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INVESTIGATION OF BREAKING PROBABILITY OF DETONATION PROCESS IN BLAST-HOLE CHARGES

The results on the researches of the influence of the process going on under the detonation of component blast-hole charges are give in this article. The limit number of joints between explosive charges is established that with 99% probability results in the failure of detonation.

Keywords: transmission of detonation, explosives, joints, the failure of detonation.

Introduction. The overwhelming number of industrial explosives are ammonically-saltpetre mixtures the main component of which is ammonium nitrate. Ammonium nitrate has low-grade explosive properties and its mixtures with individual explosives or non-explosive combustible components are kinetically inhomogeneous systems. As opposed to individual explosives under conducting detonation of industrial explosives, chemical reactions in the detonation front are going on in several stages. That's why they have lower ability and stability of detonation.

When conducting explosive works technical packaged explosives are used if a blast-hole charge consists of several explosive charges. The transmission of detonation between explosive charges also influences the stability and completeness of detonation of a blast-hole charge. In connection with this it is necessary to ground other parameters of detonation stability of explosives or the construction of blast-hole charges providing the completeness of their detonation in a blast-hole. This permits to provide safety and effectiveness of explosive works.

The analysis of the latest researches and publications. As it was established during previously conducted researches, special futures of detonation of industrial explosives are connected with stretching out of the area of chemical reactions and critical diameter of deto-

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nation, which is bigger than in individual explosives and which depends on the density of explosives. Specific recession of the detonation speed of industrial explosives is decreased directly after its maximum performance by the density grows of explosives answering certain critical density of explosives. Speed recession of detonation can be sharp that the detonation becomes unstable and can result in the failure of detonation under the increasing of density of explosives in a blast-hole charge beyond critical one.

It is shown in the works [1, 2] that the main reasons of failures of detonation and incomplete detonations of blast-hole charges and decrease on detonation ability of explosives under its dynamic compaction, separation of explosive charges in a blast-hole charge, the formation of dill fines obstacle, water obstacle, coal chippings obstacle and decrease of detonation ability of explosives under the influence of channel effect in the gap between the charge and the blast-hole wall.

Complex assessment of stability of blast-hole detonation that takes into account the mechanism of detonation transmission between charges and conditions of detonation of explosives is not given yet. It is the task that requires its solution. That's why the problem of enough stability of detonation of industrial explosives in blast-holes has big scientific meaning as it defines effectiveness and safety of their usage.

The aim of the work is researching of stability of non-stationary detonation of charges of industrial explosives in blast-holes considering anomalous dependence of their detonation characteristics on the density of explosives, the diameter, the transmission of detonation between charges of a blast-hole, charge and the compaction of explosives in the charge with the help of prior shock wave in the gap between the charge and the blast-hole wall.

Materials and results of the researches. As a result of the researches generalized dependence of imperfect speed of detonation of ammonite №6GV was obtained and expressed in form of complex function:

$$D = 5865{,}63\left(\frac{\rho_{BB}}{\rho_{кр}}\right)^{0{,}513}\left\{1-\exp\left[-0{,}64345\left(\frac{d_{BB}}{d_{кр}}\right)\right]\right\}, \text{ m/s},$$

where ρ_{BB} and $\rho_{кр}$ – the density of explosives and the density of a single crystal respectively, g/sm^3;

d_{BB} and $d_{кр}$ – the diameter of the charge and critical diameter of explosive respectively, mm.

Besides detonation characteristics of explosives the transmission of detonation between the cartridges influences the stability of detonation of the blast-hole charge.

The process of detonation transmission through inactive gaps was examined thoroughly in the work [3]. The influence of the parameters of inactive gaps on the pulsating nature of detonation was established and it was shown that the presence of gaps reduced the speed of detonation in the following blast-hole charges.

During the experiment in the work [4] it was ascertained that the transmission of detonation and its initiation in the inactive explosive charge took place in the zone where the parameters of a shock wave and the flow of detonation products from an active charge were so big that the pressure in the reflected wave front satisfied the inequality $\Delta P \geq 3*10^7$ Pa, if not the initiation of detonation is always preceded by the period of combustion of explosives.

In the work [4] the dependence for calculation of the mean critical flow speed $W_{кр}$ was established, necessary for initiation of detonation of explosives in inactive ammonite №6GV charge according to Garanson theory [4] through impedances for surrounding and the substance of explosives for the influence time on the inactive charge by air flow and explosion products of the active charge $\tau > \tau_{кр}$.

The dependences given in the work [4] permit to simulate the conditions of detonation transmission between the charges of explosives, setting the parameters of shock waves, formed by the explosion of the active charge and the value of critical speed of detonation of explosives in the inactive charge. Their critical quantities can be established using the experiment of the transmission of detonation between ammonite charges №6GV $W_{кр}$ =4530 m/s and $D_{кр}$=1270 m/s.

