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Influence of a Primer on the Velocity of Detonation of ANFO and Heavy ANFO Blends

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Abstract: ANFO is the most common explosive for civil use in the fields of mining and civil engineering. Some properties of ANFO, like poor water resistance, low density and low velocity of detonation can be improved by mixing ANFO with a certain percentage of an emulsion. These explosives are called Heavy ANFO blends. This paper presents a study of the influence of a primer on the velocity of detonation of ANFO and Heavy ANFO blends. Three types of primers were used for the initiation of the explosives and the velocity of detonation was measured *in situ* by a continuous method. Based on the results of these measurements, the relationship between the detonation velocity of the primer used and the detonation velocity of the primed explosive were established.

Keywords: ANFO, Heavy ANFO, primer, velocity of detonation

1 Introduction

Ammonium nitrate fuel oil (ANFO) explosives are simple, two-component explosives that consist of ammonium nitrate(V) (AN) prills and fuel oil (FO). ANFO is an explosive which, despite having a low velocity of detonation and detonation pressure, is characterised by high blasting efficiency due to the large volume of gas generated [1]. The main disadvantage of ANFO is the lack of water resistance. ANFO explosives when mixed with an emulsion are called Heavy ANFO blends. The advantages of these explosives when compared to ANFO are:

- higher density,
- higher velocity of detonation,
- better water resistance, *etc*.

There are numerous articles describing the influence of individual factors on the detonation parameters of ANFO explosives and a smaller number of articles for Heavy ANFO blends. For ANFO, the main factors are the properties of the AN prills [2-4], the fuel/oil ratio, the density and the charge diameter [5]. The influences of the initiating energy [6], the charge temperature [7] and the addition of an active ingredient (organic nitrate) to the fuel oil [8] on the velocity of detonation of ANFO explosives have also been described. For Heavy ANFO explosives the influence of the percentage of the emulsion matrix on the velocity of detonation [9-11] and detonation pressure [12] have been described. Data on the influence of the addition of ANFO to a pure emulsion explosive are available. According to the report, for blends including 20% and 30% of ANFO, it appears that the addition of ANFO to an emulsion decreases the early energy release, but the late energy release values are similar to the case of the pure emulsion [13].

A primer is a unit of a cap sensitive explosive equipped with a detonator or detonating cord and is used to initiate other explosives, and a booster is a unit of a cap sensitive explosive without a detonator. Manufacturers of ANFO and Heavy ANFO blends require boosters with a detonator or detonating cord for priming the explosives in the blast hole. Boosters are usually made of a high energy, high density molecular explosive with a high velocity of detonation. Except for priming, a booster can be inserted at a specific point in the explosive column to create a zone of high energy release along the column length. Very often miners do not use boosters; they use a different type of commercial explosive, with much lower velocities of detonation, as a primer. The present paper presents measurements with the aim of establishing the relationship between the velocity of detonation of ANFO and Heavy ANFO blends and the primer used. The velocity of detonation of the explosive was measured *in situ* in a borehole, by the continuous method.

2 Material and Methods

2.2 Material

ANFO and Heavy ANFO blends with different percentages of the emulsion were used for testing. The AN/FO ratio for the ANFO explosive was 94.5/5.5 wt.%. The fuel oil density was 842 kg/m^3 (at 15 °C) with a kinematic viscosity of 3.02 mm^2/s (at 40 °C). The properties of AN prills used, according to the manufacturer's data, are presented in Table 1. The percentage of the emulsion added to the ANFO was 10, 15, 20 and 70 wt.%. The properties of the emulsion matrix are presented in Table 2. The explosives were initiated using primers with different densities, masses and velocities of detonation. The properties of the primers are presented in Table 3.

Table 1. Properties of the AN prills

Ammonium nitrate content (NH_4NO_3) [wt.%]	>99
Water [wt.%]	<0.12
Combustible substance [wt.%]	<0.20
Acidity [pH]	4.7-5.5
Density [kg/m^3]	690-750
Oil absorption [%]	>10
Prills with diameter below 0.5 mm [wt.%]	<1

Table 2. Properties of the emulsion matrix

Oil phase [wt.%]	5.9
Ammonium nitrate [wt.%]	66.1
Potassium nitrate [wt.%]	13.3
Water [wt.%]	14.7
Density [kg/m^3]	1410

Table 3. Properties of the primers

Type of primer	I	II	III
Density [kg/m^3]	1060	1200	1360
VoD [m/s]	4500	5600	6500
Weight [kg]	1.5	2.25	2.5

2.2 Velocity of detonation measurements

The velocity of detonation (VoD) is the velocity at which the chemical reaction zone propagates through a given explosive. It is one of the most important detonation parameters [14]. Methods for the measurement of VoD can be divided into two groups:

- Point-to-point method, and
- Continuous method.

