Assessment of explosive performance by detonation velocity measurements in Turkey

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ABSTRACT: Real performance of an explosive can be determined by conducting continuous velocity of detonation (VOD) measurements in full scale blast environments. This paper presents and discusses the results of continuous VOD measurements of five different blasting agents carried out at three mines in Turkey. The results show that VOD of a blasting agent varies depending on mainly the rock properties (confinement), presence or absence of sensitizer (chemical formulation), blasthole diameter, and type of primer. The method of continuous VOD measurement is an indispensable and invaluable tool in explosive and primer selection.

1 INTRODUCTION

Blast optimization studies attract more attention than before due to increasing economical pressures. Inadequate blast designs besides environmental hazards can cause decreased efficiencies in loading, hauling, crushing and grinding cycles and lead to increase in the unit cost of overall operation. A blast design implemented according to the site specific conditions and mine objectives may decrease overall operation cost together with provision of safety and elimination of environmental hazards.

With new PC based blast monitoring instrumentation systems and recently introduced new analytical methods of analysis, the operator can easily eliminate most of the guess work involved in designing efficient blasts and in evaluating explosive performance in any mining environment (Chiappetta 1998).

Within the scope of a research and development project on explosives and blasting techniques, over 70 continuous VOD measurements were conducted at seven different blasting sites till now. However, this paper presents a summary of continuous velocity of detonation (VOD) measurements conducted at only three mines. It is intended to investigate the performance of five different blasting agents in full scale in three mines having different rock types and its impact on the blast results.

2 VOD INSTRUMENTATION

Velocity of detonation of an explosive can be used to evaluate the performance of a product under specific rock and test conditions. Since VOD is a direct measurement of the source function, it can provide valuable information with respect to shock, stress waves, kinetics, ground vibration, airblast, fragmentation and undesirable noxious fumes. If VOD is not monitored and an explosive product is assumed to perform as specified, the interpretation of other measurements (if any) could be erroneous when product malfunction occurs. Thus, it is important to correlate the product's VOD characteristics to the rock environment, blast design, and other measurements (Chiappetta 1993 & 1998).

Field VOD measurements were performed with a continuous VOD recorder (VODR-1) developed by EG&G and BAI. The VODR-1 is a commercial version of the CORRTEX system, which was originally developed by Los Alamos National Laboratory (USA) to measure shock wave propagation in nuclear tests to determine nuclear explosive yield. In the measurement of explosive performance, a coaxial cable is placed in an explosive filled borehole with the far end of the cable taped on the primer. Operation is similar to that of RADAR where a pulse of radio waves is sent out and an echo or reflected pulse is returned to give ranging information. The VODR-1 uses standard coaxial cables to carry a fast rise time electrical pulse back and forth every 5-200 μs. Displacement versus time data can be obtained for the entire length of explosive column and the stemming region to determine explosive VOD, cap timing, shock wave transmission, etc. (Chiappetta 1993, Bilgin & Esen 1999).

3 CASE STUDIES

Three case studies are included in this paper. These are Etibakır Küre Copper Mine which is an open pit mine, Baştaş Limestone Quarry and Yeniköy Open Cast Coal Mine. Continuous VOD measurements in these full scale blast environments are presented.

Five different blasting agents namely ANFO, ELBAR-5, BARANFO 50, ELBAR-100 and BARANFO 100 are tested. ANFO is a locally prepared one using porous prills of ammonium nitrate (AN), whereas the other four are produced at factory. ELBAR-5 is a slightly sensitized ANFO. ELBAR-100 is a water resistant ANFO that contains some sensitizer and water proofing agent. BARANFO 50 is produced partly by using porous prills and partly by crushed AN. BARANFO 100 is consisting completely of porous prills of AN. These blasting agents are basically ANFO having different ammonium nitrate size and type and/or sensitizer.