The processes that are going on during the explosion of the blast-hole charge can be presented the following way. In the active blasting cartridge the front of detonation moves with the speed D_1. Then during the transmission of detonation the detonation speed jump is observed between the cartridges through the inactive gap, that results in the change of detonation speed in the second cartridge D_2. The shock wave preceding the detonation front moves simultaneously with the process of detonation in the blast-hole charge in the air gap between the blast-hole charge and the blast-hole wall. It results in the packing of the charge and in the decrease its effective cross section. But as it is known, the speed of detonation falls with the decreasing of the charge more intensively then it rises from the explosive density increase. The shock wave reflects from the bottom of the blast-hole, at a certain distance it collides with detonation wave. It results in the pressure jump that causes even bigger repacking of the explosives and it can also cause the dumping or failure of detonation.

If we assume that the main reason of breaking of detonation of the charge when having the channel effect is the gas pressure that is caused by the shock wave in the gap, then the critical condition for spreading of detonation of explosives in the charge can be written down as non-dimensional proportion of the time of the charge detonation t_d and the time of external pressure effect on the explosives that cause their dynamic multiplexing t_m:

$$t_d/t_m \le 1. \qquad (1)$$

Then if the time of detonation will be less then the time of external pressure effect, then the detonation will spread, all over the blast-hole charge. Otherwise the process of detonation will be broken as a result of the dynamic multiplexing of explosives.

The time of detonation is the sum of the time of the chemical reaction and the time of the time delay of the initiation of detonation. According to the work [5], the time of chemical reaction can be calculated if we know the diameter of the charge, the speed of detonation of explosives in the charge and the ideal speed of detonation of explosives:

$$t_{ch.r.} = \left(\frac{5}{9}\right)^{0,5} \frac{d}{D}\left[1-\left(\frac{d}{D_i}\right)^2\right]^{0,5}, \qquad (2)$$

where d – the diameter of the charge, m;

D, D$_i$ – the speed of detonation of explosives in the charge and the ideal speed of detonation respectively, m/s.

The time delay of the initiation of detonation of explosives is generally observed between the joints of the cartridges and it depends on the properties of explosives and the quality of joints. In the work [6] the strong influence of the initiation of detonation delay between the joints of the charges on the detonation of the charge is observed. The nature of the initiation of detonation delay is connected with the fact that parameters of the shock wave between the joints of the cartridges decrease as much that the initiation of detonation in the inactive cartridge comes through intermediate stage of combustion and the delay of the thermal explosion of speed of detonation of explosives. As it is known [7], that the decomposition reaction of explosives during the initiation of detonation progress in a form of adiabatic explosion, then the delay of the thermal explosion is determined by the parameters of explosives and by the critical temperature of the compression of explosives by the shock wave. It can be calculated by the formula:

$$t_d = \frac{C_v R T_{cr}^2}{QZE} \exp\left[E \big/ R T_{cr} \right], \tag{3}$$

where T_{cr} – the critical temperature of explosives;

C_v – the thermal capacity of explosives in this temperature;

Q – the heat of decomposition of explosives;

Z, E – the parameters of Arrenius level;

R – the gas constant.

The time of multiplexing of explosives is characterized by the time of the action of external pressure on the blast-hole charge of explosives. It can be represented in the following way:

$$t_m = \frac{r_0 - r(P_{cr})}{U^/}, \tag{4}$$

where r_0 – the initial radius of the charge of explosives;

$r(P_{cr})$ – the radius of the charge corresponding to the critical radius of the detonation of the charge of explosives;

$U^/$ – the speed of compression.

According to the work [7], we can calculate the compaction speed of the process substance for the case, when the shocking wave compressing the charge is gliding one (spreading of the shock wave in the gap), using the formula:

$$U^{/} = P\left(1 - \frac{1}{k}\right)\left(\frac{1}{\rho_0} - \frac{1}{\rho_1}\right), \quad (5)$$

where P – the pressure in the shock wave front, compressing the charge;

k – the degree of air compression in the charge, $k=7$ according to [7];

ρ_0, ρ_1 – the density reflecting to basic explosives and the density of explosives corresponding to action of the critical pressure.

According to the experimental works results [8] and adjusted for thermal constants of explosives [9] and critical temperature of its inflammation T_{cr}=750K (work [10]) we can calculate the stability of detonation of the blast-hole constituent of the ammonite №6GV charge by the criterion (1):

- the time of chemical reaction is $4{,}246*10^{-6}$ s;
- the time of delay is $3{,}92*10^{-5}$ s;
- the time of detonation rising in the charge of explosives is $4{,}34*10^{-5}$ s;
- the time of multiplexing of explosives in the charge by the shock wave is $9{,}21*10^{-5}$ s.

