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Detonation Performance of Aluminium – Ammonium Nitrate Explosives

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Abstract: The research on an effect of aluminium contents on detonation characteristics of ammonium nitrate explosives was carried out. Measurements of detonation velocity were performed. Parameters of blast waves produced by charges of the investigated explosives detonating in an open space were measured by the use of piezoelectric gauges. Quasi-static pressure measurements were conducted in a steel chamber of 0.15 m^3 volume filled with air. Moreover, the heat of detonation was measured with a calorimetric set in a 5.6 dm^3 bomb filled with argon. The results of measurements of QSP, detonation velocity and heat were compared with those obtained from thermochemical calculations.

Keywords: nonideal explosives, detonation, performance

Introduction

An addition of powder metals to explosives is a widely used method to improve their energetic efficiency [1]. An increase in detonation velocity is observed after including a fine aluminium into nonideal explosives, that is the explosives which characterize by a low sensitivity, relatively low detonation parameters, a wide zone of chemical reactions and a very significant difference between values of limit and critical diameters of a charge. The increase of detonation velocity as a result of aluminium adding is noticed in the explosive mixtures containing some inorganic components with a positive oxygen balance, for example, ammonium nitrate or hydrazine nitrate. Aluminium powder is the source of increasing in the work ability of that mixtures and their sensitivity to mechanical stimuli like a hammer drop or shock wave. This means that nonideal explosives become more sensitive due to the addition of aluminium powder.

There are a great number of papers devoted to the study of the influence of aluminium content on the performance and sensitivity of nonideal explosives, for example Refs. [2÷5]. At present work we measure the detonation velocity as well as the parameters of free field and confined explosions of aluminium/ammonium nitrate mixtures. The results of this investigation enable us to test an influence of secondary exothermic reactions in detonation products and air on the heat of detonation, quasi-static pressure (QSP) and blast wave characteristics.

Experimental approach and results

Characteristics of ingredients used in the explosive mixtures

To prepare the explosive mixtures some of the following components were used:

- crystalline ammonium nitrate (AN) with size of grains below 0.8 mm,
- flaked aluminium powder (Alf) with specific surface of 42 000 cm^2/g (82% Al),
- aluminium powder (Alp) with particle size below 75 μm (99% Al).

The mixtures tested were prepared by long-duration mixing of the components in a required proportion.

Detonation velocity

To measure the detonation velocity the explosive mixtures were placed into polyvinyl tubes of length of about 250 mm, 35-mm-inner diameter and 2-mm-thickness. The distance between short-circuit sensors was 40 mm. An electrical fuse and 3-g-RDX detonator were used to initiate the detonation process in the AN/Al mixtures. To exclude any influence of the initiating pulse on the detonation velocity, the measurement courses were located about 100 mm from the loaded boundary of the charge. The composition of the explosive mixtures and the results of measurements are presented in Table 1. The densities of explosive tested were approximately the same in all tests of present work. For comparison, the ideal detonation velocity is also given in Table 1. This velocity was estimated by the use of the thermochemical code CHEETAH [6] with the BKWC coefficients.

Table 1. Composition and detonation properties of AN/Al mixtures

Al contents [wt %]	Type of Al powder	Density [kg/m^3]	D_{exp} [m/s]	D_{ideal} [m/s]
10	Alf	970	2980	4669
	Alp	870	2940	4385
25	Alf	870	2680	4869
	Alp	970	2540	5359
40	Alf	760	no detonation	4084
	Alp	1030	no detonation	5239

No detonation is observed in the pure ammonium nitrate charges of 35-mm-diameter. Thus, the addition of 10% aluminium increases the sensitivity of ammonium nitrate charges and the detonation is stable. However, the explosion process disappears gradually in the charges of the mixture with 40% aluminium.

Heat of explosion

The heat of explosion of nonideal explosives was described in detail in Ref. [7]. A spherical steel bomb having an internal volume of 5.6 dm^3 was the main element of calorimetric system used for measurements. The bomb was filled with compressed argon (at a pressure of 2.0 MPa).

The 20-g-charge of explosive tested was ignited by the standard fuse and 3-g-RDX detonator. Two measurements were performed for each explosive mixture. The average values of the heat are presented in Table 2.

