

Energy Mechanism of Rock Burst in the Rock-Coal Combined Body

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Abstract—Rock burst hazards during deep mining are a dynamic phenomenon of the sudden release of elastic energy aggregated in the roof rock-coal combined body. In this paper, the occurrence mechanism of rock burst for roof rock-coal combined body was studied through energy dissipation theory. And the elastic energy attenuation degree of combined body was defined. Additionally, the effects of height ratio of roof rock to coal and elastic modulus of roof rock or coal on the rock burst were analyzed in the potentiality of the combined body. Results show that the elastic energy attenuation degree is positively correlated with the equivalent elastic modulus of combined body. And the equivalent elastic modulus is shown to a positive correlation with the height ratio of roof rock to coal and elastic modulus of roof rock or coal. Generally, the larger the height ratio and elastic modulus of roof rock or coal are, the great the equivalent elastic modulus is and the stronger the elastic energy attenuation degree is. And the roof rock-coal combined body easily occurs in rock burst. The above achievements are of great significance to understand the elastic energy attenuation characteristics and to prevent rock burst hazards of the roof rock-coal combined body.

Keywords—rock burst hazards, roof rock-coal combined body, elastic energy attenuation degree, equivalent elastic modulus; height ratio of roof rock to coal, elastic modulus of roof rock or coal

I. INTRODUCTION

With the depletion of shallow coal resources, it is necessary to develop the deep coal resources in China. However, frequent dynamic hazards can be induced by the complex geological conditions and high stress environment in deep coal mine, such as rock burst, coal bump, gas outburst and floor heave, causing huge economic losses and casualties [1-2]. Among them, rock burst is a typical dynamic disaster during deep mining. In order to prevent and control the rock burst hazards effectively, it is essential to analyze the occurrence mechanism of rock burst in deep mining.

Many engineering applications show that rock burst hazards in deep mining generally caused by the structural

instability and damage of the roof rock-coal combined body [3-5]. And the rock burst occurrence mechanism for the roof rock-coal combined body has been studied by many domestic and foreign scholars and they have obtained many interesting results. Through the slippery theory, the occurrence mechanism of rock burst for the roof rock-coal combined body was studied by Qi et al [6]. Lu et al. found that the rock burst can be induced by the hard roof rock fall [4]. Li et al. proposed that the rock burst potentiality of the roof rock-coal combined body was larger than that of the single coal or rock [7]. What's more, the effects of height ratio of roof rock to coal, roof rock strengths, homogeneity, and interface angles [3] on the rock burst potentiality of combined body were researched. Lu et al. studied the rock burst tendency of evolution and acoustic-electromagnetic effects of compound coal-rock samples [8]. In addition, the strength and failure characteristics of the roof rock-coal combined bodies under uniaxial compression [5, 9-10], cyclic loading and unloading [11] and tri-axial compression [3] were studied.

The above achievements have important significance for understanding the occurrence mechanism of rock burst for the roof rock-coal combined body. Meanwhile, due to the complexity of rock mechanics in deep mining, there are many factors that affect the rock burst occurrence. Further researches are needed on the occurrence mechanism of rock burst in deep mining. Based on these, in this paper, the occurrence mechanism of rock burst for the roof rock-coal combined body was studied through energy dissipation theory. And the effects of height ratio of roof rock to coal and elastic modulus of roof rock or coal on the rock burst potentiality of the combined body were discussed and analyzed.

II. ENERGY DISSIPATION ANALYSIS ON ROCK BURST OCCURRENCE IN ROCK-COAL COMBINED BODY

Under the influence of coal mining, the balance of system consisted of energy consumption and external energy input is formed in the roof rock-coal combined body. Firstly, the roof

rock and coal in the combined body occur elastic deformation and the energy input from the outside is aggregated in them as elastic energy. Generally, the strength and elastic modulus of the roof rock is larger than coal. Thus, the coal first occurs inelastic deformation. While, the roof rock may still be in the elastic deformation stage or occurs smaller inelastic deformation. A little bit of energy input from the outside is consumed. But most of energy input from the outside is still aggregated in the roof rock and coal of the combined body. Then the coal takes the lead in reaching the ultimate limit state and destroyed, and the elastic energy in coal released. And now the roof rock rebounds, and the elastic energy aggregated in the roof rock is released and acted on coal, aggravating the impact failure of coal. The rock burst of combined body occurs.

The rock burst is a dynamic phenomenon of the sudden release of the elastic energy aggregated in the roof rock-coal combined body. And this process occurs in the residual deformation stage of the loaded combined body [12]. Therefore, the elastic energy attenuation degree can be taken as a evaluation index for the rock burst occurrence for the roof rock-coal combined body.

