Application of regional energy criterion in the prevention and control of coal mine rockburst

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Abstract. The current coal mine dynamic disasters severely restrict the high production and efficiency of coal mines. How to use modern mechanics to predict the rockburst scientifically and accurately has been paid more and more attention. In this study, the mechanism of coal mine rockburst is studied by the theory of fracture mechanics, the evolution process of coal mine rockburst is revealed from the energy point of view, the regional energy criterion of coal mine rockburst risk is established. The distribution of stress and plastic zone in the field is analyzed by FLAC3D. Based on theoretical analysis, the elastic energy cloud chart is established by using the FISH command to simulate the energy accumulation of roadway excavation. The results show that the tendency criterion of rockburst based on elastic strain energy well reflects the stage rule of damage evolution in the process of mining stress evolution, which provides an effective test basis for evaluating the risk of rockburst through energy parameters in the engineering field. This research has a certain theoretical guidance and practical value for the prevention of rockburst.

1. Introduction

With the increasing depth of coal mining, the conditions and safety situation of coal mining are becoming more and more complex. It is difficult to meet the actual requirements of the site to study and solve engineering problems only by traditional mechanical methods. Hence, coal mining enterprises also pay more and more attention to the use of modern mechanical analysis methods. More and more coal mining enterprises use fracture mechanics, plastic mechanics and other theories, combined with modern analysis methods such as finite element and discrete element and advanced monitoring methods such as acoustic emission to solve the most difficult problems on site[1-2]. Rockburst is one of the most serious natural disasters in the process of coal mining in the world. Rockburst is a sudden and violent failure of overstressed rock resulting in the instantaneous release of large amounts of accumulated energy. It causes a large number of coal and rock throwing and damage to personnel and equipment[3-4]. The roof falling of the roadway side, the roadway blocking, hurting people, and producing huge noise and rock mass vibration, causing great damage to the safety
production of the mine. How to use modern mechanics to predict rockburst scientifically and accurately has always been the focus of people's research.

DA Beck put forward a quantitative assessment and interpretation method of the seismic hazard of planned excavation in a hard-rock mine. Parameters obtained from the modelling are associated with historical observations of seismicity in the mine, and the selected parameters which have been evaluated and shown to exert controls on seismicity, or to influence the population of seismic events in active mine domains, have been described as ‘controlling parameters’ for mine seismicity[5]. Lippmann established the elementary structural model of rock burst based on the impact tendency of coal and rock mass, and deduced the approximate conditions for the risk of initiating rock bursts[6]. Xie HP et al.[7] introduced fractal geometry and damage mechanics into the study of mechanism of rockburst based on the research of microseismic event distribution. Wang XB and Pan YS[8-10] studied the rock instability theory and energy criterion under different test indexes, and a series of advanced achievements such as unified instability criterion of rock specimen under tension and compression considering strain localization and mechanism of zoned fracture of surrounding rock in deep roadway are put forward.

On the basis of the existing research, this paper studies the rockburst which has been perplexing the safety production of coal mines for a long time, explores the mechanism of rockburst through the theory of fracture mechanics, reveals the evolution mechanism of rockburst from the perspective of energy, and establishes the regional energy criterion of rockburst risk of coal mines. The criterion is verified and studied by the finite element analysis software FLAC3D. The results have certain theoretical significance for the prevention of rockburst.

2. Criterion of rockburst tendency based on regional energy

The redistribution of stress caused by underground engineering has always been a hot topic. Based on the theory of elastic mechanics, coal and rock mass are regarded as homogeneous and continuous elastic body. The coal and rock mass without mining is usually in elastic deformation state before the excavation of roadway, and its original vertical stress is equal to the weight of the overlying strata. After the roadway is excavated, the original rock stress is redistributed and stress concentration occurs in the surrounding rock of the roadway. If the stress of surrounding rock is less than the strength of rock mass, the rock mass is still in elastic state. On the contrary, the surrounding rock will produce plastic deformation, and the peak stress will transfer to the deep. The bearing capacity near the coal wall will be reduced, and the peak of abutment pressure will gradually shift to the depth of the coal wall. The distribution of abutment pressure on the coal seam will be divided into two sections: inelastic and elastic.