The results of measuring detonation velocity and relatively small mass of charges used in calorimeter tests suggest that only explosion (no detonation) takes place inside the bomb. However, expanding gaseous products of AN decomposition react with aluminium particles. Moreover, the shock waves reflected at the bomb wall may heat the explosion products and the additional heats of reactions proceeding in the reactive medium may be released. The final heat measured in the calorimetric system increases with increasing Al content in the mixtures. Explosives rich in aluminium powder (Alp) generate more energy than that ones containing flaked aluminium (Alf). Obviously this is caused by the higher content of aluminium oxide in the flaked Al.

Table 2. Experimental and calculated heat of explosion of the AN/Al mixtures

Aluminium contents [wt %]	Type of Al	Q_{exp} [kJ/kg]	Q_{cal} [kJ/kg]
10	Alf	4960	5448
	Alp	5510	
25	Alf	6400	7958
	Alp	7040	
40	Alf	7400	8866
	Alp	8260	

The measured calorimetric heat of explosion was compared with the heat of reaction calculated by the use of CHEETAH code. The heat was calculated from the equilibrium composition of reaction products confined in the bomb volume. The explosion heat obtained from the calorimetric tests is slightly lower than the calculated heat. This means that a significant part of aluminium powders take part in reactions with gaseous products of ammonium nitrate decomposition.

Quasi-static pressure (QSP)

QSP (quasi-static pressure) tests with explosive charges were performed in a chamber of about 0.15 m^3 volume. The chamber was filled with air under a normal pressure of about 0.1 MPa. The ambient temperature was about 15 °C. A charge was hung in the centre of the chamber. Charges of 25 g weight and about 30-mm-diameter were tested. A standard fuse and 3-g-RDX detonator were used to initiate the explosion. Three tests were performed for each investigated explosive mixture.

Signals of overpressure from two piezoelectric gauges (PCB Piezotronics, Inc.) located at walls of the chamber were recorded by a digital storage scope DS-8621 (Iwatsu Electric Co., Ltd.). Exemplary overpressure histories for the mixtures containing Alf and Alp are shown in Figures 1-2.

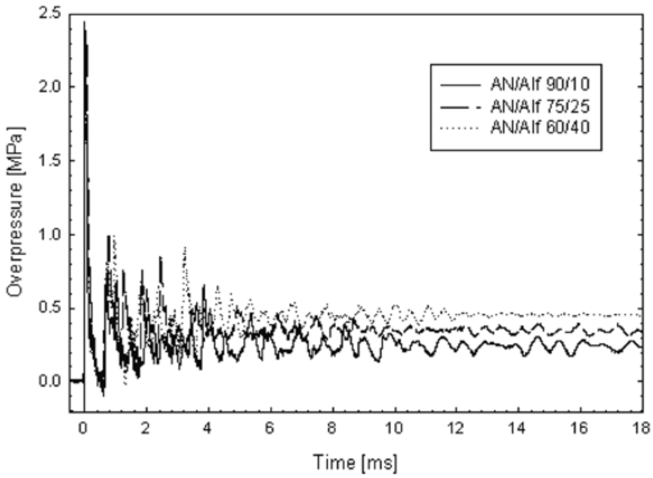

Figure 1. Exemplary overpressure histories recorded in the 0.15 m^3 chamber for ammonium nitrate/Alf mixtures.

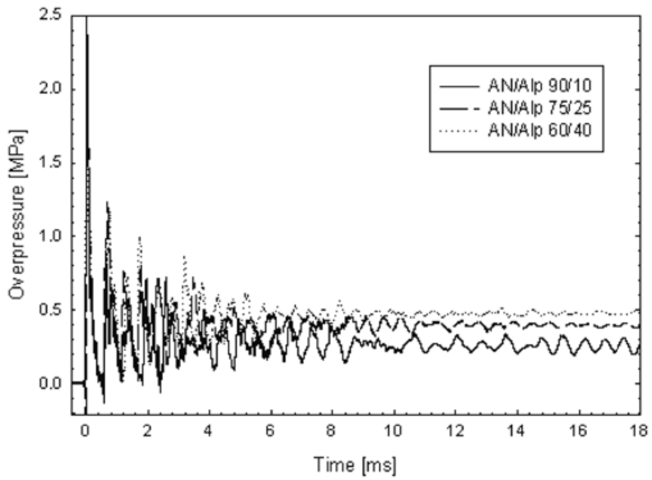

Figure 2. Exemplary overpressure histories recorded in the 0.15 m^3 chamber for ammonium nitrate/Alp mixtures.