The elastic strain energy of roof rock-coal combined body under uniaxial compression is

$$U = \frac{1}{2} \sigma \varepsilon_e = \frac{\sigma^2}{2E} \quad (1)$$

Where, U is the elastic strain energy of the combined body; E is the equivalent elastic modulus of the combined body; ε_e is the elastic strain of the combined body; σ is the axial stress, which is [13-14]

$$\sigma = E\varepsilon \exp\left[-\left(\frac{\varepsilon}{\varepsilon_0}\right)^m\right] \quad (2)$$

Where, ε is the total strain of the combined body; ε_0 is the distribution scale of Weibull distribution; m is the morphological parameter characterized in the form of strain [13].

The elastic strain energy U is determined by solving the resulting equations of Eq. (1)-(2) simultaneous,

$$U = \frac{1}{2} \sigma \varepsilon_e = \frac{E\varepsilon^2 \exp\left[-2\left(\frac{\varepsilon}{\varepsilon_0}\right)^m\right]}{2} \quad (3)$$

Therefore, the elastic energy attenuation degree η is

$$\eta = \frac{\partial U}{\partial \varepsilon} = \frac{\sigma}{E} \frac{\partial \sigma}{\partial \varepsilon} = E\varepsilon \left[1 - m\left(\frac{\varepsilon}{\varepsilon_0}\right)^{m-1}\right] \exp\left[-2\left(\frac{\varepsilon}{\varepsilon_0}\right)^m\right] \quad (4)$$

As m taken as 1, the Eq. (4) can be changed as [15].

$$\eta = \frac{\partial U}{\partial \varepsilon} = \frac{\sigma}{E} \frac{\partial \sigma}{\partial \varepsilon} = E\varepsilon \left[1 - \frac{\varepsilon}{\varepsilon_0}\right] \exp\left[-2\frac{\varepsilon}{\varepsilon_0}\right] \quad (5)$$

In Eq. (5), it can be seen that η is positively correlated with E . That means the larger the equivalent elastic modulus is, the greater the elastic energy attenuation degree is. And the roof rock-coal combined body occurs rock burst easily.

In order to obtain E , a mechanical model for roof rock-coal combined body was established, as shown in Fig. 1. In Fig. 1, L_r and L_c are the heights of roof rock and coal, respectively. And L is the height of combined body. σ_1 is the axial stress loaded by the combined body.

The axial strains of roof rock, coal and combined body are

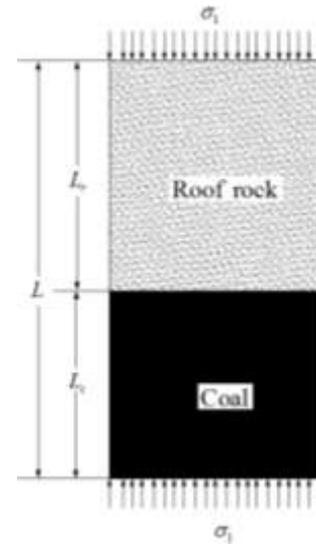


Fig. 1. A mechanical model for roof rock-coal combined body

$$\begin{cases} \varepsilon_r = \frac{\sigma_{r1}}{E_r} \\ \varepsilon_c = \frac{\sigma_{c1}}{E_c} \\ \varepsilon = \frac{\sigma_1}{E} \end{cases} \quad (6)$$

Where, ε_r and ε_c are the axial strains of roof rock and coal, respectively. E_r and E_c are the elastic modulus of roof rock and coal, respectively. σ_{r1} and σ_{c1} are the axial stresses of roof rock and coal, respectively.

It is assumed that the roof rock and coal are tightly bonded together. And the interface deformation between roof rock and coal is ignored. According to the static equilibrium and superposition principle, it can be seen that

$$\begin{cases} \sigma_1 = \sigma_{r1} = \sigma_{c1} \\ \varepsilon_r \neq \varepsilon_c \\ \varepsilon = \varepsilon_r + \varepsilon_c \end{cases} \quad (7)$$

Also, the axial deformation of the roof rock-coal combined body is

$$\varepsilon L = \varepsilon_r L_r + \varepsilon_c L_c \quad (8)$$

Therefore, the equivalent elastic modulus of the combined body can be obtained by solving the resulting equations of Eqs. (6)-(8) simultaneously,

$$E = \frac{E_r E_c L}{E_c L_r + E_r L_c} \quad (9)$$

In Eq. (9), it can be seen that E is determined by the heights and elastic moduli of roof rock and coal. And that means the height ratio and elastic moduli affect the elastic energy attenuation degree and further influence the rock burst potentiality of roof rock-coal body. And these effects are analyzed as follow.

