IMPACT OF MULTICHARGE DETONATION ON EXPLOSION PULSE VALUE

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Abstract. The paper focuses on the detonation process of a proposed multicharge system with sections separated with a profile inert interval. Basing on previous research, authors examine the detonation process of a multicharge explosion with regard to the proposed blasting pattern. It is demonstrated that the use of different explosives results in significantly different explosion pulse values in each section of the charge. It has been noted that the profile inert interval has an impact on the pulse value at the bottom of a multicharge. Conclusions have been drawn on the feasibility of the proposed blasting pattern for thorough development of the bench bottom and controlling the lump size of the blasted rock mass.

1. Introduction
Currently amounts of extracted mineral resources, e.g. iron ore, are constantly rising. The primary reason for that is growing demand on the part of steel plants. It should be noted that to maintain such performance, open pit mines start operating in a high-bench mode. In its own turn, this poses certain problems in terms of drilling and blasting. Particularly, there is an issue of achieving a certain lump size of the blasted rock mass in order to control the quality of bench bottom development. Multicharge blasting is a widely applied solution to this problem. An important advantage of such charges is that combining different explosives of different yield, one can differentiate explosion energy across the height of the bench and control the lump size of the blasted rock mass. Authors propose achieving high-quality development of the bench bottom by implementing a profile inert interval and placing it between the sections of the multicharge. However, the detonation process of such charges has not yet been properly examined.

2. Materials and methods
Researchers from the Department of Blasting Operations, St. Petersburg Mining University, have developed a multicharge construction with sections separated by a profile inert interval aimed at high-quality processing of the bench bottom (Fig.1) [1].

To generate a profile inert interval, it is proposed using a gas dynamic locking device. The working principle behind this construction is based on the internal stemming reflecting the shock wave to the bottom section of the charging cavity and by this increasing the explosion pulse on the bench bottom line.
Figure 1. Multicharge construction with the sections separated with a profile inert interval

3. The study of the structure of the modified lead-tin-base bronze

Below there is an overview of the processes taking place in the charging cavity of the multicharge, composed of different-yield explosives, starting from the detonation moment. The length of the first section of the charge is expressed as $l_1$, the second one – $l_2$. Density and velocity of detonation are $p_01$, $D_1$ and $p_02$, $D_2$ respectively.

Initial shock wave parameters for each type of explosive on the boundary detonation products – surrounding medium are determined from the following condition [2]:

\[ \text{[Equation]} \]
\[ u_x = u_1, \quad (1) \]

where \( u_x \) – velocity of the boundary line; \( u_1 \) – velocity increment for detonation products in the expansion wave.

Taking into account that:

\[ u_{li} = \frac{2}{k-1} (c_{ni} - c_i); \quad u_{xi} = \sqrt{\frac{P_{ni}}{\rho_{a}} \left( \frac{1}{\rho_{a}} - \frac{1}{\rho_i} \right)}; \quad \]
\[ c_i = c_{ni} \left( \frac{P_{ni}}{P_{si}} \right)^{\frac{k-1}{2k}}; \quad P_{ni} = A \left[ \left( \frac{\rho_i}{\rho_a} \right)^{\frac{n}{n-1}} - 1 \right] \]

equation (1) can be translated into:

\[ u_{li} = u_{xi} = \frac{2c_{ni}}{k-1} \left[ 1 - \left( \frac{P_{ni}}{P_{si}} \right)^{\frac{k-1}{2k}} \right] = \frac{P_{ni}}{P_{si}} \left[ 1 - \left( 1 + \frac{P_{ni}}{A} \right)^{\frac{n}{n-1}} \right], \quad (3) \]

where \( k \) - isentropic factor; \( c_{ni} \) - initial sonic speed in detonation products; \( c_i \) - sonic speed in detonation products under pressure \( P_{ni} \); \( P_{si} \) - pressure at the shock wave front; \( P_{ni} \) - pressure at the detonation wave front; \( \rho_a \) - medium density; \( \rho_i \) - medium density under pressure \( P_{ni} \); \( A, n \) - factors characterizing shock compressibility of the medium; \( i = 1, 2 \) - indices characterizing first and second types of explosives, composing the first and the second sections of the multicharge respectively.

