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Effect of double-primer placement on rock fracture and ore recovery

Z.X. Zhang

Department of Arctic Technology, The University Centre in Svalbard, Longyearbyen, Norway

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ABSTRACT

The double-primer placement is based on the principle of shock wave collision. When two shock waves meet each other, the final pressure is greater than the sum of the initial two pressures. Stress analysis indicates that this should be favorable to rock fracture and fragmentation in blasting. This double-primer placement was tested in Malmberget mine by using electronic detonators, aiming to improve rock fragmentation. At the same time, another method, named DRB (Dividing Ring Blasting), was tested, too. Two production drifts in an ore body were taken as test drifts. In each test drift both methods were tried. For comparison, two nearest production drifts to the test drifts were taken as reference drifts. The results showed that on average the double-primer placement recovered more iron ore than either the DRB method or the ordinary method used in the reference drifts. In addition, fragmentation looked much finer and the eyebrow break became much less for the double-primer rings, compared with the reference rings.

1. Introduction

The placement of a primer (usually containing a detonator) in a blasthole plays an important role in rock blasting. Unfortunately, the importance of primer placement in rock fracture, fragmentation, and even ore recovery has not been well understood so far. An improper or even wrong primer position in engineering can still be found.

As only one primer is placed at each blasthole, the study in [1] by means of stress wave analysis shows that the best primer position is the middle of charged blasthole, in terms of detonation energy efficiency, rock fragmentation, and rock break in the roof of a drift. The production blasts had well confirmed the above theoretical analysis since the ore extraction and recovery had been largely increased, and the eyebrow break markedly reduced by the middle-primer method, compared with the old method used in the mine [1].

It is common practice for some operators to routinely put two primers into a blasthole, and their rationale is that using a second primer is insurance against either a poor initiator/detonator or a cutoff of the hole due to shifting rock caused by a previous delay firing [2]. In many mines and quarries, two primers are often placed in each blasthole. However, in many cases, one primer is placed at the bottom and the other close to the collar of a blasthole. The latter is usually taken as a backup in case of that a malfunction occurs for the bottom primer. In this primer placement, if the two primers are initiated at the same time, the collar primer will produce serious back break and even bring about a lot of detonation energy loss. If the collar primer is initiated later than the bottom one, the result is not good, either. In brief, a two primer placement with one primer close to collar should be avoided. The above description indicates that if two primers are placed in one blasthole, their positions are to be chosen scientifically. In this paper, the double-primer placement means that two primers with same delay time are placed at correct positions in a blasthole.

When this double-primer placement is applied to a blasthole, a collision of shock waves from two primer locations will happen. Different from elastic wave collision, a shock wave collision results in that the final pressure produced is greater than the sum of the initial two shock waves, according to shock wave theory [3]. An experimental study by Dawes et al. [4] well confirmed this theory in rock blasting. Their experiments showed that the amplitude of stress waves in rock mass due to two-primer placement in a blasthole was much greater than the double of the amplitude of the waves caused by one single primer in a similar blasthole. Their experiments indicate potential applications of a two-primer placement in rock blasting. After a long time when electronic detonators came into being, shock collision theory was used to improve fragmentation at Salvador mine [5]. Even by using NONEL detonators, the shock collision theory was applied to break down remained roofs in sublevel caving mining [6]. Due to the success in breaking down remained roofs, this theory was applied to reduce eyebrow break in Malmberget mine by NONEL detonators [7]. In order to further improve rock fragmentation in the same mine,

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E-mail address: zongxian.zhang@unis.no

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from 2011 to 2012 two blast methods were tested by using electronic detonators, one is DRB (Dividing Ring Blasting) method, originally developed for vibration control [8,9], and the other is the double-primer placement. In the DRB method, one ring is separated into two parts – upper one and lower one – in charging and blasting. The blastholes in the lower part of a ring whose upper part has been blasted in previous blasting are blasted one by one with a delay time between two neighboring holes, and then in the same blast the blastholes in the upper part of the next ring are initiated one by one with a delay time. In this way, the explosive in each delay time can be reduced by about 50% if the blastholes in a ring are divided at their middles. In order to improve the fragmentation in the upper part of a sublevel ring, a 10 ms delay time between two neighboring holes was employed in the upper parts of the DRB rings.

In terms of the above description, we will briefly introduce the shock collision theory, show how the stress and energy distributions are changed due to shock wave collision, and analyze the effects of shock collision on rock fracture and fragmentation. Then the test results for the double-primer placement in the mine will be presented and discussed.

2. Theory on shock wave collision

According to one-dimensional shock wave theory [3], when one shock wave with pressure P_1 meets another shock with pressure P_2, the final shock pressure P_3 produced is greater than the sum of the pressures of the initial two shock waves, i.e.

$$P_3 > P_1 + P_2 \tag{1}$$

This case is called shock wave collision. A shock wave collision is different from an elastic wave collision. In one-dimensional condition, as an elastic stress wave with stress σ_1 meets with another elastic wave with stress σ_2, the final stress σ_3 produced is equal to the sum of the stresses of the initial two elastic waves, i.e. $\sigma_3 = \sigma_1 + \sigma_2$.

