Central European Journal of Energetic Materials, **2014**, *11*(2), 191-197
ISSN 1733-7178

Influence of Explosive Charge Temperature on the Velocity of Detonation of ANFO Explosives

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Abstract: ANFO is the most common explosive for civil use in the fields of mining and civil engineering. The effect of the explosive and the quantity of energy released by the detonation depends on the velocity of detonation. The influence on explosive performance of a large number of physical aspects of ANFO explosives and the conditions of initiation during blasting operations are mostly known, but the influence of the charge temperature on the velocity of detonation is not known. In order to quantify that influence, research on laboratory samples of smaller diameter and field samples of larger diameter, detonated in steel pipes, has been carried out. By processing and analysing the measured results the influence of charge temperature on the velocity of detonation of ANFO explosive has been determined.

Keywords: ANFO, temperature, velocity of detonation

1 Introduction

Ammonium nitrate (AN) based explosives are the cheapest and most frequently used commercial explosives [1]. ANFO explosives are more frequently used for blasting than the other two types of ammonium nitrate based explosives (emulsion and slurry explosives). According to estimates, ANFO is used for 80% of surface blasting operations in the Republic of Croatia. Satisfactory blasting performance, a relatively low price, safety during blasting operations, simple manufacture and the possibility of mechanical loading of boreholes, are

the main reasons for its frequent use.

A significant number of the individual factors that influence the detonation parameters of ANFO have been tested and determined. For pure ANFO, the main factors are the properties of the AN prills [2-4], the fuel/oil ratio, the density and charge diameter [5]. It is possible to influence the detonation parameters of ANFO by adding flammable or non-flammable components. A certain amount of aluminum powder will decrease the concentration of toxic gases in the detonation products and increase the work ability of the explosives, making them more suited to the mechanical properties of the fractured rock masses [6-7]. By increasing the amount of inert material, such as perlite or silica sand, in an ANFO mixture, the velocity of detonation, CJ pressure and CJ energy of the ANFO explosive will decrease [8]. These kinds of explosives are suitable for the explosive welding of metals.

During a number of years of explosives testing in the Croatian National Laboratory it was observed that the velocities of detonation of ANFO explosives mixed by the same manufacturer, and composed of the same AN and fuel oil in identical AN/FO ratios, differed at different periods of the year and weather temperatures. Due to these results, it was decided to examine the influence of ANFO charge temperature on the velocity of detonation of ANFO explosives.

2 Materials and Methods

2.1 Materials

The tested ANFO was mixed in an AAMCOR-LLC ANFO mixing truck. The density of the AN prills was 822 kg/m^3, the minimal oil absorption was 6% and the size of more than 90% of the prills was between 1.0 and 2.83 mm. The density of fuel oil used was 842 kg/m^3 (at 15 °C). The AN/FO ratio was determined by an ANFO test, after the sample had been mixed, and was 94.5/5.5. The measured ANFO bulk density was 823 kg/m^3.

Table 1. Properties of APG 20 ”Mini Booster”

Diameter (mm)	20
Length (mm)	90
Explosive weight (g)	20
Gross weight (g)	29
Density of pressed charge (kg/m^3)	> 1500
Velocity of detonation (m/s)	> 6500

Detonators, or detonators and boosters were used to initiate the ANFO samples. The explosive charge mass of an electric detonator was 720 mg of PETN. Boosters of trade name APG 20 "Mini Booster" were used. The booster properties, according to the manufacturer's data, are presented in Table 1.

2.2 Velocity of detonation measurements

The velocity of detonation is one of the most important detonation parameters. The methods used for detonation velocity measurement can be divided into optical and electrical types [9]. In the present case, the velocity of detonation was measured by the electrical method using an electronic timer Explomet-Fo-2000 and fiber optic probes. The method measures the time necessary for the detonation wave front to traverse the distance between two probes. The velocity is calculated on the basis of the measured time and the pre-defined distance between the probes. The accuracy of the time measurement was ± 0.1 μs in a total duration of up to 10 000 μs. The velocity of detonation was measured at a testing site for the larger samples, and in a laboratory for the smaller samples.

