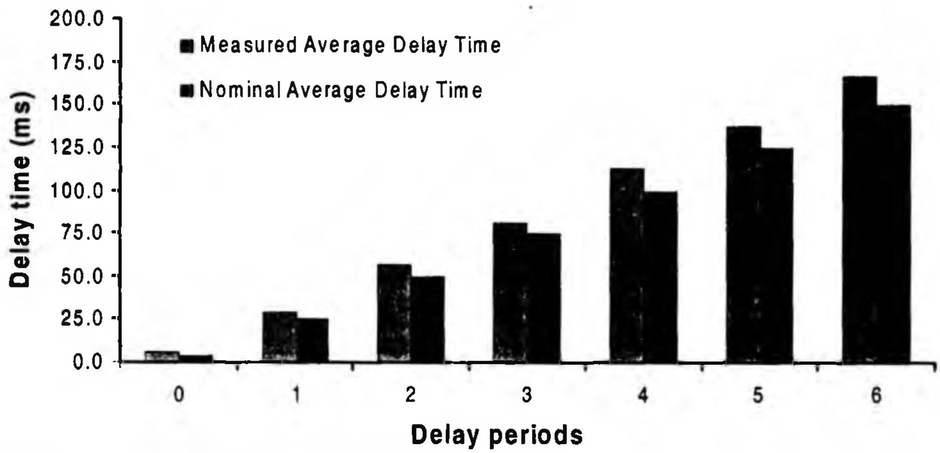

Fig. 9: Comparison of measured and nominal average delay time

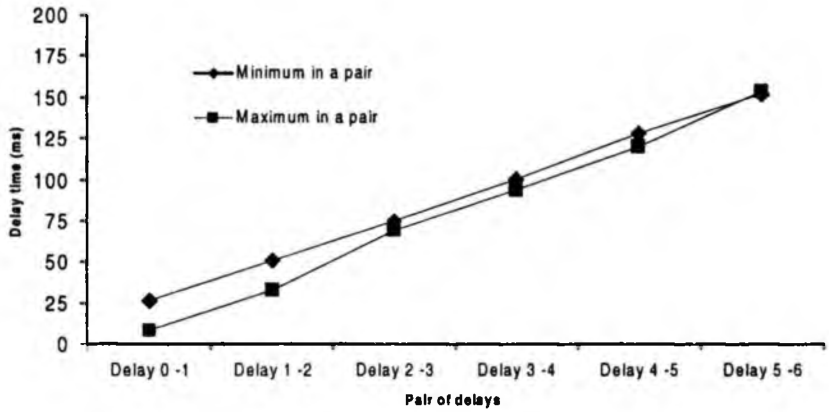

Fig. 5: Plot for overlapping possibility between two consecutive delays

2. In general all samples recorded improvement in AGS in subsequent lots. Emulsion explosive sample A and B improved the AGS values to 3 cm in the last two lots. NG based samples C and D recorded 20 cm of AGS by the end of the study.
3. It is observed that with the progress of study with successive lots VOD values started reaching the declared ranges and the quantum of samples falling within the range increased.
4. Density values of all the samples have gradually improved towards their declared nominal average value excepting for one sample of explosive C tested in first lot. Two out of three samples of explosive D were found to have their density value higher than their declared range. With regards to cap sensitivity, all the samples of permitted explosives were found to be performing satisfactorily.
5. It is evident from the graphical and statistical analysis that the measured delay time for the each delay detonator is higher than their declared nominal value. Further, none of the detonator in any of the delay period recorded deviation in the negative direction.
6. Winzer index also corroborates the highest overlapping possibility between delay period 5 & 6. The index is found to be 3.56, being very close to value 3, the

threshold value for overlapping between any two periods

7. Periodic check tests for ascertaining quality of explosives very ably send message to different manufacturers to promptly adopt appropriate quality control measures during manufacturing process and supply only explosive materials of assured quality. Improvement in quality samples is evident by the observed improvement in their VOD, AGS and Density values. Such explosive materials have shown definitely better performance in the blasting operations resulting into improved productivity and cost saving.

8. Absence of regulatory bodies such as DGMS for construction industry to evaluate the performance parameters of explosives results in deviation of the explosives and accessories from the requisite leading to increased number of misfires, accidents and wastage of cycle time. A concept of quality ascertaining which is commonly implemented in mining industry is described. The same concept of periodic quality check mechanism can be used by the construction industry.

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