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Explosion energy transmission under side initiation and its effect on rock fragmentation

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ABSTRACT

Side initiation is a common initiation method in rock blasting. Reasonable initiation methods have an important influence on rock fragmentation. In this study, the explosion energy-transmission process under the side-initiation method is analyzed. The rock-fragmentation result of side initiation and end initiation are compared with transition material blasting excavation field tests in the Changhe Dam. The results from this theoretical analysis and the field tests show significant differences in the partition of shock and gas energy between different initiation methods. In view of energy transmission, compared with end initiation, shock energy can be converted to gas energy, which results in a reduction in shock energy and an increase in gas energy. In addition, the side-initiation method is suitable for blasting in soft and fissured rocks and for contour blasting. It is unwise to use side initiation in the blasting of hard and compact rocks because it will reduce the proportion of shock energy.

1. Introduction

Deep-hole blasting technology has been widely used in mining, cutting excavation and hydropower engineering construction due to its high efficiency. Smooth blasting and presplitting blasting technology has been widely used to effectively control contours and overbreaks, which in deep-hole blasting and contour blasting involves placing a detonating cord along the wall of a blasthole before charging the explosive column. Then, the explosive column is continuously side initiated by a detonating cord.

Because a typical explosive column detonates in a very short time, one might view the initiation and propagation of a stable detonation front as occurring instantaneously. For some applications, this simplification can be made without significant error. Usually, people assume that a constant VOD applies starting at the time of initiation. Some studies have focused on the detonation characteristics of continuous side initiation, and important results have been obtained. Liang et al.[1] studied the detonation-propagation characteristics of superposition explosive materials by testing materials' detonation velocity. Their experimental results showed that the maximum detonation-propagation velocity depended on the explosive materials with the highest velocity of all explosive materials. Singh[2,3] discussed the interaction between ANFO and the detonating cord. He made a comparison with other products on the basis of half-cast factor and percentage overbreak and found that tracer blasting produced much less damage. Lownds and Du Plessis[4] conducted a series of experiments and found that transient steady detonation did not immediately appear in the main explosive column after being initiated by the detonating cord. On the contrary, a low-level lateral detonation wave that formed in the main explosive column followed the detonating cord front. Comparison tests between end and axial initiation methods were conducted in granite by Duvall and Pugliese.[5] The results showed that the axially detonated charges produced radial strain pulses that had shorter rise times than end detonated charges. However, their tests did not study the effect of continuous side initiation of blasting.

After the explosive is detonated, part of the energy is exerted immediately on the wall of the blasthole in the form of shock wave. The shock wave crushes the surrounding rock if the intensity of the stress is more than the dynamic compressive strength of the rock.[6] The outgoing shock wave also develops radial fractures due to tangential tensile stresses.[7,8] A zone of very high pressure and temperature gases occupies the blasthole behind the detonation front. These gases penetrate the crushed zone around the blasthole and flow into the radial or naturally occurring cracks. The gas pressure tends to wedge open the cracks and cause them to extend.[9] Recent studies have revealed that the stress wave is responsible for the initiation of the crushing zone and the surrounding radial fractures, and the gas pressure further extends the fractures.[10] Two basic forms of energy are released

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when an explosive reacts, namely the shock energy and the gas energy.[11] Rock fragmentation is the result of the combined effect of these two components.

Regarding the rock-fragmentation effect of shock energy and gas energy, Kurokawa et al.[12] conducted several blasting tests in 1 m^3 volume of cement blocks by adding aluminum powder to an emulsion explosive. The results showed that the gas energy was strongly correlated with the detonation velocity, and the shock energy had a slight influence on the breakage of rock mass. However, Brinkman[13] used a borehole casing method to prevent expansion gas from penetrating the surrounding medium to separate the effect of the shock wave and explosion products. His study indicated that the shock wave plays a leading role in the process of rock breakage while making little contribution to the heaving and throwing in rock blasting.

Xu and Gu[14] investigated the effect of a change in the ratio of shock energy to gas energy on the peak value of explosion stress waves and the distribution of fragment size by means of a comparison blasting experiment conducted in a concrete model with cylindrical charges. The total explosion energy was approximately equal. The experimental results showed that the distribution of the fragment size depended primarily on the combined action of the original wave and secondary wave. Furtney et al.[15] later expanded on this work by considering real explosive product isentropes in an elasto-plastic rock model which allowed calculation of these energy partitions from a rock deformation perspective. Other scholars, such as Konya et al.,[16] have conducted research on detonating cord initiation. However, due to the complexity of the experimental conditions and the detonation process, these conclusions have not been widely recognized, and some views even conflict with each other.