The overpressure records have the oscillating nature. The main oscillations are caused by shock wave reverberation at the chamber wall. Their amplitudes decrease with time. The averaged overpressure is obtained by using the following formula:

$$\Delta p_{av}(t) = \Delta p_0 (1 - \exp(-at)) \exp(-bt) \tag{1}$$

where Δp_0, a and b are constants. The parameter Δp_0 can be treated as the maximal average overpressure (*Quasi-Static Pressure*) at the chamber wall.

Parameters Δp_0, a and b were evaluated for each overpressure history. The mean values of Δp_0 are presented in Table 3.

Table 3. Measured and calculated values of QSP for mixtures tested

Aluminium contents [wt %]	Type of Al	Δp_0 [MPa]	$\Delta p_{0,calc}$ [MPa]
10	Alf	0.32 ± 0.03	0.37
	Alp	0.34 ± 0.02	
25	Alf	0.37 ± 0.01	0.55
	Alp	0.44 ± 0.02	
40	Alf	0.45 ± 0.01	0.70
	Alp	0.48 ± 0.02	

To estimate the final overpressure in the chamber theoretically, thermochemical calculations were made by using CHEETAH code. A constant volume explosion state was determined for an explosive charge and air closed in the chamber. Apart from an explosive charge and air filling the chamber, the fuse and detonator explosives were taken into account in calculations. The results of thermochemical calculations are shown in Table 3.

The QSP values measured in the chamber for AN/Al charges are lower those calculated ones. The discrepancy become greater with increasing Al contents in the mixture. However, the fact should be taken into consideration that calculations were performed under an assumption of thermochemical equilibrium of the reactive mixture.

Blast wave parameters

Parameters of blast waves produced from free air explosion of investigated explosive mixtures were measured inside a concrete bunker in a manner allowing to avoid the influence of reflected waves. Two piezoelectric gauges were placed at distances of about 1.5 and 2.1 m from an explosive charge and they recorded the overpressure of an incident shock wave, sliding on the working surface of the device. The charge and pressure sensors were about 1.5 m above the ground.

Cylindrical charges used for measurements of blast wave parameters weighted 150 g and they had 40 mm diameter. To initiate the main charge, a fuser and a 3-g-booster made of RDX were used. Two tests were performed for explosive mixtures containing 10 and 40% aluminium. In addition to the AN/Al mixtures, phlegmatized RDX charges were also investigated. Exemplary results of blast wave measurements are presented in Figures 3-4.

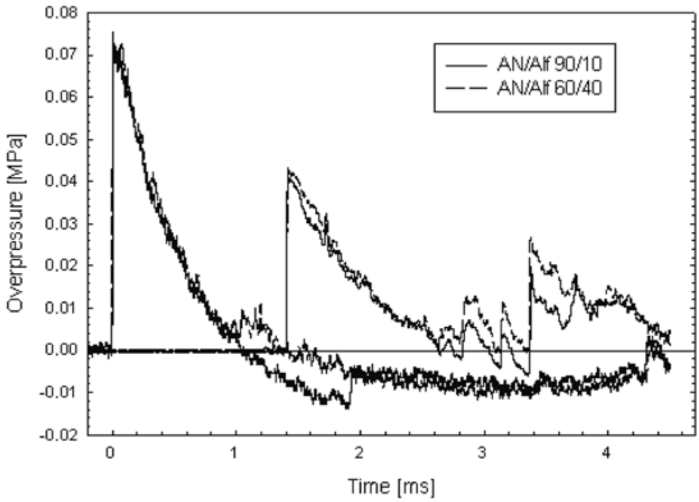

Figure 3. Overpressure profiles of incident blast waves for AN/Alf mixtures.