In shock wave collision, the final pressure depends on both initial two shock pressures and the material. In the following, we will see how much the final pressure is increased by shock collision, taking TNT (cast) as an example. Assume a shock A with pressure $P_1 = 15$ GPa travelling in positive direction in the explosive (one-dimensional), as shown in Fig. 1. In the same explosive there is another shock B with pressure $P_2 = 15$ GPa travelling in negative direction. The Hugoniot values for TNT (cast) are $\rho_0 = 1.614\ \mathrm{g/cm^3}$, $C_0 = 2.39\ \mathrm{km/s}$, and $s = 2.05$ [3]. When the two shock waves approach each other head-on, the collision will cause two new shock waves that are reflected back in each direction.

We start with the Hugoniot curve for the new wave in negative-x direction. This Hugoniot is coming from state P_1, u_1, and that u_1 is positive, see Fig. 1 and Fig. 2. This state was arrived at by the initial shock A in positive-x direction, into $u_0 = 0$ material. The Hugoniot curve of this initial shock is

$$P = \rho_0 C_0 u + \rho_0 s u^2 \tag{2}$$

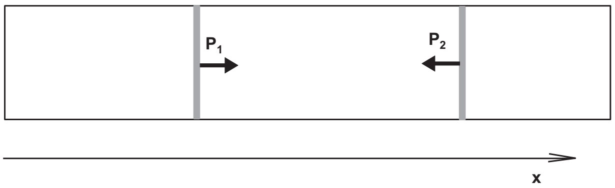

Fig. 1. Coordinate for shock collision.

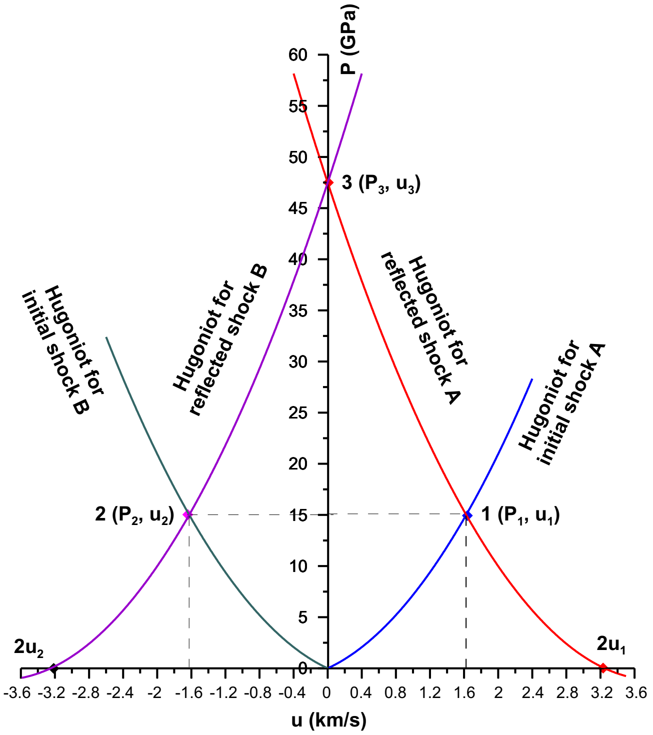

Fig. 2. Solution of shock wave collision caused by initial two shocks P_1 and P_2.

Since $P_1 = 15\mathrm{GPa}$, we get $u_1 = 1.625\ \mathrm{km/s}$ from Eq. (2). The Hugoniot curve for the new shock in negative direction must be rotated around this point and will intercept the $P_0 = 0$ or u axis at $2u_1$ (see Fig. 2), and its equation is

$$P = \rho_0 C_0 (2u_1 - u) + \rho_0 s (2u_1 - u)^2 \tag{3}$$

Now we consider the Hugoniot curve for the new wave in positive-x direction. This Hugoniot is coming from state P_2, u_2, and that u_2 is negative; see Figs. 1 and 2. This state was arrived at by the initial shock B in negative-x direction, into $u_0 = 0$ material. The Hugoniot curve of this initial shock is

$$P = \rho_0 C_0 (u_0 - u) + \rho_0 s (u_0 - u)^2 \tag{4}$$

Since $P_2 = 15\mathrm{GPa}$, $u_0 = 0$, we get $u_2 = -1.625\ \mathrm{km/s}$ from Eq. (4). The Hugoniot curve for the new shock in positive direction must be rotated around this point and will intercept the $P_0 = 0$ or u axis at $2u_2$ (see Fig. 2), and its equation is

$$P = \rho_0 C_0 (u - 2u_2) + \rho_0 s (u - 2u_2)^2 \tag{5}$$

The solution for the particle velocity after the collision can be obtained from equating the two Hugoniot Eqs. (3) and (5). This gives rise to

$$u_3 = 0 \tag{6}$$

Then the pressure at the interaction can be obtained by using this particle velocity in either Eqs. (3) or (5):

$$P_3 = 47.5\mathrm{GPa} \tag{7}$$

Obviously, $P_3 = 47.5\mathrm{GPa}$ is much greater than the sum $P_1 + P_2 = 30\mathrm{GPa}$ of the initial two pressures. In brief, the final pressure caused by shock wave collision is greater than the sum of the initial two shock waves.