The point to point method is used to measure the average velocity of detonation between two points placed at a known separation. The continuous method is used to obtain the real distribution of the velocity of detonation with time. In this paper the VoD of the explosive was measured *in situ* in a borehole, by the continuous method. A MicroTrapVoD/Data Recorder, an instrument by MREL, and a corresponding measurement probe were used. The MicroTrapVoD/Data Recorder uses the proven continuous resistance wire technique for monitoring VoDs. A probe of known linear resistance (*i.e.* ohm/m or ohm/ft) is placed axially in the explosive sample or explosive column. As the detonation front of the explosive consumes the probe, the resistance of the circuit decreases in proportion to the reduction in length of the probe. The instrument records the resulting decrease in voltage across the probe versus time. The software automatically converts the recorded data into a graph of distance versus time. The slope of this graph at any position is the VoD of the explosive at that particular position [15]. A characteristic measurement graph is presented in Figure 1.

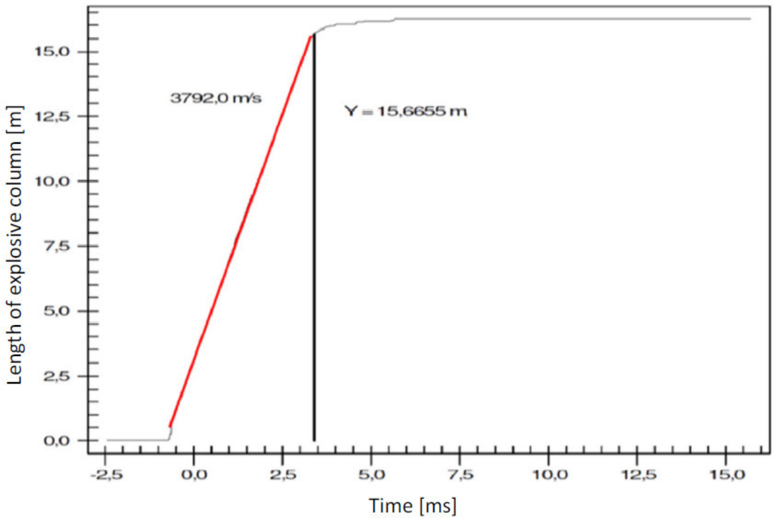

Figure 1. Characteristic measurement graph of VoD by the continuous method.

The measurements were carried out in boreholes of diameter 84 mm with different lengths. Three different types of explosives were used as the primer. The measurement probe was placed on the primer that was put in the bottom of the borehole. After that, the borehole was loaded with the necessary quantity of ANFO or Heavy ANFO and closed with a stem made of gravel. Each type of explosive was initiated by each type of the primer. The Figure 2 presents the cross-section of the borehole and the measurement arrangement.

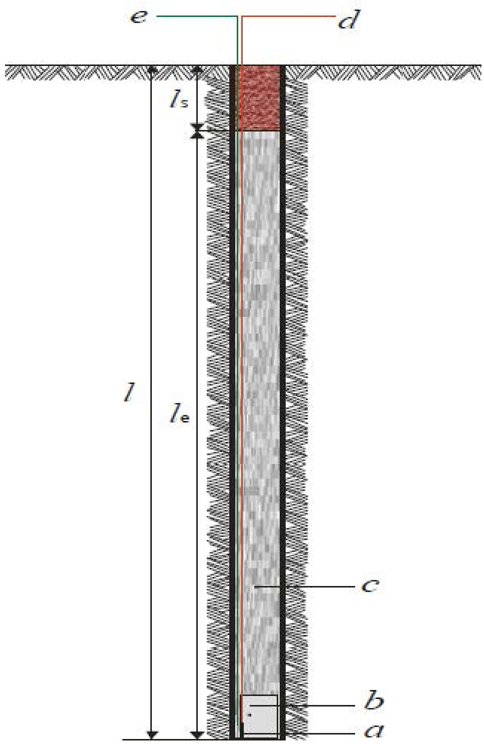

Figure 2. Cross-section of the borehole and measurement arrangement. l – borehole length; l_e – length of explosive column; l_s – stem length; *a* – detonator; *b* – primer; *c* – ANFO or Heavy ANFO; *d* – shock tube; *e* – measurement probe.