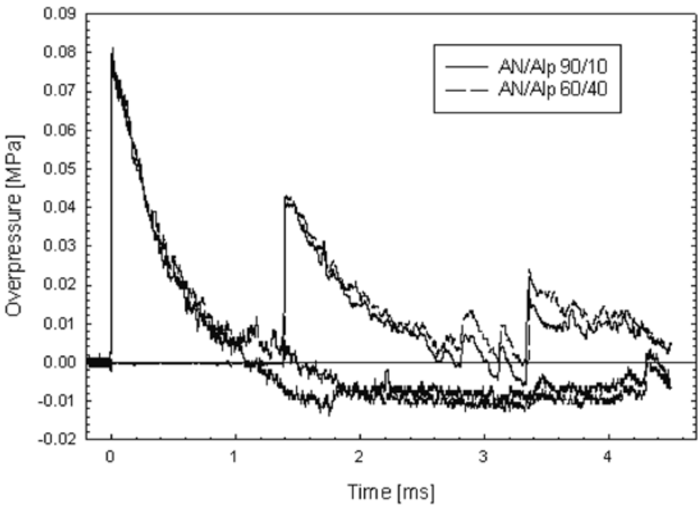

Figure 4. Overpressure profiles of incident blast waves for AN/Alp mixtures.

The averaged values of the overpressure peak (Δp_m), time-duration of a positive phase of overpressure (τ_+) and specific impulse (I^+) of incident blast waves are presented in Table 4. The differences between the average value and the extreme measured results are also shown.

Table 4. Measured parameters of blast waves for mixtures tested

Explosive mixture	Distance of 1.5 m from a charge			Distance of 2.1 m from a charge		
	τ_+ [ms]	Δp_m [kPa]	I^+ [Pa·s]	τ_+ [ms]	Δp_m [kPa]	I^+ [kPa·s]
AN/Alf 90/10	1.04	71.0 ± 2.5	28.9 ± 0.1	1.22	42.1 ± 1.0	22.1 ± 0.5
AN/Alp 90/10	1.05	78.5 ± 0.8	29.0 ± 0.4	1.30	41.9 ± 1.2	23.2 ± 0.2
AN/Alf 60/40	1.03	72.5 ± 4.2	31.8 ± 0.5	1.22	42.7 ± 0.6	26.2 ± 0.4
AN/Alp 60/40	1.46	77.5 ± 5.0	34.2 ± 0.5	1.60	45.7 ± 2.7	28.5 ± 2.2
RDXph	0.97	96.5 ± 5.0	32.3 ± 0.7	1.14	53.8 ± 1.2	24.2 ± 0.1

The experimental data imply that the amplitude of blast waves of tested aluminized mixtures are lower than that of measured for RDXph charges of the same mass. The ratio of maximal values of overpressure is about 73-80% at the first gauge and 80-85% at the second one. However, the relation between the impulses generated by the tested aluminised mixtures and RDXph is quite different. The ratio of impulses measured at the first gauge changes from 90 to 105%. At the second gauge, this ratio is from about 90% to 118%. This means that aluminium particles react with the decomposition products of nitrate ammonium behind the detonation wave and the reaction heat enhances the impulses.

Conclusions

The most important conclusions from this paper are:

1. The detonation velocity of AN/Al mixtures decreases with increasing aluminium contents from 10 to 25%. The explosion process disappears gradually in the charges of the mixture with 40% of aluminium.
2. The final heat measured in the calorimetric system increases with increasing Al content in the mixtures. Explosives rich in aluminium powder generate more energy than that ones containing flaked aluminium. This might be caused by the presence of aluminium oxide in flaked aluminium (active metal contents of about 82%).
3. The explosion heat obtained from the calorimetric tests is slightly lower

than the calculated one. This means that a significant part of aluminium powders take part in reactions with gaseous products of ammonium nitrate decomposition inside the calorimetric bomb.

4. The QSP values measured in the 0.15 m^3 chamber for AN/Al charges are lower those calculated ones. The discrepancy become greater with increasing Al contents in the mixture.
5. The quasi-static pressure measured for the mixtures containing flaked aluminium is lower than that of compositions with powder aluminium.
6. The overpressure peak of incident wave for tested aluminized mixtures is lower than that of recorded for RDXph. However, the ratio between the impulses generated by the tested aluminised mixtures is comparable with that measured for RDXph. This means that aluminium particles react with the gaseous products of ammonium nitrate decomposition behind the detonation wave.

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