During testing at the testing site, the velocity of detonation was measured on samples placed in steel pipes of Ø 52/57 mm, inner/outer diameter, and of approximate length 400 mm. The fiber optic probes (P1 and P2) were placed at a separation of 100 mm. The first probe, P1, was placed at a distance of more than 250 mm from the place of initiation. The samples were initiated by detonators, or detonators and boosters. The measurement setup is shown in Figure 1.

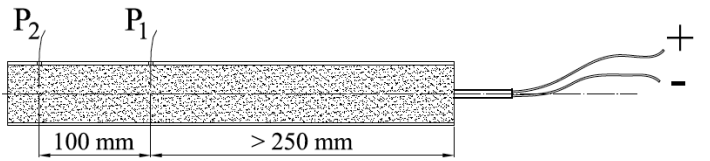

Figure 1. Measurement scheme for velocity of detonation, steel pipe Ø 52 mm.

Samples initiated by boosters were conditioned to temperatures of 0, 10, 15, 20 and 25 °C, and samples initiated by detonators to temperatures of 0, 10, 15, 20 and 30 °C. The temperature of each charge was measured and recorded immediately before detonation. The temperature was measured using a platinum resistance thermometer probe PT 100 (Class A) which was connected to Rotronic Hygrolog NT2-D-CL. The probe was positioned inside the explosive in the steel pipe.

Steel pipes of Ø 23.5/27.5 mm, inner/outer diameter, and of approximate length 160 mm were used for measuring the detonation velocity in the laboratory.

Fiber optic probes (P1 and P2) were placed at a separation of 60 mm. The first probe, P1, was placed at a distance of more than 80 mm from the place of initiation. The samples were initiated by detonators only. The measurement setup is shown in Figure 2.

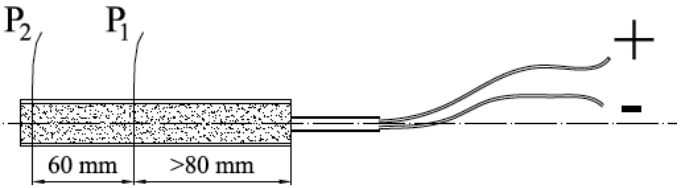

Figure 2. Measurement scheme for the velocity of detonation, steel pipe Ø 23.5 mm.

Samples were conditioned to temperatures from 0 to 30 °C, with the difference between individual temperatures of 5 °C. The temperature of each sample was measured and recorded immediately before detonation, as described above.

3 Results and Discussion

The velocity of detonation was measured on 51 different charges, 30 charges in steel pipes of internal diameter 52 mm and 21 charges in steel pipes of internal diameter 23.5 mm. Individual detonation velocities at different temperatures are shown in Table 2. The graphical representation of the influence of explosive charge temperature on the detonation velocity is shown in Figure 3.

It was impossible to achieve the exact targeted temperatures of 0, 10, 15, 20, 25 and 30 °C at the testing site. Although the samples were conditioned to exactly the required temperatures, placing them in the measurement locations caused their temperatures to change due to the surrounding temperature and the time necessary to prepare them for detonation. Therefore, the testing was repeated under laboratory conditions where the temperatures of the samples were exactly as required. During the initiation of the samples in steel pipes by boosters, the highest measured velocities ranged from about 2600 to 3250 m/s for charges of diameter 52 mm. Slightly lower measured velocities (from about 1150 to 2000 m/s) were recorded for charges of diameter 52 mm initiated by detonators, and the lowest velocities (from about 600 to 950 m/s) were recorded for charges of diameter 23.5 mm initiated by detonators. The difference between

the measured velocities of detonation for charges of diameter 52 mm using the different means of initiation is the result of the different initiation energies of detonators and boosters. Due to that, for the samples initiated by boosters which have higher initiation energies, a higher velocity of detonation was recorded. The higher velocities of detonation for charges of diameter 52 mm compared to charges of diameter 23.5 mm, both initiated by detonators, are due to the different diameters of the samples. The tests confirmed that the velocity of detonation increases with the increase in diameter. It should be mentioned that the velocity of detonation measured on charges of diameter 23.5 mm was below 1000 m/s, consequently it is more appropriate to call that reaction an explosion, and not a detonation. Low measured velocities are the result of a small charge diameter and initiation by detonators.