It is well known that the initiation method has a significant influence on rock-blasting fragmentation. However, previous studies have concentrated primarily on the influence of the initiation point position on rock fragmentation.[17,18] The fragmentation effect of continuous side initiation has not yet been studied in depth, particularly the influencing mechanism of the continuous side-initiation method on the partition of shock and gas energy. In engineering practice, the phenomenon of adopting of unreasonable and even wrong initiation methods is still widespread. Therefore, it is necessary to study the law of explosive energy transmission under the side initiation method and its effect on rock fragmentation. Such focus will help to further reveal the energy utilization in deep-hole blasting and contour blasting to provide an important theoretical basis for improving blasting techniques.

In the present study, the total energy of the explosive was kept constant, and the initiation method was varied. The aim was to investigate the partition of shock and gas energy between side initiation and end initiation. The theoretical analysis of the influencing mechanism of continuous side initiation method on the partition of shock and gas energy was also verified with the field study results in the Changhe Dam. On this basis, we put forward the selection principle of initiation methods for rocks of different intensities.

2. Mechanism of continuous side initiation

When using a detonating cord to initiate the explosive, we usually tie the cartridge explosive to the detonating cord or place a detonating cord along the wall of a blasthole before charging with the bulk explosive. To simplify the detonation process, most previous studies have assumed that the steady VOD of the main explosive applies immediately after being detonated by a detonating cord and have ignored the unstable detonation process after the detonation of explosives. Other researchers have argued that the detonating cord initiation belongs to a strong shock initiation. According to this view, because the detonating cord has higher detonation velocity and pressure than the main explosive column, it may 'overdrive' the adjacent explosive column after a 'run-down distance' to reach the steady-state VOD. The detonation process is shown as curve 2 in Fig. 1, the opinion that the detonating cord may overdrive the explosive column is obviously defective.

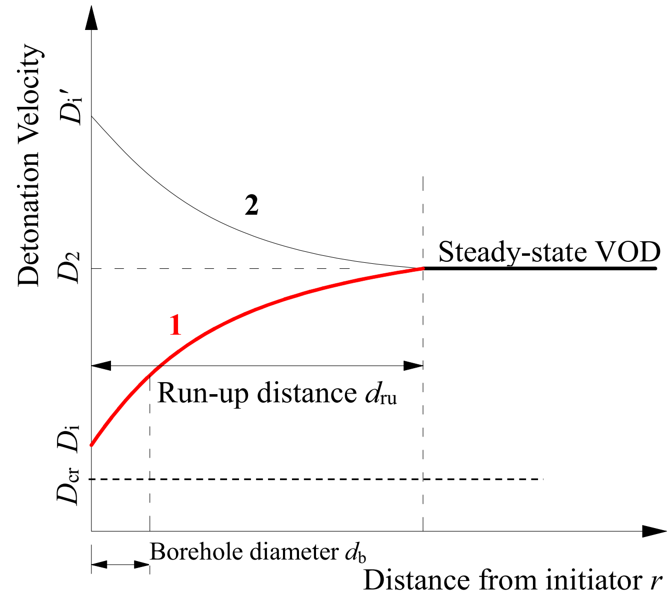

Fig. 1. Detonation process of explosives under shock wave.

Evidences have revealed an unsteady detonation process during the initiation process of explosives.[19,20] Furthermore, this unsteady process often cannot be ignored on the time and spatial scales, particularly for small detonation structures. The distance required to reach a steady-state velocity is called the 'run-up distance'. The run-up distance depends on the detonation pressure (or initiation velocity) and the strength of the main explosive.

When the velocity of the detonation shock wave exceeds the critical velocity D_{cr} but is lower than the steady-state VOD, the detonation of explosives will gradually grow in the radial direction after a certain distance to achieve a stable detonation, as shown in curve 1 in Fig. 1. As the input detonation velocity decreases, the run-up distance becomes longer. As observed, with a detonation velocity that is lower than the main explosive, a partial reduction in the detonation velocity of the main explosive is produced. The explosive columns are continuously side initiated by the detonating cord. The ordinary detonating cord is funicular blasting priming equipment that uses RDX or PETN as a continuous cord wrapped with cotton yarn, a paper slip layer and moisture-proof material packaging or plastic wrap, as shown in Fig. 2.

After the initiation of the detonating cord, the detonating cord front propagates along the axial direction with the velocity of D_1, then, the explosion gases of a high temperature and a high pressure penetrate through lateral wraps. Finally, the impact velocity D_i acts on the main explosive contact with the detonating cord is significantly lower than its axial detonation velocity D_1. This structure is similar to the decoupling charge structure. Although the detonation velocity of the detonating cord is higher than that of the main explosive, the lateral-impact velocity action on the main explosive is lower than that of the main explosive. Considering that the diameter of the detonating cord is much smaller than the blasthole, the detonation process in the main explosive caused by the side initiation of the detonating cord is an 'underdriven' transition zone. Therefore, the theory that continuous side