Research of ANFO cylindrical explosive charge detonation in air using modern numerical modeling methods

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Introduction

Issues related to the air detonation require including basic factors, such as dimensions, shape charges and the type of explosive. These elements have a significant impact on the geometrical shape, pressure values and impulse of blast wave in air in different directions, especially close to explosion. Using computers models is possible very detailed analysis and quantitative assessment of the impact explosion on environment.

This paper presents the numerical results of ANFO cylindrical explosive charge based on ammonium nitrate with addition of aluminum and fuel oil. The results obtained in numerical simulation were verified experimentally. Research under real condition made it possible to determine the shape of detonation products and estimate impulse density in Held's Method.

Experimental part

Geometrical and numerical model construction

An approximate three – dimensional model of detonation in the air was constructed by using Ansys Ls-Dyna. Geometrical model is represented by cylindrical explosive charge placed in the air. Cylindrical shaped charge is characterized by the diameter d = 48 mm and length L = 240 mm. It is initiated as a central spot from the one end. Figure 1 shows the sketch of analyzed discreet geometrical model represented by the mesh. The model was built with 290,000 items.

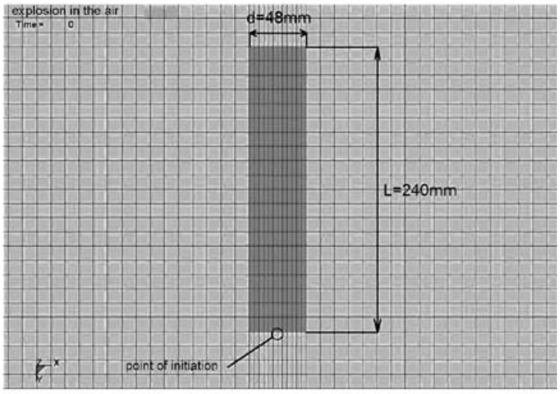

Fig. 1. Model description

For the explosives, JWL equation of state was used in form:

$$p = A\left(1 - \frac{\omega}{R_1}\cdot\frac{\rho}{\rho_0}\right)e^{-R_1\frac{\rho_0}{\rho}} + B\left(1 - \frac{\omega}{R_2}\cdot\frac{\rho}{\rho_0}\right)e^{-R_2\frac{\rho_0}{\rho}} + \omega E\frac{\rho}{\rho_0} \qquad (1)$$

where: p – pressure, ρ – density, E – internal energy, A, B, R_1, R_2, ω – material parameters.

For the air description EOS LINEAR POLYNOMIAL equation was used:

$$p = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E \qquad (2)$$

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where: p – pressure, E – internal energy, C_0, C_1, C_2, C_3, C_4, C_5, C_6 – material parameters.

Material parameters for ammonal basic on ammonium nitrate with addition of aluminum and fuel oil are shown in Table 1.

Table 1

JWL equation of state parameters for ANFO explosive

ρ_0 kg/m³	Pc-j GPa	A, GPa	B, GPa	R_1	R_2	ω
931.0	5.15	49.46	1.891	3.907	1.118	0.333

The modeling results

In numerical analysis process was obtained very wide set of results including time of detonation shape charge and expansion of detonation products in air. Below are presented selected parts of numerical calculations results in spatial 3D.

Figure 2 presents detonation process for shape charge with length 240 mm. Time of detonation is approximately 64 μs.

