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Praca doświadczalna / Research paper

Investigation of the initiating ability of conically shaped charges

Badanie zdolności inicjującej detonatorów o kształcie stożkowym

(Дослідження ініціюючої здатності детонаторів конічної форми)

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Abstract: The influence of the shape of donor charges on their initiating ability is investigated. The composition of these charges, based on chopped ammonium nitrate(V) and nitromethane in the ratio of 95-80% to 5-20%, was investigated experimentally. The composition has a detonation velocity of 3000-3300 m/s and a critical diameter of 5-9 mm. It is established that the use of the truncated conical form of donor charges with a truncated taper angle of 15°, 30° and 45°, contributes to the concentration of the detonation wave along its axis. The use in these charges of a composition based on ammonium nitrate(V) and nitromethane with low energy characteristics will increase the quality of blasting operations. For reasons of safety, it is proposed that mixing is carried out on-site.

Streszczenie: Zbadano wpływ postaci detonatora pośredniego na jego zdolności inicjujące. Mieszanka użyta w badanych stożkowych detonatorach pośrednich zawierała kawałki azotanu(V) amonu oraz nitrometan w proporcji 95-80% do 5-20%. Prędkość detonacji tej mieszanki wynosiła 3000-3300 m/s, a średnica krytyczna wynosiła 5-9 mm. Stwierdzono, że w przypadku detonatorów pośrednich o kącie stożka 15°, 30° i 45°, ze stożkiem ściętym, obserwuje się skupienie fali detonacyjnej wzdłuż ich osi. Zastosowanie detonatorów pośrednich z mieszaniną azotanu(V) amonu oraz nitrometanu pozwala na otrzymanie wyrobów o niskiej energii wybuchu, co powinno zwiększyć wydajność prac strzałowych. Ze względów bezpieczeństwa, proponuje się wytwarzanie, omawianych w pracy, wyrobów w miejscu prowadzenia prac strzałowych.

Keywords: charge, cone, initiating ability, detonation wave

Słowa kluczowe: detonator pośredni, stożek, zdolność inicjowania, fala detonacyjna

1. Introduction

At present, donor charges of a concentrated cylindrical or rectangular form based on TNT are used to initiate borehole charges, for example, T-400G checkers with a detonation velocity of 6.9 km/s [1]. Such intermediate

detonators are made by pressing the TNT in moulds. The efficiency of these charges depends on the density achieved during pressing.

The known intermediate ammonite 6ZhV charges contain 79% ammonium nitrate(V) (NH_4NO_3 , AA) and 21% TNT, while the components of ammonite 6GV are finely crushed, providing a detonation speed of about 3600 m/s with a cartridge detonator used as the donor in underground explosive works. Standard cartridges are made with diameters of 32 mm, 45 mm, 60 mm and 90 mm more often from ammonite 6ZhV, than ammonal. Ammonite 6ZhV is a finely divided mixture of crystalline potassium nitrate(V) with TNT in the ratio of 79:21. It is stacked on plastic shells on automatic devices, with a density of 1.0-1.2 g/cm³.

Donor charges are selected with the condition that their detonation velocity is higher than the detonation velocity of the borehole explosive, that is, the donor charge overdrives the acceptor.

With the development of new explosive compositions, such as emulsion explosives with a detonation velocity of 5.1 km/s, more powerful donor charges, for example, TNT-RDX TG-500, THF-500E, TNT-PETN, and others began to be manufactured [2]. The improvement of the characteristics of these charges was carried out at the expense of increasing the capacity of the used compositions, that is, the transition from TNT to hexogen, PETN and increased mass. The power of donor charges currently used is higher than the main charge, *i.e.* the initiation of borehole charges takes place in an overdriven state.

When a cylindrical charge is centrally detonated, the detonation wave propagates perpendicularly to the lateral charge axis. The force of the detonation wave along the charge axis is not sufficient to initiate the borehole charge. In this case, the front of the detonation wave becomes established in a well-charge with a detonation velocity characteristic of the charge, at a distance of two to four diameters of charge [3].