3.1 *Etibakır Küre Copper Mine*

VOD measurements were conducted while blasting massive copper ore which was classified as high strength rock. Performances of four blasting agents (ANFO, ELBAR-5, BARANFO 50 and ELBAR-100) are evaluated by these measurements. Blast design parameters are given in Table 1.

ANFO and Powergel Magnum (an emulsion explosive, 90x200 mm) were the blasting agent and primer respectively in the first test. A single hole is monitored by VODR-1 system. A zoomed-in raw VOD record is illustrated in Figure 1.

The following results were obtained by analyzing the single hole record and from observations:

- run-up distance (the length of explosive column detonating at low velocity and measured from the point of initiation to the point where steady state VOD is reached) is 1.47 m.

Table 1. Blast design parameters at Etibakır Küre Copper Mine.

Blasthole diameter	159 mm
Bench height	12 m
Hole depth	13.5 m
Burden (B)	3 m
Spacing (S)	3 m
Stemming length	4.5 m
Blasthole inclination	Vertical
Charging configuration	Bottom priming, continuous charging
Blasthole pattern	Square
Initiation system used	Shock tube
Initiation pattern	Square V
Delay between rows	25 ms

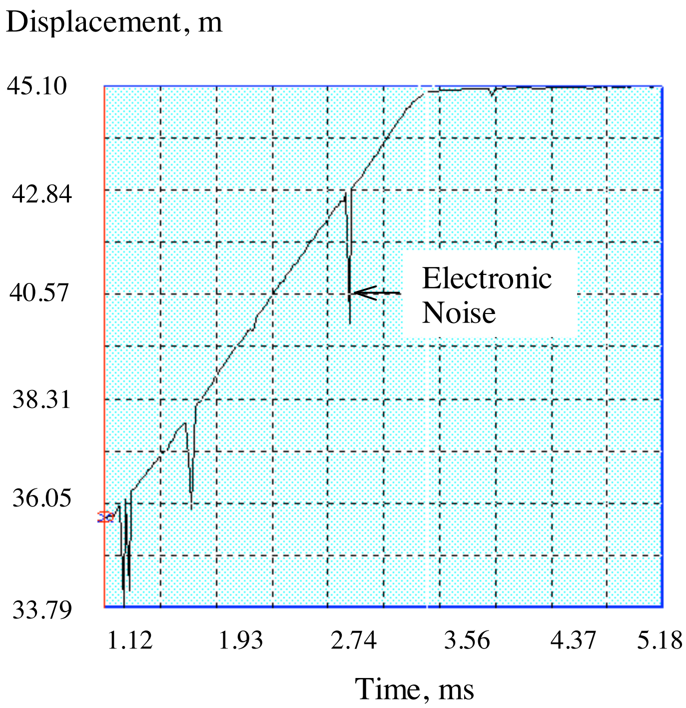

Figure 1. Zoomed-in raw VOD record for ANFO.

- the start-up VOD at the hole bottom is 2525 m/s (Fig. 2).
- low order detonation at the hole bottom results from poor priming and causes toe problem.
- average VOD of ANFO is 4141 m/s.
- poor fragmentation is observed by qualitative visual analysis of the muckpile. It is due to the poor detonation performance of ANFO at the hole bottom, and improper drilling pattern. Later, by changing the drilling pattern to 3.5 m x 5.5 m, fragmentation is improved by blast optimization studies (Esen et al., unpubl.).
- bad muckpile profile resulting from the blast causes difficulties in loading operation.
- a few number of electronic noise in the VOD record shown in Figure 1 indicates quite clearly that the rock mass surrounding the length of the explosive column was quite intact with very minor structural discontinuities and no soft formations.

VOD measurements for ELBAR-100, BARANFO 50 and ELBAR-5 were carried out to select the best blasting agent for the mine. These explosives were charged into 3 different holes in the order given above. These were primed by Gelatinous Dynamite (90x100 mm) and initiated by shock tube. A single row consisting of three holes is prepared for VOD measurements and a different blasting agent is charged into each hole. The results of the measurements are given in Table 2.