Thus, the time of detonation and the time of multiplexing are of the same order. Rating due to criteria (1) gives the result that it is possible to use such mechanism of action of the shock wave and its influence during the channel effect on the detonation of explosives in the charge in which there are joints between the cartridges. However, analytical calculation does not allow taking into account the amount of joints in the charges the delay of detonation of explosives on the joint identifies as a limit case. In the reality limit cases of initiation of detonation of explosives with the delay do not always happen on the only joint between the cartridges. The possibility of such process rises with increasing of the number of joints and it can determine the stability of detonation of explosives. The experimental works by V. Zenin [11] confirm that supposition.

Using the results we can estimate the number of joints between the cartridges in the blast-holes, providing the failure of detonation of the charge of explosives with possibility 0,99. In the possibility of methods of estimation using Laplas integral theorem, we calculate the number of joints in the charge for the failure of detonation of explosives in the charge. The initial conditions are:

p=0,05; q=0,95; k1=1; k2=n; P(1,n)=0,99.

$$P(k,n)=\Phi(x_2)-\Phi(x_1)=\Phi\left(\frac{k_2-np}{\sqrt{npq}}\right)-\Phi\left(\frac{k_1-np}{\sqrt{npq}}\right).$$

By the inserting the initial conditions we can receive following results:

$$0,99=\Phi\left(\frac{n(-0,05+1)}{0,22\sqrt{n}}\right)-\Phi\left(\frac{1-0,05n}{0,22\sqrt{n}}\right),$$

$$0,99=\Phi\left(\frac{\sqrt{n}}{0,23}\right)-\Phi\left(\frac{1-0,05n}{0,22\sqrt{n}}\right).$$

Obviously, the quantity of joints n>1, therefore, $\frac{\sqrt{n}}{0,23}>\frac{1}{0,23}\approx 4,35$. Taking into account that $\Phi(4,35)=0,5$ and Laplas function is increasing function, we can assumed, that $\Phi\left(\frac{\sqrt{n}}{0,23}\right)=0,5$. Therefore:

$$0,99=0,5-\Phi\left(\frac{1-0,05n}{0,22\sqrt{n}}\right),$$

or

$$\Phi\left(\frac{1-0,05n}{0,22\sqrt{n}}\right)=-0,49,$$

it means that

$$\frac{1-0,05n}{0,22\sqrt{n}}=-2,34,$$

$$0,05n-0,515\sqrt{n}-1=0.$$

Solving the square equation we can find, that $\sqrt{n}=12$. So n=144. The detonation of the explosives on the joint is no doubt will damp with possibility 0,99 if the number of joints between charges will be equal or more than 144.

For the condition of Donbass, approximately 40…60 blast-holes are used during explosive works with the 3…6 cartridges of explosives in every blast-hole, and we can estimate the number of joints between the cartridges of explosives and the possibility of the failure for these conditions. The analysis of these results showed that in 65% of cases during explosive works we can observe the failure of detonation of blast-hole charges with the 99% probability. This demands creating the construction of the blast-hole charge without joints between the cartridges of explosives.

Conclusions. Resuming the results of the researches, concerning the stability of detonation of the blast-hole charge which consists of separate cartridges, we can make following conclusions.

1. Comparing of the time of detonation of explosives with the time of dynamic multiplexing during the channel effect shows that this time can be enough for establishing critical meanings of detonation parameters, especially adjusted for the time delay of initiation on the joints of cartridges. Growth of the number of joints between the cartridges of explosives results in the failure and non-full detonation.

2. It is established that the limit number of joints between the cartridges causing the failure of detonation of the blast-hole charge of ammonite №6GV is equal to 144 with 99% probability.

3. A reliable method of ensuring detonation stability of explosives in the blast-hole is using mono-charges and charging of the blast-hole on the full cross-section.

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ИССЛЕДОВАНИЕ ВЕРОЯТНОСТИ ОТКАЗА ДЕТОНАЦИИ ШПУРОВЫХ ЗАРЯДОВ

В работе приведены результаты исследования влияния процессов, протекающих при детонации составных шпуровых зарядов. Установлено предельное число стыков между патронами ВВ, приводящее с вероятностью 99% к отказам.

Ключевые слова: передача детонации, ВВ, стыки, отказ.

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ДОСЛІДЖЕННЯ ВІРОГІДНОСТІ ВІДМОВИ ДЕТОНАЦІЇ ШПУРОВИХ ЗАРЯДІВ

У роботі наведені результати дослідження впливу процесів, що протікають при детонації складених шпурових зарядів. Встановлена кількість стиків між патронами ВР, що призводить з вірогідністю 99% до відмови детонації.

Ключові слова: передача детонації, ВР, стикі, відмова.