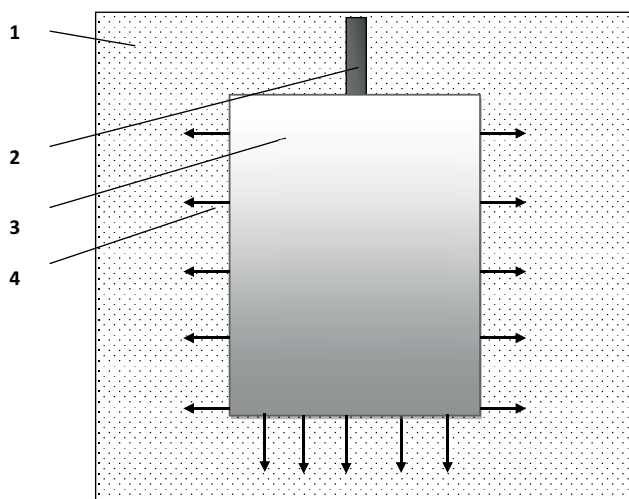


Fig. 1. Cylindrical concentrated charge with power detonation lines: 1 – borehole charge; 2 – capsule detonator; 3 – intermediate detonator; 4 – power lines of the detonation wave

To increase the effectiveness of initiation of the simplest explosives, it is proposed to use more powerful linear donor charges containing 100-200 g of explosive per linear meter [4, 5]. The linear donor has a length equal to the length of the main charge, with the front of the detonation wave directed to the walls of the borehole. The pressure of the detonation wave on the borehole wall will be much greater than at the initiation point. If, at the point of initiation of the charge, the pressure of detonation products (P) is determined (Equation 1) only by the density of the explosive ρ and its detonation velocity V :

$$P = \frac{\rho V^2}{n+1} \quad (1)$$

as linear initiation is dependent not only on the parameters of the main charge, but also on the detonation velocity of the linear initiator V and the angle of reflection of the detonation wave from the walls of the borehole. Unfortunately, the use of linear initiators is limited by both technical and economic considerations.

At the moment, there are practically no papers dealing with the influence of shape of donor charges on their ability to initiate borehole charges. In addition, there is no data on the use of formulations of donor charges with low energy characteristics, as well as studies on the influence of the mass of the donor on the output of the well bore charge on the stationary detonation regime.

The author carried out investigations on the influence of the design of donor charges on their ability to initiate borehole charges. When initiating a cone-shape donor charge at the wide end face, the detonation wave propagates perpendicularly to the lateral creations, which creates a cone, that is, its direction is practically perpendicular to the angle of the lateral surface of the donor's cone. This creates increased pressure between the lateral surface of the conical charge and the borehole wall to undermine the charge. The detonation wave, narrowing from the angle of the cone of the donor, covers the entire column of acceptor charge, limited by the borehole wall.

This concentrates the donor's detonation wave across the intersection of the borehole charge along its axis. With an increase in the angle of the cone, the diameter of the donor approaches the diameter of the acceptor, which promotes initiation over the entire diameter of the charge. The detonation wave, focusing along the axis of the donor and the borehole charge, covers the entire area and, like that of the cumulative charge, creates increased pressure. Thus, all the energy of the donor passes into the working explosive.

The truncated conical structures of the donor charge with a taper angles from 15° to 45° , with the transition to a cylindrical shape in the truncated part, are considered. A diagram of the conical charge with the direction of the force detonation lines is presented in Figure 2.