In the process of elastic to inelastic transformation of the abutment pressure from the original rock stress area, according to the comparison between the peak stress and the original rock stress, the bearing pressure is divided into four parts by different stress concentration, which are stress reducing area, stress increasing plastic area, stress increasing elastic area and original rock stress area. The area near the peak stress is the main bearing body of the weight of overburden and the load caused by roadway excavation. At the same time, the internal stress in this area changes most dramatically after the excavation of underground engineering, which is also the direct source of the energy of rockburst.

Based on the energy balance theory of fracture mechanics[11], Griffith established the relationship between fracture strength and crack size of completely brittle materials, and deduced the formula by energy analysis:

$$\sigma_f = \frac{2E\gamma}{\pi a (1-\nu^2) \pi}$$

(1)

Where: $\sigma_f$ is the fracture stress; $E$ is the elastic modulus; $\nu$ is the Poisson's ratio; $\gamma$ is the surface energy; $a$ is the crack size. The above formula explains that the actual strength of the material is
much lower than the theoretical strength because of the influence of cracks. There are abundant fractures in the coal and rock mass of the roadway, which results in the actual strength of the coal and rock mass is much lower than that calculated by the theory, so there will be greater uncertainty in the judgment of the instability of the coal and rock mass based on a single stress index. Therefore, based on the theory of fracture mechanics and elasticity mechanics, the evaluation index of strain energy density of coal and rock mass is established by considering the action of six stress components. According to elastic mechanics, the strain energy density of elastomer is:

\[
W = \frac{1}{2E} \left[ \sigma_x^2 + \sigma_y^2 + \sigma_z^2 + 2\nu(\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x) + (1+\nu)(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2) \right]
\]

That is to say, the larger the ratio of the strain energy per unit distance near the peak value of stress to the elastic property of the original rock stress, the more likely the rockburst will occur, and with the increase of stress value, the ratio continues to increase, and the possibility of rockburst is also increasing. When the plastic zone is formed and the stress peak is transferred inward, the ratio decreases and the impact risk of the original zone decreases. It can be used to accurately describe the risk criteria of rockburst in each area.

3. Numerical simulation verification

In order to further verify the reliability of the strain energy density to represent the deformation and instability of coal and rock, based on the actual situation of a coal mine, a FLAC 3D simulation of the tunnel excavation process is carried out. Based on the above theory, fish language is developed, and the energy distribution and strain energy density evaluation indexes are analyzed to verify the accuracy of the criterion.

3.1. Establishment of FLAC 3D simulation model

This mine adopts the development mode of vertical well plus concealed inclined shaft, with the first level of -400m and the second level of -980m. At present, the resources of -400m level are nearly exhausted, and the exploitation work of -980m level is in progress. In order to improve the production speed of -980m level, the chambers such as pump house, substation, water warehouse, pipeline, refuge chamber, gangue warehouse, coal bunker and other chambers and so on are all arranged at -980m level. The arrangement is relatively dense, and the rock is mainly composed of weak mudstone and argillaceous sandstone, with low degree of cementation and relatively developed joints. Comprehensive factors lead to the difficulty of support.

In order to verify the reliability of the elastic energy criterion mentioned above, based on the actual situation of the mine, the finite element software FLAC 3D is used to simulate the excavation process of the tunnel, and at the same time, the secondary programming of FLAC 3D is used to draw the elastic energy density cloud chart, to analyze the surrounding rock plastic area and energy distribution law and the evaluation index of strain energy density. In order to effectively simulate the deformation law of surrounding rock under different conditions, combined with the field tunnel size, the model size is determined to be 50m × 30m × 40m. The horizontal displacement is constrained around the model, and the vertical displacement is constrained at the bottom. Mohr Coulomb model is used for rock stratum and cable element is used for bolt simulation during support. The in-situ stress is simulated by applying external force on the model surface. Referring to the in-situ stress test results, it is determined that the vertical load applied by the numerical model is 24.8 MPa and the horizontal load is 28.5 MPa, and the specific numerical model is shown in Figure 1. According to the field geological report, the basic mechanical parameters of each stratum in the numerical model are determined as shown in Table 1, and the basic mechanical parameters of anchor bolt are determined as shown in Table 2.
Table 1. Mechanical parameters of rock stratum

