Journal of University of Science and Technology Beijing
Volume 13, Number 3, June 2006, Page 193

Mineral

Study on orientation fracture blasting with shaped charge in rock

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(Received 2005-03-24)

Abstract: On the basis of the theories of mechanics of explosive and rock fracture mechanics, the mechanism of crack initiation and its expansion of directional fracture controlled blasting with shaped charges in rock were studied, then the blasting parameters were designed and tested by a model test in laboratory and field experiment. The experimental and test results showed that the energy from blasting is directionally concentrated for the cumulative action. The directional expansion of cracks is satisfactory, the results of the model test and field test suggested that the orientation fracture blasting with shaped charge is a good means of excavating tunnels or cutting rock.

Key words: explosive mechanics; fracture mechanics; orientation fracture blasting; shaped charge; model test

1. Introduction

Stones for decoration or bowlder are excavated from ore bodies; however, the stones must be excavated with specific technique requirements. Experience shows that blasting is the method with low cost and high efficiency. The most familiar methods are smooth blasting and pre-splitting blasting. It is well-known that the split faces must be integrated when blasting is used to excavate stone. As for smooth blasting, there is a dilemma between charge quantity and the spacing interval of holes, which must be solved scientifically, and the formation of fracture face by smooth blasting is not good because the over-excavation or under-excavation is too much. Although the fracture effect of conventional pre-splitting blasting is better than that of smooth blasting, it needs specific drilling tools, which makes the drilling more difficult and the drilling efficiency is too low, all these badly restrict its popularization. To accurately control the fracture direction in rock by smooth blasting and pre-splitting blasting, scholars of Sweden had introduced shaped charge to blasting in rock and put forward the blasting method with linear shaped charges [1]. Scholars of China had been studying theoretically and carrying out large numbers of experiments with this technique. They had applied the technique to oil development, roadway tunneling, and metal cutting, and obtained satisfactory effects. In the meantime, they had been optimizing the structure of charges [2-4].

For the sake of optimizing the blasting effect of shaped charge, the author studied the directional fracture controlled blasting with shaped charges in rock. And this was made to control the formation of the fracture face accurately even though there are no specific requirements of holes, and popularized it.

2. Orientation fracture blasting with shaped charge in rock

Cumulative energy effect is called Mohaupt effect as well, which improves the local damage caused by the metal liners of shaped charges [5]. When the detonation wave from the initiation point reaches the outfaces of the liner, the liners are extruded intensively by the detonation wave and move with a high speed to their axial line or symmetry plane, the inner faces collide violently with each other, which leads to the fact that a mass of minute metal particles are extruded from the inner faces of the liner to form jets with high velocity, temperature and energy, *i.e.*, cumulative energy jet. At the same time, a pestle with a low speed is formed with the jet. As for the shaped charge with wedge shape liners, the shape of the formed cumulative jet is bladed. Compared to the charges without liners, the penetration ability of the charges with liners is improved greatly because of the cumulative energy jets.

The charge structure of the directional fracture controlled blasting with shaped charges in rock is specific, as shown in Fig. 1. The shaped charges are placed into holes, the direction of the open slot of the wedge-shape liner is consistent with the direction of the fracture and

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the holes must be sealed well. During the formation of the bladed jet, the shock waves and jet will impact the walls of the holes in the direction of the open slot of liners, hence, a slot (initial guide fracture) and a plastic zone of collapse will first come into being in the walls of the holes in this direction of the bladed jet. In the other direction, in time, owing to the inertia of the outtube of the shaped charge, the attenuation effect from the tube on the load of explosion products and hysteresis, the pressure in these directions decreases greatly. Although a fraction of stress waves transmit through the tube, tney need to propagate in the air gap between the tube and the walls of the holes before impacting the walls of the holes, the butter effect of the air gap makes the pressure decrease lower, so the impact on the walls of the holes by explosion gas is mitigated in high limit and cracks cannot expand, they can not even form in these directions, the integrity of the surrounding rock is maintained accordingly.

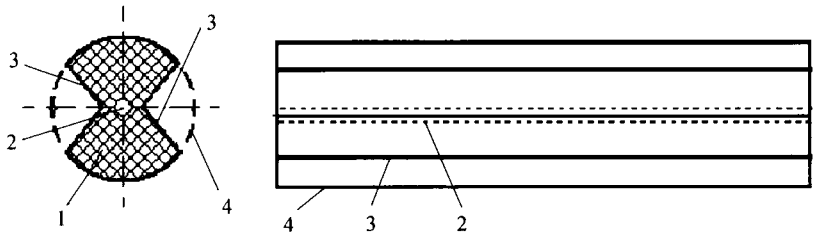

Fig. 1. Structure of shaped charge with wedge-type liner. 1—explosive; 2—booster hole; 3—wedge-shaped liner; 4—tube.

After the effects of cumulative energy jet and shock wave, the explosion gases with high temperature, pressure and velocity will burst into the initial guide fracture and distend in it, which is hence called the wedging action. At the same time, tension stress concentration can happen in the crack tip. According to the theory of fracture mechanics, when the (tension) stress intensity factor of the crack tip exceeds the fracture toughness of the rock, the crack will propagate because of destabilization, the wedging action and stress concentration will accelerate the propagation. In the end, the rock is split in the scheduled direction. If the shaped charges in two or more holes detonate synchronously, superposed stress fields between adjacent holes will emerge and the tension stress increases. When the superposed tension stress is greater than the tensile strength of rock, the split will form. If the spacing interval of holes is appropriate, through cracks between the two adjacent holes even smooth faces will form. In a way, the accurately directional fracture controlled blasting is realized.

3. Mechanism of crack initiation

According to the theories of rock fracture mechanics, in the process of crack expansion, the stress intensity factor (K_I) of the crack tip, is expressed by the following equation:

$$K_I = pF\sqrt{\pi(r_b + a)} \tag{1}$$

where p is the quasi-static pressure of gas in the crack, a is the length of the crack, r_b is the radius of the hole, F is the coefficient of correction of the stress intensity factor [6], $F = F[(r_b + a)/r_b]$.

When the slot (initial guide fracture) is formed in the wall of the hole by the bladed jet, if the gas pressure in the hole can make the stress intensity factor of the crack tip (K_I) and fracture toughness (K_{IC}) meet the following equation,

$$K_I \geq K_{IC} \tag{2}$$

Then the crack will emerge at the tip of the guide slot and expand in the predefined directions. Otherwise the crack will be arrested. Therefore, according to Eqs. (1) and (2), the necessary condition of crack expansion is expressed by the following equation:

$$p \geq \frac{K_{IC}}{F\sqrt{\pi(a + r_b)}} \tag{3}$$

With the expansion of cracks and the decreasing of gas pressure in the holes, the driving force of crack expansion decreases and the crack will be arrested as long as the following equation is met,

$$p < \frac{K_{IC}}{F\sqrt{\pi(a + r_b)}} \tag{4}$$

On the basis of the theories of rock fracture mechanics and Mohr-Coulomb criterion, the following equation can be obtained easily,

$$a_0 = \frac{B}{2}\cot\frac{\theta}{2} \tag{5}$$

where a_0 is the depth of the initial guide fracture; θ is the included angle of the guide slot, $\theta = \frac{\pi}{2} - \phi$, ϕ is the internal friction angle of the rock; B is the base breadth of the wedge-shaped liner.