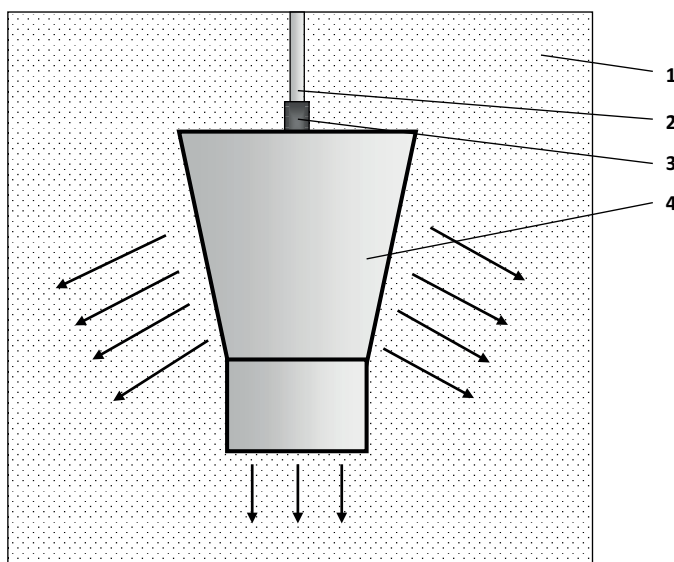


Fig. 2. Conical intermediate detonator in the well: 1 – borehole charge; 2 – detonating waveguide; 3 – capsule detonator; 4 – conical intermediate detonator

Investigations have been carried out on the possibility of using new compositions of intermediate donors based on AA and nitromethane (CH_3NO_2 , NM). AA and NM separately are not explosive materials and only added when the mixture acquires explosive properties.

AA is not an explosive substance and is mainly used as fertilizer in agriculture. According to GOST 2-85 it is also used as an oxidizer in the production of simpler explosives such as igdanite, where diesel is used as a fuel.

NM is the simplest nitro compound of the aliphatic series; a colourless liquid with a smell of bitter almonds, a boiling point of 101.2°C , a melting point of -29°C , a flash point of vapour in an open crucible of 45°C ,

a density of 1.138 g/cm³ and soluble in water (9.77%) [6]. It can be mixed with ordinary organic solvents (except for paraffins), is a good solvent for many organic and inorganic substances and forms an azeotropic mixture with water. NM is not sensitive to impact (0-8% for load 10 kg and height 25 cm) but sensitive to friction and flame. In recent years, due to the expansion of the class of industrial explosives for the mining and coal industry abroad, there is information on the use of NM with various substances, both as initiators of the explosion, and industrial explosives. It is known that NM is used as a component of rocket fuel and as an additive to automotive fuel to increase engine power.

Production of a composition based on AA was carried out as follows: the AA was dried, ground and sifted through a sieve with a diameter of cells of 200 μm . In a laboratory mixer with Z-shaped blades, the nitrate was mixed with NM, topping it in portions in the required amount. Four samples with a content of 5%, 10%, 15% and 20% NM were made.

2. Results

Thermodynamic calculations of these formulations of predicted formulations of explosives on the basis of AN and NM were carried out using the Avakyan method [7, 8]. This method makes it possible to calculate the energy characteristics of the explosive: the heat of explosion, the volume of gases in the explosion, the oxygen balance. The thermodynamic characteristics of AA compositions with NM are given in Table 1.

Table 1. Thermodynamic calculations of the AN:NM

Name of metrics	AA:NM ratio			
	80:20	85:15	90:10	95:5
Oxygen balance [%]	+8.14	+11.10	+14.04	+17.03
Heat of explosion [kcal/kg]	880	717	601	489
Temperature of explosion [K]	2278	1964	1735	1489
Volume of gases [dm ³ /kg]	949	958	963	972
Detonation speed [m/s]	3370	2985	2370	1780
Critical diameter [mm]	5-6	6-7	7-8	8-9

Note: Fullness of detonation of charge with a diameter of 20 mm is complete. The transfer of detonation between cartridges was 4-5 cm.

The crushed and dried ammonium nitrate was sieved to remove clumped particles, as well as to obtain crystals of a given size. A sieve made of metal (brass) nets № 04 with a nominal mesh size of 0.4 mm was used for the dispersion of AA. In this case, they received AA with a particle diameter no greater than 400 μm .