Table 2. Measured velocities of detonation (D) of ANFO charges

No.	Charge Ø 52 mm Initiated by booster		Charge Ø 52 mm Initiated by detonator		Charge Ø 23.5 mm Initiated by detonator	
	Temperature [°C]	D [m/s]	Temperature [°C]	D [m/s]	Temperature [°C]	D [m/s]
1	6.0	2620	2.8	1180	0.1	650
2	6.3	2770	3.3	1210	0.1	620
3	6.5	2650	2.6	1140	0.1	620
4	10.2	2880	11.0	1460	5.0	760
5	10.9	2930	11.1	1410	5.1	650
6	11.3	2890	10.9	1470	4.9	730
7	15.8	3000	15.3	1680	10.0	800
8	16.1	2960	15.7	1640	10.1	800
9	16.4	3060	16.1	1610	10.2	800
10	18.8	3170	21.1	1740	15.3	880
11	19.1	2980	22.7	1620	15.2	840
12	18.9	2950	22.2	1680	15.3	760
13	20.9	3190	29.6	1920	19.8	860
14	24.9	3260	30.7	1930	20.0	880
15	24.8	3240	31.2	1990	20.1	810
16					25.3	830
17					25.6	880
18					25.5	880
19					30.0	880
20					30.1	910
21					30.1	970

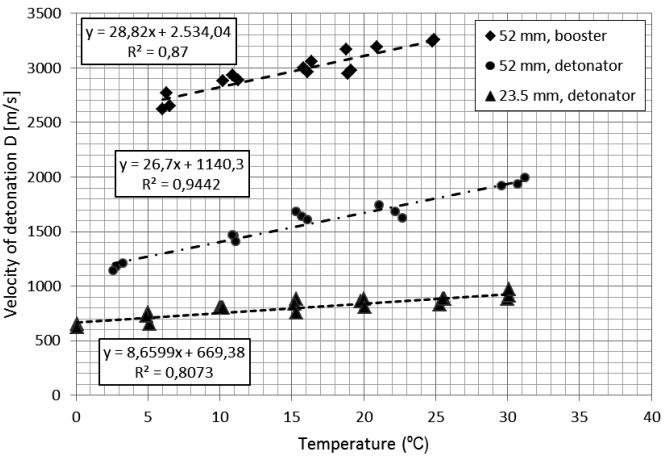

Figure 3. Influence of explosive charge temperature on the velocity of detonation.

The increase in the velocity of detonation with the increase in charge temperature was observed for all three series of tests. The influence of the charge temperature on the detonation velocity of the explosives for all samples are represented by linear plots (Figure 3). Linear equations and the corresponding factors of determination are given for each plot. High values of the factors of determination ($R^2 = 0.87$, $R^2 = 0.94$ and $R^2 = 0.81$) indicate a strong cause-effect relationship between the temperature of the ANFO charge and the velocity of detonation.

Conclusions

The influence of explosive charge temperature on the velocity of detonation of ANFO explosive was demonstrated by the measured results for both charge diameters and was defined with similar plots. It is significant that, in the cases of the higher measured velocities of detonation produced by a larger charge diameter or higher initiation energy, the plot has a steeper slope. That means that during blasting under actual borehole conditions, a larger decrease of the velocity of detonation could be expected with smaller changes in charge temperature. That would lead to larger energy losses and reduced blasting efficiency. The results obtained should be verified under real borehole conditions, and, according to those results, the real energy loss for blasting operations at different environmental temperatures could be evaluated.

Acknowledgements
The results presented here were obtained within the scientific project 'Emulsion explosives, initiating devices and environmental influence of blasting' supported by the Croatian Ministry of Science, Education and Sports. The authors are grateful to PETROKEMIJA, Plc. Fertilizer Company, for providing AN samples and AN test data.

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