The following results were obtained from three hole, one row shot VOD record and from observation:

- high VOD recorded at hole bottom in each blast-hole indicates good priming of ANFO. So, Gelatinous Dynamite is a suitable primer.

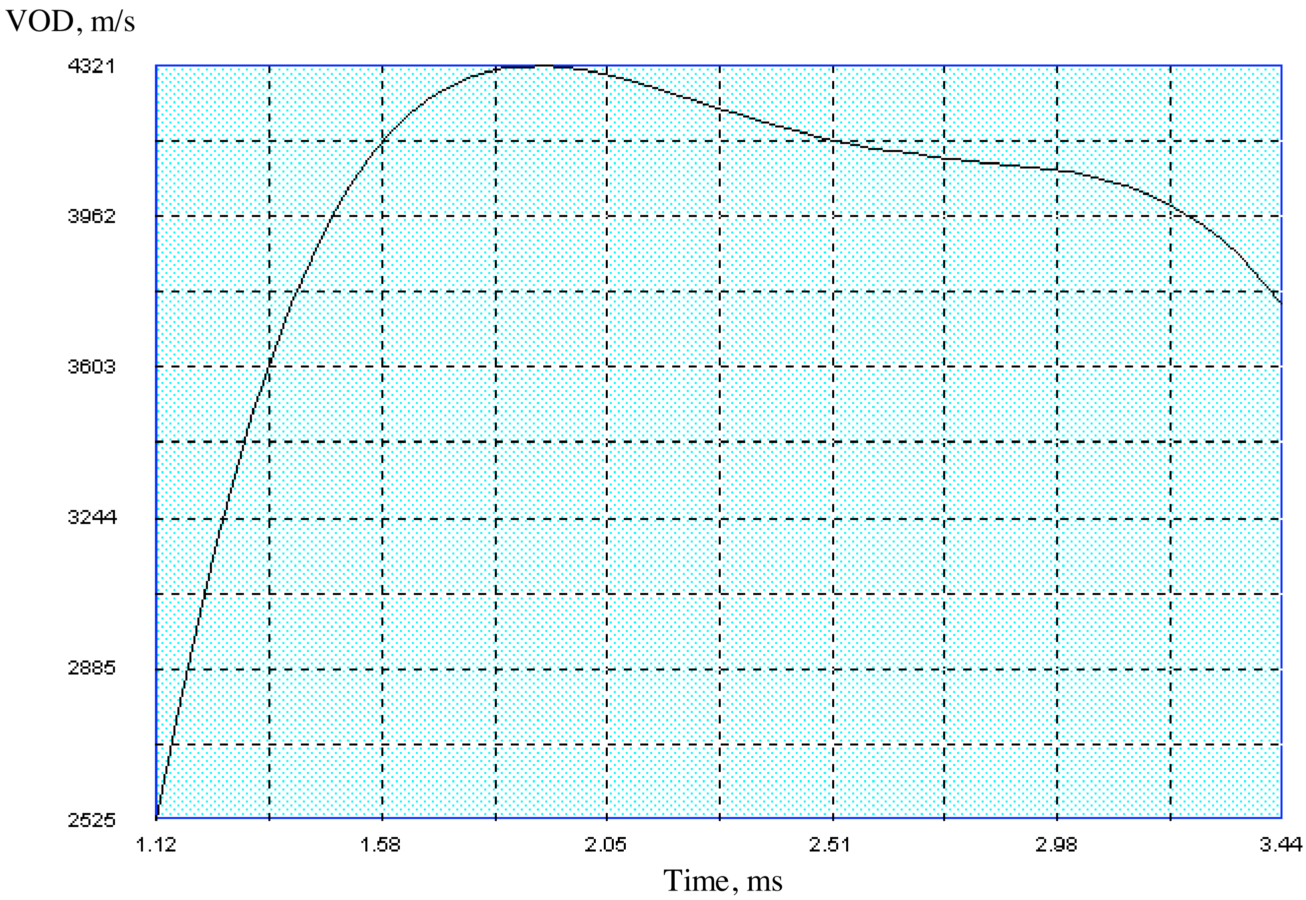

Figure 2. VOD-time graph of raw VOD record for locally prepared ANFO.

