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Application of high-pressure water jet technology and the theory of rock burst control in roadway

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ABSTRACT

This paper puts forward using high-pressure water jet technology to control rock burst in roadway, and analyzes the theory of controlling rock burst in roadway by the weak structure zone model. The weak structure zone is formed by using high-pressure water jet to cut the coal wall in a continuous and rotational way. In order to study the influence law of weak structure zone in surrounding rock, this paper numerically analyzed the influence law of weak structure zone, and the disturbance law of coal wall and floor under dynamic and static combined load. The results show that when the distance between high-pressure water jet drillings is 3 m and the diameter of drilling is 300 mm, continuous stress superposition zone can be formed. The weak structure zone can transfer and reduce the concentrated static load in surrounding rock, and then form distressed zone. The longer the high-pressure water jet drilling is, the larger the distressed zone is. The stress change and displacement change of non-distressed zone in coal wall and floor are significantly greater than that of distressed zone under dynamic and static combined load. And it shows that the distressed zone can effectively control rock burst in roadway under dynamic and static combined load. High-pressure water jet technology was applied in the haulage gate of 250203 working face in Yanbei Coal Mine, and had gained good effect. The study conclusions provide theoretical foundation and a new guidance for controlling rock burst in roadway.

1. Introduction

Rock burst refers to the dynamic process of sudden and intense release of elastic energy accumulated in coal-rock mass during underground mining [1]. Rock burst can cause disasters such as gas explosion, abnormal gas-effusion, water inrush and other major disasters. Statistics show that 75% of rock burst disasters have occurred in the haulage gate and material gate of working face. Therefore it is of great significance to study the prevention of rock burst technology in roadway [2–4].

Domestic and foreign scholars considered controlling rock burst in roadway from the aspects of pressure relief and support, and a lot of theoretical and practical research had been conducted. In the aspect of support, since 1960s, Rabcewicz put forward a new "NATM". Since then, Jing et al. put forward the roadway support theory based on broken surrounding rock [5]. He et al. put forward the theory of key parts coupling combined support system, which realized the support system and surrounding rock to share the load to improve the stability of surrounding rock [6]. Kang et al. studied the characteristics of two kinds of high-stress roadway under the condition of strong dynamic pressure in deep mining, and put forward the theory of high pre-stress and strong support, and high-stress roadway support design criterion [7]. Zhang et al. studied the stability control of surrounding rock in deep mining, and put forward the model of "three high" anchor control technology [8]. The previous research have formed mature support theories and technologies, however, the rock burst still occurs frequently in roadway. On the basis of support theory, many scholars had proceeded thorough researches in the aspect of pressure relief. Dou et al. put forward intensity weakening theory for rock burst [9]. Lu et al. put forward intensity weakening control theory for rock burst [10]. Gao established the mechanical model of "strong-soft-strong" (3S) structure in rock-burst roadway [11]. Pan et al. studied the results of micro-seismic monitoring, and the theory of rock burst start-up was put forward [12]. The theory claimed that rock burst occurred in roadway had three periods: rock burst start-up, rock burst energy transfer and rock burst occurrence.

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The above research have important significance for support and prevention of rock burst. The studies pointed out the disadvantages of traditional ways of pressure relief on the basis of support methods in Yanbei Coal Mine. For instance, pressure release blasting in deep holes technology can produce a certain range of distressed zone by instantaneous blasting [13,14]. However, if the quantity of explosive is not reasonable, it may lead to insufficient pressure relief or release a lot of blasting energy and induce rock burst. High-pressure water injection technology has advantages of easy operation and low standard rate, but its mechanism is still a difficult problem and some of the construction process is determined by experience [15]. Large diameter drilling technology is easy to operate and its pressure-relief efficiency mainly depends on the diameter of drilling, however, the larger the drilling, the more energy and mechanical wear [16]. Lin et al. had successfully applied high-pressure water jet technology in the field of prevention of coal and gas outburst [17,18]. This paper creatively put forward using high-pressure water jet technology to control rock burst in roadway. This paper analyzed the influence law of weak-structure zone in roadway by mechanics model and FLAC3D numerical simulation, and the field test and field monitoring were applied in the haulage gate of 250203 working face in Yanbei Coal Mine. It shows that the distressed zone can effectively control rock burst under dynamic and static combined load. The authors attempt to propose a new approach for controlling rock burst based on the high-pressure water jet technology.