For testing, a composition based on 80% AA with 20% NM was used. This composition has a critical diameter of 5-6 mm, while the detonation velocity is about 3.3 km/s.

A conical donor was manufactured directly at the site of blasting operations (field testing). A dense papier mache facsimile of a given donor was fabricated from wooden models of tapered charges, which was filled with a pre-prepared mixture of AN:NM. For reliability, the papier mache was wrapped with tape. Intermediate donors with tapers of 15°, 30° and 45° were made to evaluate the brisance effect (Fig. 3).

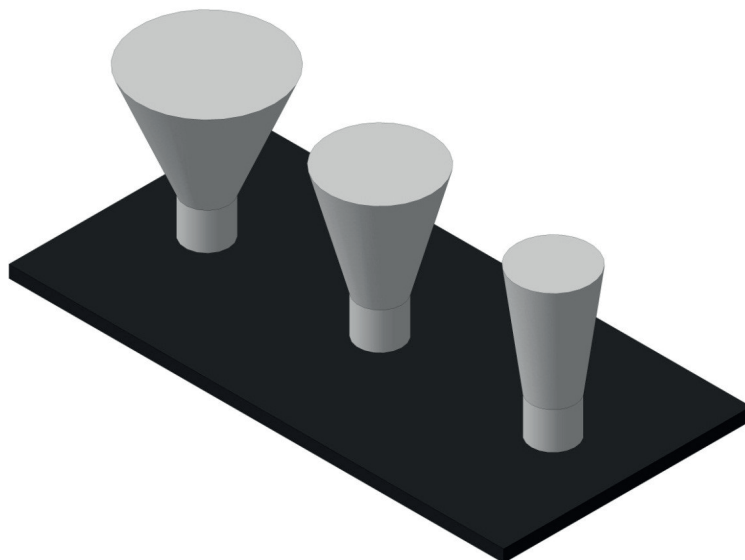


Fig. 3. Truncated conical initiation donors with cone angles of 45°, 30° and 15°

Tests of the conical donors were carried out on metal witness plates of 5 mm thickness (Fig. 4).



Fig. 5. An donor with a taper angle of 30° on a metal witnessplate

Brisance was estimated by the degree of break through of the metal plates using donors of different taper (Fig. 5).



Fig. 6. Estimation of the brisance of donors of different taper

Results of field tests (Fig. 6) for breaking through a 5 mm thick steel plate with donor charges of the following explosives:

- 1 – cylinder ammonite 6ZhV – 200 g,
- 2 – cone ammonite 6ZhV 30° – 150 g,
- 3 – cylinder AN:NM – 200 g,
- 4 – cone AN:NM 15° – 150 g,
- 5 – cone AN:NM 30° – 150 g,
- 6 – cone AN:NM 45° – 150 g.

Analysis of the results showed that when using truncated conical donors, the number of metal plates penetrated was greater than with larger cylindrical charges. Obviously, the mixture of AN:NM has a good penetration capability. The truncated conical shape of the donor increases the breaking capacity.

To confirm this conclusion, tests of a charge of granulate 79/21 were carried out using poured density charges of 80 mm diameter and 600 mm length. Charges were initiated by an electrodetonator ED-8 in conjunction with donors: a regular T-400G and a tapered donor with a taper angle of 30° and mass of 200 g. Measurement of the velocity of detonation was carried out by the Dotrich method at a distance of 100 mm from the donor and at a distance of 500 mm from the intermediate donor. The measurement base in all cases was 120 mm. In the application of a regular donor T-400G with a detonation velocity of 5.8 km/s, the initiation took place in an overdriven state (the detonation rate of granulate 79:21 bulk density is 3.75 km/s). In the application of a conical donor as an initiating charge, a composition of AA with NM in the ratio of 80:20, was used.