III. EFFECTS OF HEIGHT RATIO AND ELASTIC MODULI OF ROOF ROCK AND COAL ON ROCK BURST POTENTIALITY OF COMBINED BODY

A. Effect of height ratio of roof rock to coal on rock burst potentiality of combined body

The Eq. (9) can be changed as

$$\frac{1}{E} = \frac{L_r}{E_r L} + \frac{L_c}{E_c L} \tag{10}$$

And,

$$L = L_c + L_r \tag{11}$$

Thus,

$$\frac{1}{E} = \frac{1}{E_r} + \left(\frac{1}{E_c} - \frac{1}{E_r} \right) \frac{1}{1 + \frac{L_r}{L_c}} \tag{12}$$

In Eq. (12), under the same condition, E is positively correlated with the height ratio of roof rock to coal. These results are basically consistent with previous experimental and numerical simulation studies [10], as shown in Fig. 2. And this illustrates that the larger the height ratio is, the greater the equivalent elastic modulus is, and the stronger the elastic energy attenuation degree is. Therefore, the rock burst is easy for the roof rock-coal combined body to occur.

There are many evaluating indicators to evaluate the rock burst potentiality of coal, as shown in Table I, mainly including the dynamic failure time D_T , elastic energy index W_{ET} and bursting energy index K_E . And one or more evaluating indicator can be used to evaluate the rock burst potentiality of the roof rock-coal combined body. Taken K_E as an evaluating indicator, Lu analyzed the effects of height ratio on rock burst potentialities of roof rock-coal combined

body, as shown in Fig. 3 [15]. Through the cyclic loading test, Song et al. analyzed the rock burst potentiality of roof rock-coal combined bodies with height ratios of 1:1 and 2:1, such as D_T , W_{ET} and K_E , as shown in Table II [16]. And using PFC^{2D} software, the uniaxial compression tests on combined bodies with different height ratios were conducted by Guo et al. [17]. And they evaluated the rock burst potentialities of the combined bodies with different height ratios based on K_E , as shown in Table 3.

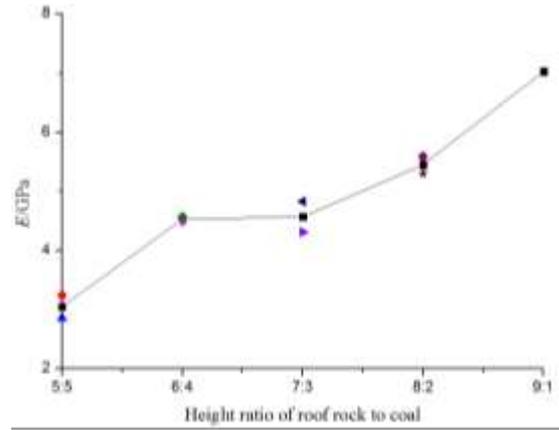


Fig. 2. Relationship between elastic modulus and the height ratio of roof rock to coal [10]

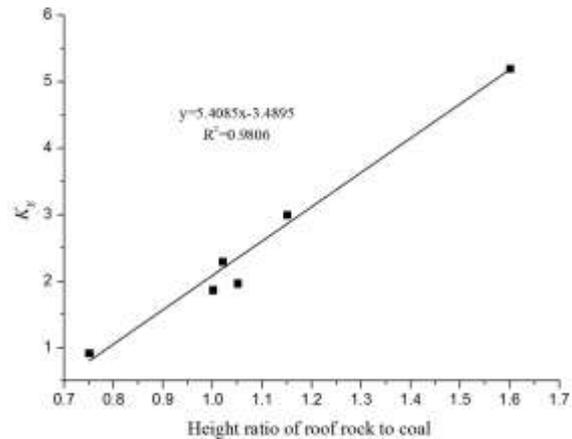


Fig. 3. Relationship between K_E and height ratio of roof rock to coal [15]

TABLE I. ROCK BURST POTENTIALITY CLASSIFICATION FOR COAL

Category		I	II	III
Rock burst potentiality		No	Weak	Strong
Evaluating indicator	Dynamic failure time (D_T)/ms	>500	50 < D_T ≤ 500	≤ 50
	Elastic energy index (W_{ET})	< 2	2 < W_{ET} ≤ 5	≥ 5
	Bursting energy index (K_E)	< 1.5	1.5 < K_E ≤ 5	≥ 5

TABLE II. ROCK BURST POTENTIALITIES OF ROOF-COAL STRUCTURE BODY IN DIFFERENT HEIGHT RATIO [16]