2. Prevention of rock burst mechanism in weak structure zone

2.1. Weak structure zone

There are two ways for high-pressure water jet to cut the coal. Fig. 1a demonstrates that high-pressure water jet can cut the coal in a discontinuous and rotational way. Fig. 1b demonstrates that it can cut the coal in a continuous and rotational way. The way of Fig. 1a can achieve pressure relief and strong permeability in the coal, and this way can provide advantageous condition for gas release and stress relieving. The way of Fig. 1b can form large range of distressed zone, and the distressed zone can transfer and reduce the concentrated static load. The way of Fig. 1b can form weak structure zone in the coal and effectively control rock burst.

2.2. Mechanism of weak structure zone

When the roadway is excavated, the in-situ stress field is destroyed in strata, and the stress in roadway surface is relieved, so that the surrounding rock changes from triaxial stress state to plane stress state. It means that the in-situ stress field will form a new state of plane stress, and there will form concentrated static load in roadway. According to the energy criterion, when the releasable energy stored in coal-rock mass is greater than the energy itself consumed, the system of coal-rock mass breaks its own equilibrium state and rock burst occurs. The energy judgment criterion of rock burst is expressed as Eq. (1).

$$\frac{dE_s}{dt} + \frac{dE_r}{dt} > \frac{dE_b}{dt} \quad (1)$$

where E_s is the energy stored in coal; E_r the energy stored in rock; and E_b the energy consumed when rock burst occurred.

According to the energy criterion, when the roadway is excavated, the concentrated static load σ_s and the concentrated dynamic load σ_d can induce rock burst, as shown in Fig. 2. The energy judgment criterion of rock burst is expressed as Eq. (2).

$$\frac{dE_s}{dt} + \frac{dE_r}{dt} + \frac{dE_d}{dt} > \frac{dE_b}{dt} \quad (2)$$

where E_d is the energy of the concentrated dynamic load.

Eqs. (1) and (2) demonstrate the mechanism of two kinds of typical rock burst in roadway from the perspective of energy criterion. When a new roadway is excavated, using high-pressure water jet to cut the coal wall can transfer the concentrated static load σ_s to the deep coal wall and reduce the its maximum peak. New concentrated static load σ_s' and new energy E_s' will be stored in the deep coal wall. In this process, the variation of energy stored in the coal wall is expressed as Eq. (3).

$$E = E_s - E_s' \quad (3)$$

where E is the variation of energy stored in the coal wall.

Using high-pressure water jet to cut the coal wall, a certain range of weak structure zone can be formed in the coal wall. The weak structure zone makes coal wall produce a certain extent of plastic deformation. Its strength becomes low and its porosity becomes large. With the change of physical properties of coal-rock mass in the weak structure zone, the travel time of elastic stress wave will add Δt. When the energy of concentrated dynamic load goes through the weak structure zone in the form of elastic stress wave, the weak structure zone can scatter and absorb the elastic stress wave and the elastic stress wave will decay. The weak structure zone can effectively weaken the influence of dynamic and static combined load in roadway. As there is a weak structure zone, the energy judgment criterion of rock burst is expressed as Eq. (4).

$$\frac{dE_s'}{d(t+\Delta t)} + \frac{dE_r}{d(t+\Delta t)} + \frac{dE_d}{d(t+\Delta t)} < \frac{dE_b}{dt} \quad (4)$$

where E_d is the energy of concentrated dynamic load; and Δt the addition of travel time.

Weak structure zone is formed by using high-pressure water jet technology. This technology can make the maximum peak of original concentrated static load σ_{max} reduce to σ_{max}', and it also lets the maximum peak area move to the deep coal wall, and in the width range of B, the average value of concentrated static load P_n decreases to a low level. Based on Terzaghi theory, the mechanical model of Fig. 3 shows that when the floor of OCDF area is in a

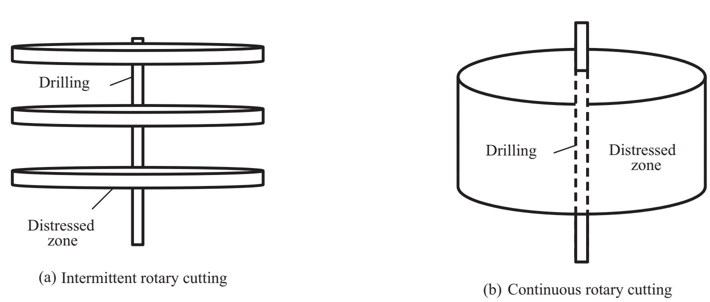

Fig. 1. High-pressure water jet cutting the coal schematic diagram.

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