Detonation velocity \( D_i \) and initial increment of internal energy per mass unit \( \Delta E_i \):

\[ D_i = \frac{P_{ni} - P_a}{\rho_a u_i}, \]
\[ \Delta E_i = \frac{P_{ni} + P_a}{2} \left( \frac{1}{\rho_a} - \frac{1}{\rho_{ni}} \right), \quad (4,5) \]

where \( P_a \) - medium pressure before the shock wave front.

For the first and the second sections of the charge, remaining parameters can be defined by the following expressions [3]:

\[ P_{ni} = \frac{\rho_{01} D_1}{k+1}; P_{n2} = \frac{\rho_{02} D_2}{k+1}; \]
\[ c_{n1} = \frac{k}{k+1} D_1; c_{n2} = \frac{k}{k+1} D_2; \quad (6) \]

Basing on the results described in [6], time changes in shock wave parameters can be determined using the average pressure in the pipe filled with detonation products from two types of explosives (radial motion neglected) [4].

Cavity processes are analyzed for the case of instant detonation.

Taking into account homogeneity of the wave pattern, it will be sufficient to focus on two half-layers of the explosives with an origin of coordinates on the boundary line between them (Fig.2) [5].
Figure 2. A graph to the calculation of explosion pulse values

In the moment of \( t = 0 \), there is an expansion wave generated in the detonation products. Parameters of a steady-state shock wave can be calculated using the above mentioned equations (2) – (5), and then:

\[
u_s = \frac{2c_{2m}}{k - 1} \left[ 1 - \left( \frac{P_s}{P_2} \right)^{\frac{k-1}{2k}} \right]; D_s = \frac{P_s - P_{1m}}{\rho_s u_s}; c_s = \bar{c}_1 \left( \frac{P_{1m}}{P_s} \right)^{\frac{k-1}{2k}} \tag{7}\]

where \( s \) index stands for shock wave parameters, whereas \( m \) index is used for instant detonation.

The front of a simple expansion wave moves at the velocity of \( c_{2m} \). The boundary line between this wave and the steady-state expansion wave moves at the velocity, expressed as follows:

\[
u_s - c_s = \frac{1}{k - 1} \left[ 2c_{2m} - (k + 1)c_s \right] \tag{8}\]

At the center of the upper charge two waves collide, which is equivalent to their reflection from a rigid wall.

According to research on the detonation process in the charging cavity, described in [7], explosion pulse values can be calculated for different time intervals in each section of the charge.

Explosion pulse values for each section of the multicharge:

\[
I_1 = \pi d \int_{x_1}^{0.5l_2} i_1 \, dx \tag{9}
\]

\[
I_2 = \pi d \int_{-0.5l_2}^{x_2} i_2 \, dx \tag{10}
\]

where \( d \) – charge diameter; \( i_1, i_2 \) - specific pressure pulses in the upper and lower sections of the multicharge respectively.

Taking into account the profile inert interval in the lower section of the charge, resulting pulse value can be formulated as follows [8]:

\[
I_{2r} = I_2 + I_{n-1} = S_1 \int_{t_{n-1}}^{t_n} P_{o_{n-1}} \, dt \tag{11}
\]

4. Conclusion

Analysis of expressions (9 – 11) demonstrates the presence of a heterogeneous stress field along the length of the charge. Therefore, multicharge blasting with a profile inert interval creates shear
stress, provided that different sections of the charge have different energy concentrations. One can observe collision of detonation waves at a certain distance from the interval, which results in maximum values of compressive stress [9].

It should be noticed that the greatest effect from multicharge blasting is achieved when the properties of explosives differ as much as possible, and the primers are located as shown in Fig.1. In this case detonation products pulse along the charge height and create maximal heterogeneity of the stress field. By selecting the right types of explosives and defining their optimal ratio within the structure of the multicharge, it is possible to achieve impulse (manifold) loading of the rock mass and thus not only solve the problem of high-quality processing of the bench bottom, but also control the lump size of the blasted rock mass within a specified range.

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