Height ratio of roof rock to coal	D_T /ms	K_E	Elastic energy index	Uniaxial compressive strength/MPa	Rock burst potentiality
1:1	166	2.82	3.92	16.28	Weak
2:1	12.3	9.44	5.53	19.20	Strong

TABLE III. ROCK BURST POTENTIALITIES OF ROOF-COAL STRUCTURE BODY IN DIFFERENT HEIGHT RATIO [17]

Height ratio of roof rock to coal	K_E	E /GPa	Uniaxial compressive strength/MPa
1:1	4.63	5.29	18.71
2:1	3.31	6.45	19.74
3:1	2.21	7.05	19.98

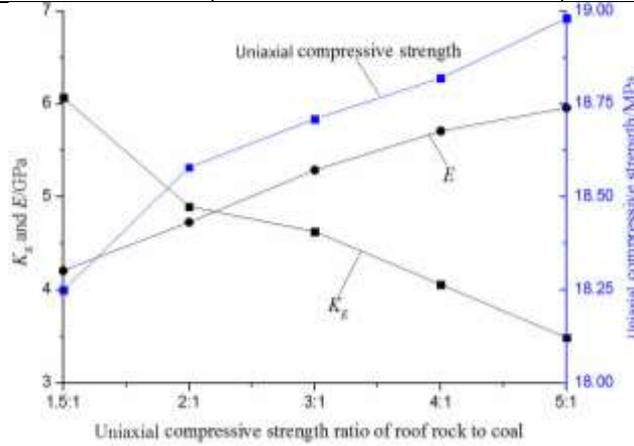


Fig. 4. Relationships between uniaxial compressive strength, E , K_E , and uniaxial compressive strength ratio of roof rock to coal [17]

In Fig. 2 and Table II and 3, it can be seen that with the increase of height ratio of roof rock to coal, the rock burst potentiality of combined body is enhanced. Especially, in Table II, the combined body with a height ratio of roof rock to coal of 2:1 shows a strong rock burst potentiality. Furthermore, in Table III, E increases with a increase of the height ratio of roof rock to coal.

B. Effect of elastic modulus of rock burst potentiality of combined body

In Eq. (10), it can be seen that under the same condition, E is positively correlated with the elastic modulus of roof rock or coal. And this means the smaller the elastic modulus of roof rock or coal is, the lower the equivalent elastic modulus is, and the weaker the elastic energy attenuation degree is. And the roof rock-coal combined body rock burst could hardly occur.

Meanwhile, many studies show that the elastic modulus of rock or coal is positively correlated with the uniaxial compressive strength [18-19]. Therefore, there is a positive correlation between uniaxial compressive strength and rock burst potentialities of the roof rock-coal combined body. Fig. 4 gives the relationships between uniaxial compressive strength, E and K_E of the roof rock-coal combined body and uniaxial compressive strength ratio of roof rock to coal [17].

In Fig. 4, with the increase of uniaxial compressive strength ratio of roof rock to coal, the uniaxial compressive strength and E of the roof rock-coal combined body increase. Meanwhile, K_E decreases with the increase of height ratio of roof rock to coal. And this means that the rock burst potentiality of roof rock-coal combined body is enhanced.

IV. PROPOSALS ON PREVENTION OF ROCK BURST IN DEEP MINING

According to the above analysis, the rock burst potentiality of roof rock-coal combined body is affected by the height ratio of roof rock to coal and elastic modulus of roof rock and coal. The height ratio of roof rock to coal is generally determined on working face. Therefore, in order to effectively reduce and prevent the rock burst hazards, many techniques can be adopted to reduce elastic modulus of roof rock and coal, especially the elastic modulus of coal. And these techniques mainly include coal seam infusion, borehole pressure relief in coal and pressure-relieving groove in coal, etc.

V. CONCLUSIONS

The rock burst is a dynamic phenomenon of the sudden release of the elastic energy aggregated in the roof rock-coal combined body. The elastic energy attenuation degree can be taken as a evaluation index for the rock burst occurrence for the combined body. And the elastic energy attenuation degree is positively correlated with its equivalent elastic modulus. Meanwhile, the equivalent elastic moduli of the combined body is determined by the height ratio and elastic modulus of roof rock and coal. Generally, the larger the height ratio and elastic modulus of roof rock or coal are, the great the equivalent elastic modulus is and the stronger the elastic energy attenuation degree is. Therefore, rock burst of the roof rock-coal combined body can easily occur. Combining the actual conditions of the coal mine, many techniques can be adopted to reduce elastic modulus of coal for to reduce or prevent the rock burst of combined body, such as coal seam infusion, borehole pressure relief in coal and pressure-relieving groove in coal, etc.

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