Table 2. Comparison of VOD results at Etibakır Küre Copper Mine.

	ANFO	EL-BAR-100	BAR-ANFO 50	EL-BAR-5
Density, g/cm^3	0.810	0.994	0.928	0.803
Primer	Power-gel M.	Gel. Dyn.	Gel. Dyn.	Gel. Dyn.
Average VOD, m/s	4141	5041	4832	4184
VOD at hole bottom, m/s	2525	5163	4859	4379
VOD at the top of explosive column, m/s	3810	4871	4782	3983

- Due to high VOD at hole bottom, no toe problem was observed during and after mucking.
- Figure 3 shows VOD-time graph for the second hole where BARANFO 50 was the blasting agent. VOD is not constant and decreases along the explosive column, but the decrease is not much and seems acceptable.
- The minimum reduction in VOD is obtained for the explosives BARANFO 50 and ELBAR-100 (Table 2).

Explosives having high VOD and low attenuation in VOD are generally preferred for massive high strength rocks. So, the most suitable blasting agent for this blast environment is BARANFO 50 and/or ELBAR-100. Since ELBAR-100 has higher VOD, density and unit price, it may be utilized as bottom charge, whereas BARANFO 50 may be used as column charge. ANFO consisting completely of porous ammonium nitrate prills is not recommended as a blasting agent for this mine as it has lower VOD and density and much greater reduction in VOD along the explosive column.

A research study conducted by Esen et al. (2000) has shown that coarser fragmentation is obtained by utilizing ANFO containing only porous AN prills in hard rock environments due to its lower shock energy. Blasting agents with high shock energy (high VOD and density) such as BARANFO 50 and ELBAR-100 are recommended in these blast environments. Blasting agent selection based on the VOD measurements agrees well with the findings of Esen et al. (2000).