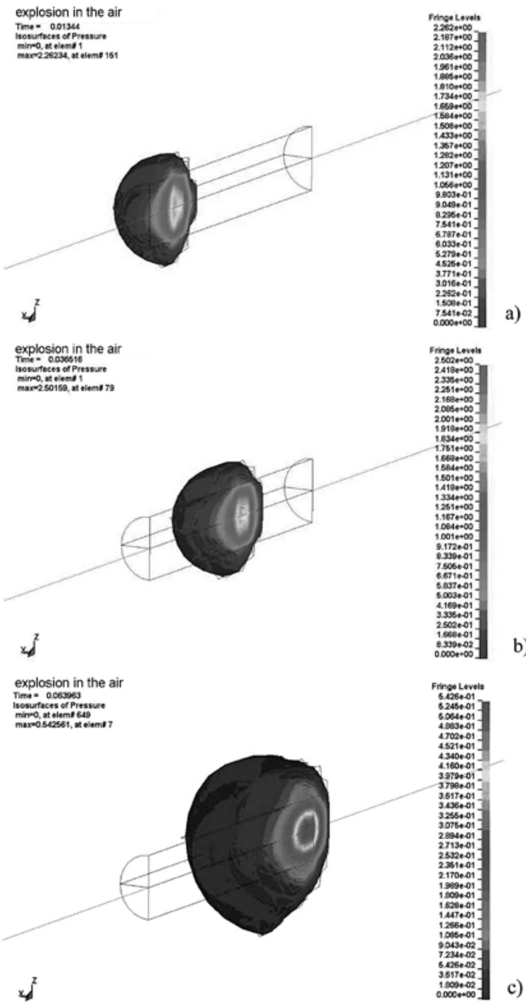

Fig. 2. Explosive charge detonation after: a) 13 μs, b) 36,5 μs, c) 64 μs

Expansion of detonation gas products with fringe levels shows Figure 3.

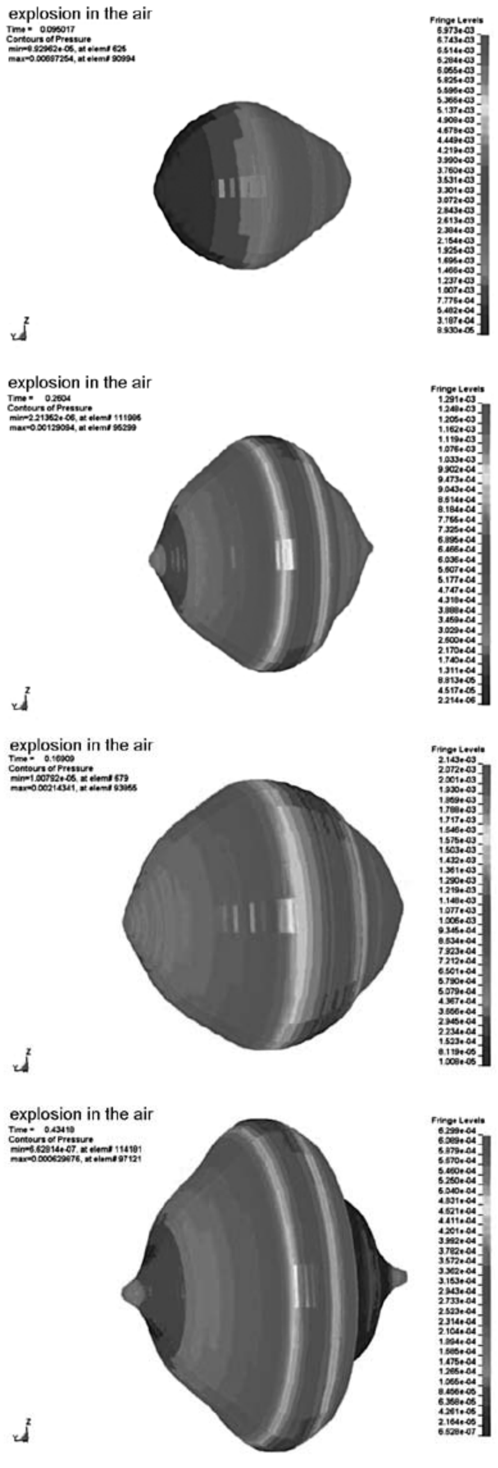

Fig. 3. Expansion of detonation gas products from 95 μs to 434 μs

In a 2D configuration (Fig. 4) shows a picture of detonation products and front of pressure blast wave, inducted after time about 1219 μs. Before spreading the detonation products is observed in air overpressure wave front.

Important for safety in blasting work are flagrant factors occurring during detonation. These factors include overpressure generated by shape charge. In order to determine blast wave overpressure in air were performed simulations for assumed model and were determined values of pressures in three directions: angle 0° (at the initial position), in a place under an angle of 90° to the direction of propagation of the detonation and angle 180° (opposite the igniter position). Figure 5 shows test arrangement of spaced measurement points.