| Density/\(\text{kg/m}^3\) | Tensile strength/\(\text{MPa}\) | Cohesion/\(\text{MPa}\) | Internal friction angle/\(\degree\) | Shear modulus/GPa | Bulk modulus/GPa |
|--------------------------|-------------------------------|--------------------------|---------------------------------|------------------|-----------------|
| Mudstone                 | 2400                          | 2.25                     | 1.5                             | 30               | 2.65            | 3.5             |
| Sandstone                | 2550                          | 3.1                      | 2.6                             | 27               | 3.34            | 4.6             |

Table 2. Mechanical parameters of anchor bolt

| Elastic Modulus/GPa | Tensile Strength/kN | Prestress/kN | Length/mm | gr_coh/(kN/m) | gr_fric/\(\degree\) |
|---------------------|---------------------|--------------|------------|----------------|----------------------|
| Bolt                | 200                 | 130          | 60         | 2200           | 2000                 | 30               |

3.2. Evolution law of numerical simulation

The stress cloud chart after tunnel excavation is shown in Figure 2. After the tunnel excavation, the original rock stress changes. With the increase of the distance, the stress value first increases to the peak value. The analysis shows that this location is the main energy source for the occurrence of rockburst, and then decreases steadily. At the place far away from the excavation, the stress value tends to be stable to the original rock stress. The excavation of underground engineering causes the stress balance of the original rock to be broken, which leads to a great loss of the bearing strength of the coal and rock mass, and some of the coal and rock mass even lose the ability to bear the external load.

The distribution of plastic zone after roadway excavation is shown in Figure 3. According to the analysis of the evolution law of the plastic zone of the model, under this condition, the most serious damage of surrounding rock is the two sides of roadway. The distribution of plastic zones is the "V"
This kind of shape shows that there is no obvious plastic change in the roof and floor under the existing conditions. Comparing the elastic-plastic situation of the roadway after support, it can be seen that the plastic range of the two sides and the floor of the roadway after support is obviously reduced, the bearing capacity of the surrounding rock mass is greatly increased, and the stability is greatly improved.

![Plastic zone before support](image1)

![Plastic zone after support](image2)

Figure 3. The distribution of plastic zone after roadway excavation.

In order to verify the reliability of the regional energy criterion, the strain energy density of the coal mine roadway is simulated, and the elastic energy cloud diagram after the roadway mining is drawn based on the self compiled FISH language, as shown in Figure 4. Based on the change of displacement and stress in each direction, the strain energy density can clearly reflect the energy accumulation on both sides of the roadway. At the same time, because the roadway adopts bolt support to change the mechanical state of surrounding rock, forming a whole and stable rock area around the roadway, the strain energy density can clearly show the scope of the stable area, and the strain energy density of the stable area is significantly lower than the stress concentration area on both sides. The elastic strain energy cloud chart based on fish language is clear and intuitive, which can provide accurate data support for the evolution of energy accumulation in the construction process and help for safety production.

![Cloud chart of elastic strain energy](image3)

Figure 4. Cloud chart of elastic strain energy.

4. Conclusion
1. Through theoretical analysis, the evaluation index of strain energy density of coal and rock mass is established. The larger the ratio of the strain energy per unit distance near the peak value of stress to the elastic property of the original rock stress, the more likely the rockburst will occur, And with the
increase of stress value, the ratio continues to increase, and the possibility of rockburst is also increasing. When the plastic zone is formed and the stress peak is transferred inward, the ratio decreases and the impact risk of the original zone decreases. It can be used to accurately describe the risk criterion of rockburst, and has certain theoretical significance for the prevention of rockburst.

2. The cloud chart of elastic strain energy is drawn based on the FLAC 3D fish language, which can intuitively display the accumulation of elastic energy of the model. Through the analysis of the cloud chart of elastic strain energy, it has a certain guiding role in the study of energy situation, and provides an effective data support for the engineering to evaluate the risk of rockburst through energy parameters.

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