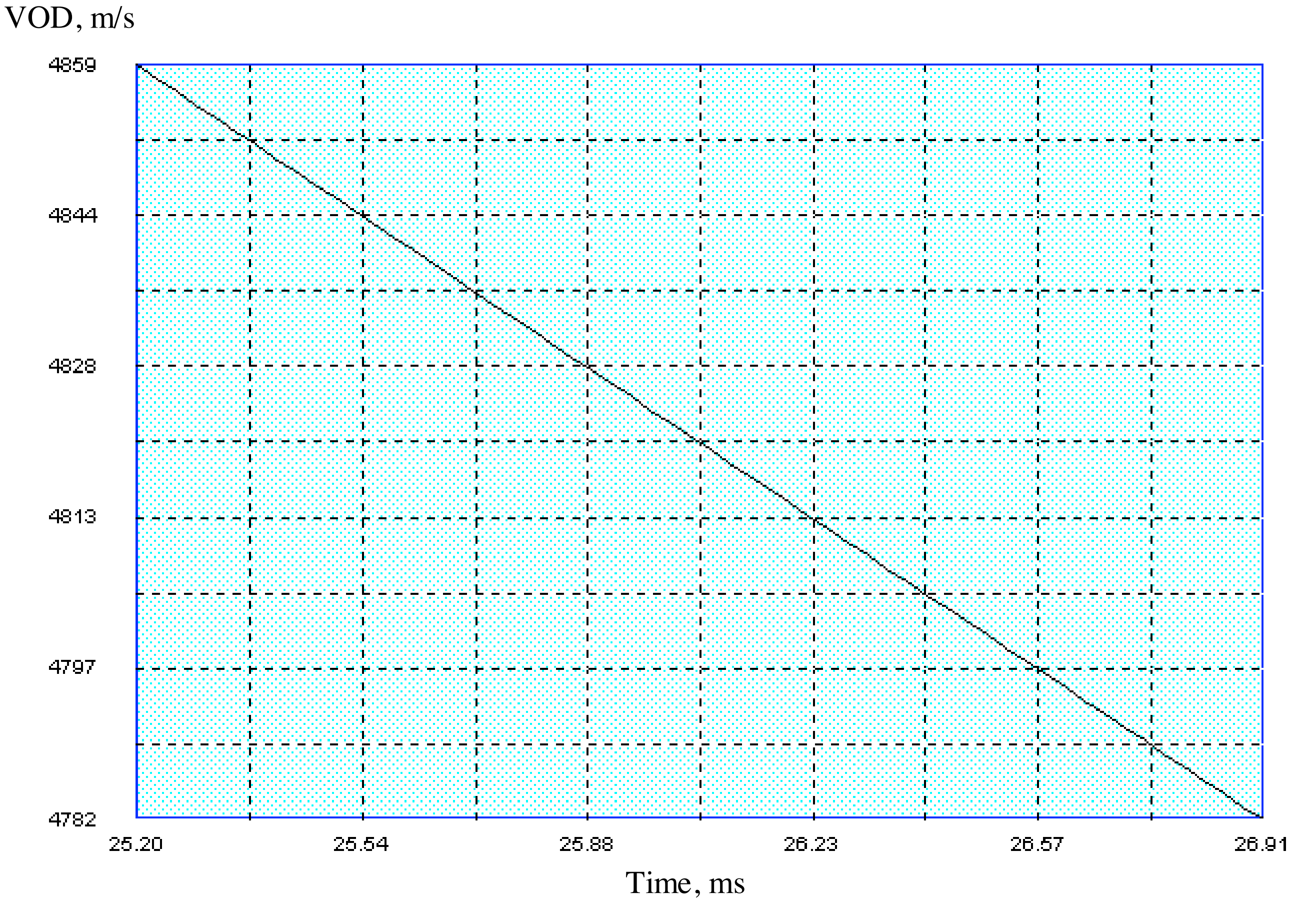

Figure 3. VOD-time graph of BARANFO 50 at Küre Copper Mine.

3.2 *Baştaş Limestone Quarry*

Performances of blasting agents ELBAR-5, BARANFO 50 and ELBAR-100 are evaluated by conducting VOD measurements also at Baştaş Limestone Quarry at two different blasthole diameters (89 mm, 165 mm) and at two separate parts of the quarry coded as “as” and “uy” which were classified as high strength and medium strength rocks, respectively. Results of the VOD measurements are shown in Table 3.

It is proven once more that VOD of a commercial explosive material varies depending on hole diameter and confinement (Table 3). When the VOD records are evaluated, high VOD at the hole bottom is observed showing good priming of the blasting agents tested. ELBAR-100 and BARANFO 50 are suggested for parts “as” and “uy” respectively by considering the measured velocities (Table 3). Proper selection of blasting agent and primer have led to good fragmentation and elimination of toe problems at the quarry.

Table 3. VOD results at Baştaş Limestone Quarry.

Blasting Agent	Hole Diameter, mm	Rock Definition	Average VOD, m/s
Elbar-5	89	as	3240
	165	as	4268
	165	uy	4171
BAR-ANFO 50	89	as	3735
	165	as	4588
	165	uy	4229
Elbar-100	89	as	4017
	165	as	4900
	165	uy	4749

3.3 *Yeniköy Open Cast Coal Mine*

VOD measurements were also conducted at Yeniköy Open Cast Coal Mine to evaluate the performances of ELBAR-5, BARANFO 50 and BARANFO 100 in weaker rock environments. Measurements were conducted at İkizköy District of the mine where stripping operations were carried out. Marl is the principle rock type blasted during overburden loosening which is subsequently removed by shovel truck combination. It is classified as low strength rock. Blasthole diameter, burden, spacing and hole length are 235 mm, 9 m, 9 m and 9.6 m, respectively. 100 kg blasting agent is charged into each blasthole. Blasting agents tested were primed by either 100x90 mm Gelatinous Dynamite or 90x150 mm Powergel Magnum cartridges. Results of the VOD measurements are given in Table 4.