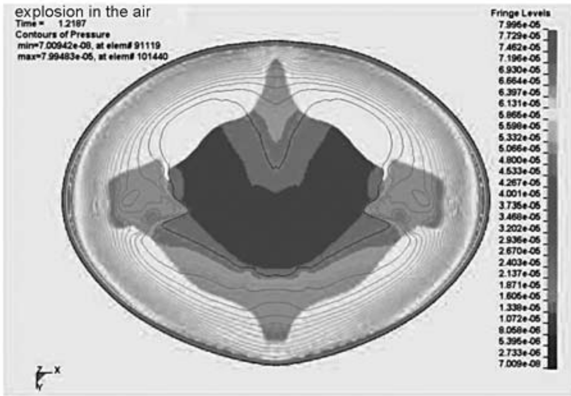

Fig. 4. 2D view of detonation products and blast wave overpressure

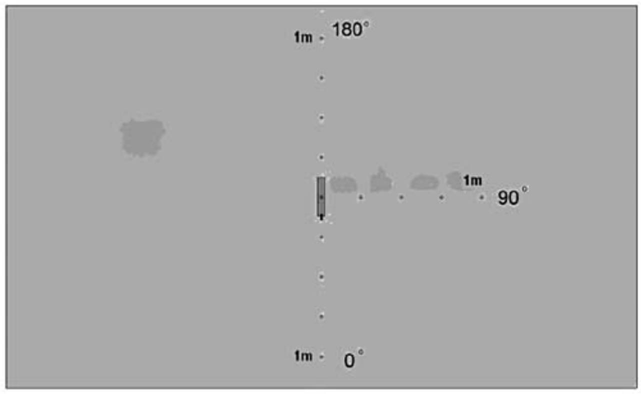

Fig. 5. Test arrangement of spaced measurement points

Figure 6 shows a graph of pressures obtained by numerical analysis at selected measuring points.

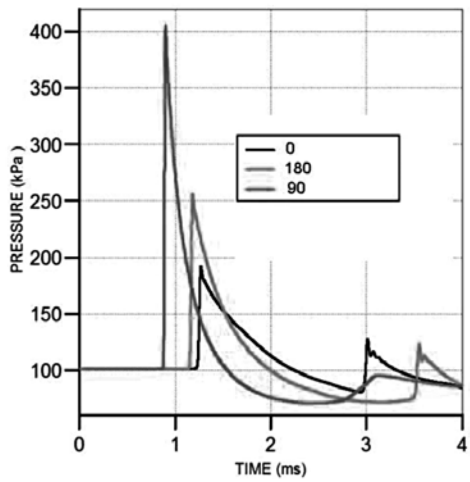

Fig. 6. Graphs of pressures obtained in modeling at a distance of 1 m

Based on the above graph can be concluded that the most damaging effect of pressure wave is generated in the direction of 90° orthogonal to the axis of charge (P_{max} = 405 kPa). Maximum pressure observed for the other direction is much lower: in direction 0° P_{max} = 192 kPa and in direction 180° P_{max} = 256 kPa.

Measurement of blast wave in Held's Method

Results for examination of ANFO explosive charges obtained from computer simulations were compared with the results obtained in proving ground researches. In proving ground were detonated charges with the following compositions:

- AN „EXTRA" 91.85 %. oil 4.51 %. Al flakes 3.64 %
- AN „EXTRA" 88.71 %. oil 4.02 %. Al flakes 7.27 %
- AN „EXTRA" 85.23 %. oil 2.65 %. Al flakes 12.20 %.

Cylindrical test shaped charges have a length 250 mm, diameter 42 mm and average density of 0.99 g/cm^3.

Photo 1 shows test setup with spaced relative to each other at an angle of 90° by three piezoelectric sensors. Sensor distance from center of explosive charge is 1 m.