From Table 1 it follows that the detonation rate of the conical charge, with AN:NM in the ratio 80:20, is up to 3370 m/s. Thus, the initiation of the charge of granulate 79/21 by means of a tapered donor takes place in the undesired detonation mode.

Composite AN:NM has a high sensitivity to initiation, due to the low value of the critical diameter. The diameter of the wide conical part of the charge of the donor was selected as 80 mm, which ensured the angle of the cone of 25° and the equal diameters of the donor and the acceptor. The equal diameters of the two will provide a stable detonation rate of the acceptor at a minimum distance from the point of initiation [8]. The results of investigations are shown as Figure 7.

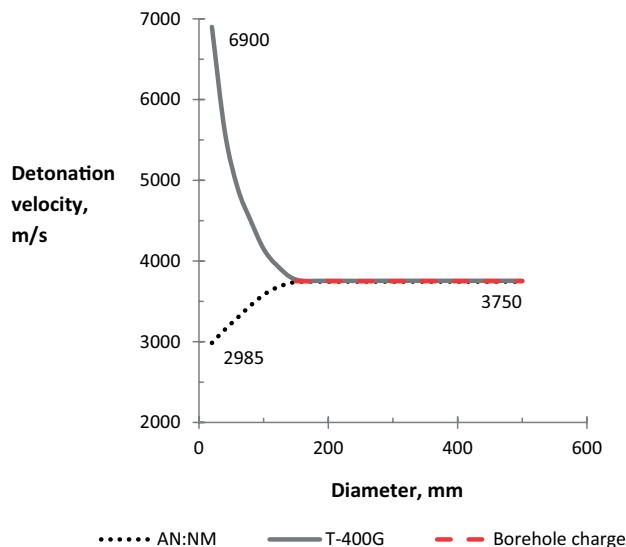


Fig. 7. Influence of the shape of the PD on the output of the granulate charge 79/21 on the stationary detonation velocity, depending on the distance from the initiator: AN:NM (intermediate cone shaped detonator weighing 200 g) and T-400G (checker)

It follows from the diagram that initiating the charge of granulate 79/21 as a powerful intermediate detonator with a T-400G (overdriven) and low power of the conical intermediate detonator (underdriven), the output of the stationary detonation rate was obtained at almost the same distance from the point of initiation [9]. This once again confirms that the conical shape of the donor ensures high pressure of the detonation products along the initiating charge axis and, therefore, increased initiating power. As a result, when using a conical donor, the run to a stable detonation of the acceptor, is less than that of a cylindrical donor.

3. Conclusions

A donor charge in the form of a cone is proposed. It was established that in this donor, the detonation wave travels along the charge axis. This creates an increased pressure on the acceptor charge and provides for the establishment of a stable velocity of the borehole charge at a small distance from the point of initiation.

The forms of conical donors are considered. Experimentally, on the metal witness plates, the brisance effect of these using different explosive compositions, depending on the angle of their taper, is shown.

As a formulation for these donors, a safe composition based on ammonium nitrate(V) and nitromethane has been proposed. Ammonium nitrate(V) and nitromethane are not separately explosive materials and only when mixed, acquire explosive properties with a low value of the critical diameter.

The composition for tapered donors based on chopped ammonium nitrate(V) with nitromethane in the ratio of 95-80% to 5-20% was experimentally investigated. The composition has a detonation velocity of 3000-3300 m/s and a critical detonation diameter of 5-9 mm. The composition works reliably from the capsule detonator ED-8 and detonating cord. It is proposed that the preparation of these explosives is carried out on sites of blasting operations by mixing non-explosive ammonium nitrate(V) and nitromethane and filling into pre-prepared conical glasses. This eliminates the transport of explosives around the country, adding to the safety of the population.

It has been experimentally proved that the developed low power conical donors provide the output of the borehole charge with a stable detonation regime at a small distance from the point of initiation. It is shown that when using a conical donor, the acceleration to a stable detonation of the acceptor charge is less at its lower mass than the standard T-400G.

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