Table 4. Results of the VOD measurements at Yeniköy Open Cast Coal Mine.

Blasting Agent	Primer	Average VOD, m/s	Run-up Distance, cm
ELBAR-5	Gelatinous Dynamite	4550	-
ELBAR-5	Powergel Magnum	3895	35
BARANFO 50	Gelatinous Dynamite	4675	-
BARANFO 50	Powergel Magnum	4350	62
BARANFO 100	Gelatinous Dynamite	4175	-
BARANFO 100	Powergel Magnum	3811	38

Bulk densities of ELBAR-5, BARANFO 50 and BARANFO 100 are 0.803, 0.928 and 0.714 g/cm^3, respectively.

The following conclusions are drawn both from Table 4 and field observations:

- no run-up distance is measured when blasting agents are primed by Gelatinous Dynamite showing adequate priming. The initial high VOD at the hole bottom proves that Gelatinous Dynamite is a suitable primer.
- run-up distances were measured only when Powergel Magnum (an emulsion explosive) is used as a primer. Therefore, Powergel Magnum is not as good as Gelatinous Dynamite as a primer.
- presence of run-up distance indicates poor performance of the blasting agent at the hole bottom. For example, run-up distance of BARANFO 50 due to poor priming is 62 cm, that is, about 25 kg explosive is wasted during detonation.
- low VOD at the hole bottom causes low productivity in excavation during stripping operation. The result is an economical loss for the mine.
- type of primer affects the detonation velocity even if the explosive type, the rock type, the diameter of the hole and the initiator are the same. Average VOD's of BARANFO 50, BARANFO 100 and ELBAR-5 primed by Gelatinous Dynamite are 4675, 4175 and 4550 m/s, respectively. That of these explosives primed by Powergel Magnum are 4350, 3811 and 3895 m/s, respectively.

Explosives having low VOD and density are generally preferred in low strength rocks. Therefore, BARANFO 100 is selected for stripping operations of the mine due to its low VOD and density.

4 CONCLUSIONS

1. VOD of a blasting agent depends heavily on formulation characteristics, rock properties (confinement), blasthole diameter and priming.
2. A VOD record can provide excellent information on the integrity, structural and geomechanical condition of the surrounding rock mass.
3. When an explosive is primed adequately, VOD at hole bottom is high and decreases towards the end of the explosive column. So, VOD of a commercial explosive is not constant.
4. Low VOD at the hole bottom indicates poor priming of blasting agent. Inadequate priming creates low order detonation resulting in poor explosive performance at the hole bottom. It leads to hard toe (difficult digging) and coarse fragmentation.
5. BARANFO 100 is the most suitable explosive for the low strength rocks of Yeniköy Open Cast Coal Mine. BARANFO 50 is the most proper explosive in blasting medium strength rocks. Higher VOD (higher shock energy) and higher density explosives such as ELBAR-100 and BARANFO 50 having low attenuation in VOD are proven to be suitable for blasting operations in hard rock environments such as seen in Etibakır Küre Copper Mine.
6. Since performance of primer and blasting agent affect blasting results, selection of explosives should be made properly for each blasting site. VOD measurement carried out at full scale is an excellent and indispensable tool for the selection.
7. VOD measurements conducted during full scale blasting certainly offers important information to be used in blast design optimization and the detection of low order detonation, deflagration and misfire.

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