Photo 1. Test setup in Held's Method with piezoelectric sensors

Held's Method allows to describe the impulse density blast wave for explosive charges based on scattered steel and aluminum probes. Table 2 summarizes the maximal and averaged values of the impulse densities all data or tested explosive materials. Values of the impulse densities I_{DS} are given in scaled form (I_{DS}), referred to the weight of the explosive charge.

Table 2

Maximal and averaged values of the impulse densities (I_{DS}) for tested explosives

Explosive %	Radius 0.5m Steel probes		Radius 0.75m Aluminum probes	
	I_{DS} 10^5Pa*s/kg$^{-1/3}$		I_{DS} 10^5Pa*s/kg$^{-1/3}$	
	max	av.	max	av.
AN 91.85 fuel 4.51 Al flaked 3.64	1.44E-002	5.19E-003	9.3E-003	3.18E-003
AN 88.71 fuel 4.02 Al flaked 7.27	1.14E-002	4.88E-003	9.02E-003	3.69E-003
AN 85.23 fuel 2.65 Al flaked 12.20	1.58E-002	5.36E-003	1.01E-002	4.02E-003

Figure 7 illustrates the averaged values of the scaled impulse densities I_{DS} for tested explosives.

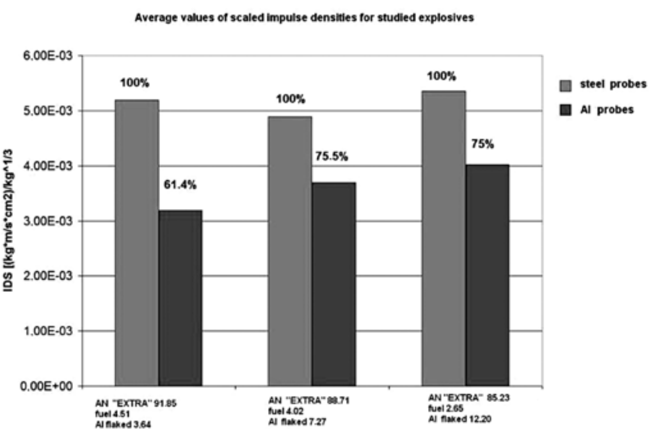

Fig. 7. Averaged values of scaled impulse densities for tested explosives

Figure 7 shows that for all tested ANFO explosives scaled impulse densities of steel probes (radius 0.5 m) is lower than for the aluminum ones (radius of 0.75 m).

Held's Method allows to describe expansion detonation products and pressure values as a function of the charge geometry. For this purpose, in the same time pressure measurements were performed using the blast wave piezoelectric pressure sensors with multi-channel digital oscilloscope.

After detonation explosive charge observed spreading probes, whose image shows a convergent shape of formation detonation products registered in the numerical simulation. Below are shown images recorded in a computer simulation (Fig. 8) and in experiment (Photo 2).