3 Results and Discussion

The results of the measurements are presented in Tables 4-8. The measured VoDs and the mean values of the VoDs were rounded to 10 m/s and the masses of the explosives in the borehole to 1 kg. From the results of the VoD measurements for 141 shots, it was evident that the velocity of detonation of the explosives depends on the percentage of added emulsion, the VoD of an explosive increases with the increase in the percentage of the added emulsion for all types of primers used for initiation. The measurements also showed that the VoD does not depend on the length of the explosive charge in the borehole, since it was not possible to establish a relationship between the mass of the explosive charge and the measured VoD.

It seems that the type of primer used has a significant influence on the measured VoD for all types of explosive. For the ANFO explosive the mean value of the VoD increases from 3280 m/s (primer type I) to 3560 m/s (primer type III), for ANFO with 10 wt.% emulsion from 3620 to 3770 m/s, for ANFO with 15 wt.% emulsion from 3790 to 3890 m/s, for ANFO with 20 wt.% emulsion from 3900 to 4020 m/s and for ANFO with 70 wt.% emulsion from 4690 to 5100 m/s. In order to quantify the influence of a primer on the VoDs of the ANFO and Heavy ANFO blends graphs were constructed. Figure 3 presents the influence of the primer used on the VoDs of the ANFO and Heavy ANFO blends.

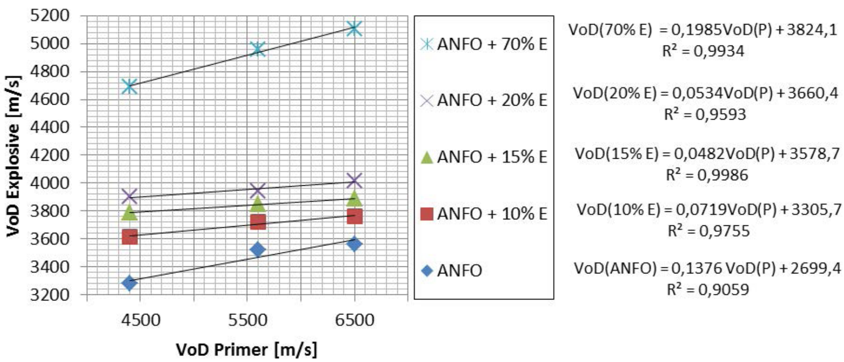

Figure 3. Influence of the VoD of the primer used on the VoDs of ANFO and Heavy ANFO blends.

Table 4. Measured velocities of detonation (VoD) of the ANFO explosive

Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [9] [m/s]
Type I	33	3480	Type II	95	3520	Type III	46	3510
	25	3160		45	3580		45	3510
	28	3510		44	3580		35	3520
	25	3080		55	3480		28	3670
	15	3340		32	3500		20	3600
	27	2990		35	3490		45	3550
	27	3150		90	3400		25	3580
	45	3300		52	3600		25	3560
	27	3400		47	3540		30	3570
	17	3410		52	3550			
	Meanvalue	3280		Meanvalue	3520		Meanvalue	3560

Table 5. Measured velocities of detonation (VoD) of the Heavy ANFO explosive with 10 wt.% of emulsion

Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [9] [m/s]
Type I	25	3590	Type II	35	3740	Type III	50	3790
	28	3610		35	3740		30	3770
	35	3590		55	3670		75	3790
	30	3600		45	3710		75	3770
	30	3620		40	3760		72	3790
	27	3570		37	3690		65	3770
	71	3610		35	3650		43	3790
	44	3700		40	3760		48	3710
	53	3630		45	3740		35	3740
	50	3640		29	3760		8	3730
	Meanvalue	3620		Meanvalue	3720		Meanvalue	3770

Table 6. Measured velocities of detonation (VoD) of the Heavy ANFO explosive with 15 wt.% of emulsion

Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [9] [m/s]
Type I	68	3770	Type II	58	3850	Type III	35	3880
	60	3800		50	3850		40	3860
	55	3800		50	3820		110	3900
	80	3780		70	3840		25	3910
	40	3780		50	3840		120	3900
	50	3820		85	3850		43	3900
	20	3780		55	3840		45	3910
	50	3800		82	3830		95	3910
	30	3770		50	3940		26	3830
	41	3800		40	3850		65	3910
	Meanvalue	3790		Meanvalue	3850		Meanvalue	3890