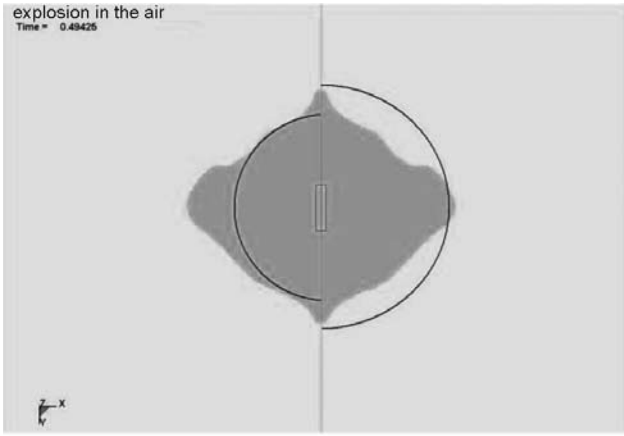

Fig. 8. Held's Metod – spreading detonation products in simulation

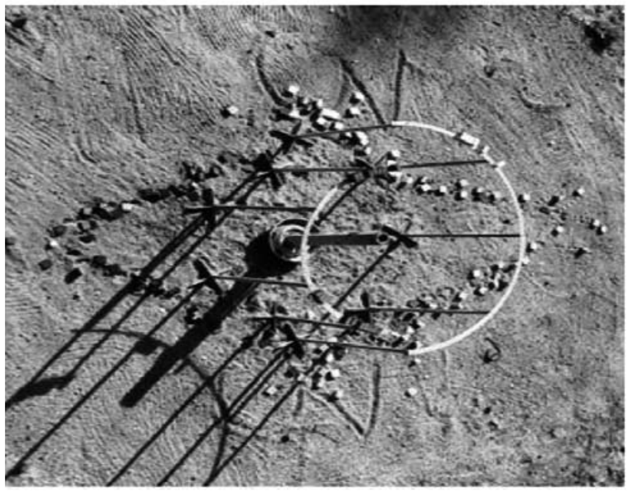

Photo 2. Held's Metod – spreading probes in experiment

Measurement of blast wave overpressure with piezoelectric sensors

In order to determine the value of overpressure generated from explosive charge following elements were used: digital oscilloscope (GwINSTEK GDS-2204 – the maximum sampling rate 1Gs s^1) and pressure sensors PCB Piezotronics Inc. Series 137A. Table 3 presents the parameters used sensors.

Table 3

Technical parameters of pressure sensors PCB Piezotronics Inc. Series 137A

Parameter	Unit of measure	Sensor 137A22	Sensor 137A23
Measuring range	kPa	0–3448	0–345
Resolution	kPa	0.069	0.069
Sensitivity (±15%)	mV/kPa	1.45	14.50
Maximum pressure	kPa	6895	6895

The results obtained from the experiment in three characteristic points are as fallows (Fig. 9):

- opposite the igniter position – registration on channel 1 (CH1)
- in a place under an angle of 90° to direction of propagation of the detonation – registration on channel 2 (CH2)
- at the initial position, angle – registration on channel 3 (CH3).

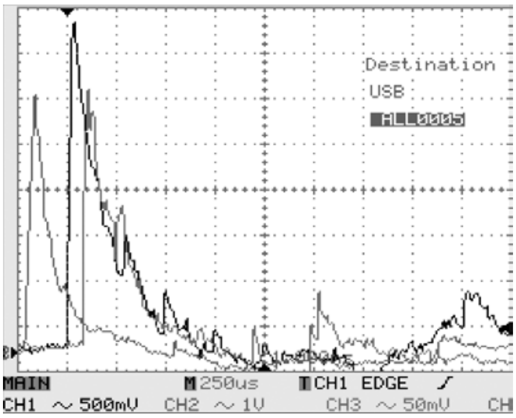

Fig. 9. Profiles pressure registered on oscilloscope

Table 4 presents results of maximum pressure registered on an oscilloscope with taking into account the sensitivity of each sensor and set the sensitivity of each channeloscilloscope.

Table 4

Results of pressure shock wave generated by means of pressure sensors

Channel oscilloscope No.	Sensor type	Sensitivity, mV/kPa	P_{max}, kPa
1	sensor 137A23 serial No. 7282	14.32	254.2
2	sensor 137A23 serial No. 7283	13.88	406.3
3	sensor 137A22 serial No. 7233	1.42	204.2

From a comparison the results obtained from measurements using sensors in proving ground experiment shows that, they are compatible with the pressure profiles obtained in a computer simulation, given the same time position of the individual pressure pulses. In addition, duration of pulse pressure (overpressure area) is similar and amounts to approximately 670 ms and 650 ms for case of the pressure recorded at 90°.

Conclusions

This paper presents results of processes taking place during the detonation and expansion of detonation products in the air. Detailed analyzes were ammonal cylindrical explosive charge. Processes taking place during detonation in air modeled in LS-Dyna Ansys as spatial models (3D). Due to computer analysis characteristics of the pressure wave and the shape of the detonation products cloud were estimated. Observations made on the computer give a clear picture of the phenomena occurring during the detonation and expansion of detonation products. Confirmation of a very rich set of results obtained from numerical simulation are results obtained experimentally. Both shock wave pressure measurement and image obtained from the spread of probes in Held's Method confirmed, that the greatest expansion of detonation products for examined shape charges occurred in perpendicular direction to axis of charge.

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Translation into English by the Author

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