According to the slopes of the correlation lines, the influence of a primer on the VoD is highest for pure ANFO explosives and ANFO with the addition of 70 wt.% emulsion. The slopes of the correlation lines for ANFO with the addition of 10, 15 and 20 wt.% of emulsion are similar to each other. For ANFO and each type of Heavy ANFO explosive the influence of the primer on the VoDs of the ANFO and Heavy ANFO blends is expressed for each explosive by linear equations with high determination coefficients (from 0.906 to 0.999). By using the equations, presented in Figure 3, it is possible to calculate the VoDs of the ANFO and Heavy ANFO explosives with different percentages of emulsion in relation to the primer used.

Table 7. Measured velocities of detonation (VoD) of the Heavy ANFO explosive with 20 wt.% of emulsion

Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [9] [m/s]
Type I	45	3910	Type II	55	3960	Type III	50	3980
	35	3900		45	3950		47	4010
	45	3910		40	3940		67	4010
	40	3910		40	3950		32	3980
	42	3880		37	3950		35	4030
	60	3910		45	3920		75	4020
	45	3870		40	3940		40	4090
	105	3920		45	3930		40	4040
	60	3900		50	3940		5	3990
	105	3900		55	3980		55	4000
	Meanvalue	3900		Meanvalue	3950		Meanvalue	4020

Table 8. Measured velocities of detonation (VoD) of the Heavy ANFO explosive with 70 wt.% of emulsion

Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [m/s]	Primer	Explosive weight [kg]	VoD [9] [m/s]
Type I	120	4740	Type II	120	5020	Type III	125	5160
	130	4650		130	4970		135	5100
	140	4690		135	4880		140	5080
	135	4690		35	4970		137	5060
	46	4700		40	5010		50	5070
	60	4690		93	4880		40	5130
	35	4750					50	5120
	60	4630						
	97	4660						
	Meanvalue	4690		Meanvalue	4960		Meanvalue	5100

The primer used also influences the dispersion of the measurement results. The highest dispersion of the results is evident in the case of explosive initiation by primers with the lowest VoD, and the lowest dispersion in the case of primers with the highest VoD. The influence of the primer used on the dispersion of the measurement results is the most visible in the case of the ANFO explosives. The Figure 4 presents the mean, minimum and maximum measured values of the VoD for the ANFO explosives initiated by different primers.

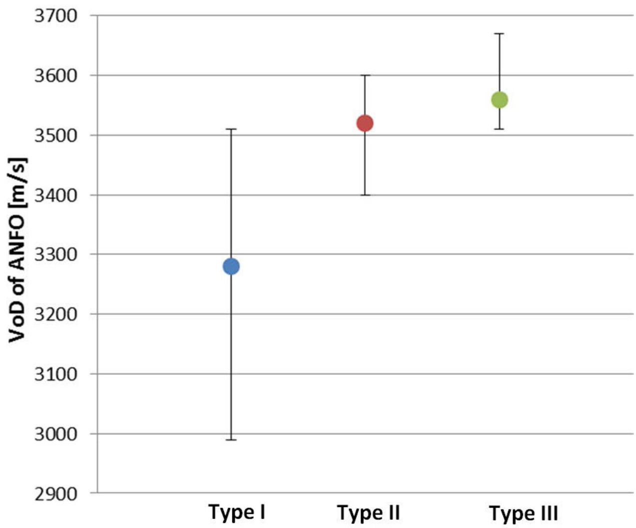

Figure 4. Mean, minimum and maximum measured values of the VoD for the ANFO explosive initiated by different types of primer.

4 Conclusions

This paper demonstrates the influence of a primer on the VoDs of ANFO and Heavy ANFO blends. Mathematical analysis of the measured data leads to the conclusion that ANFO or Heavy ANFO blends with the same percentage of added emulsion, the same density and the same diameter borehole may have more than one value of the steady state VoD. The VoD depends on the properties of the primer used, and, in each case, it is described by equations that show the influence of the primer used on the VOD of the ANFO or Heavy ANFO blends. The VoDs of the ANFO and Heavy ANFO blends increases with the increasing VoD of the primer used. The research presented here contributes to a better understanding of the non-ideal detonation of ANFO and Heavy ANFO blends.

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