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The acoustic emission technique research on dynamic damage characteristics of the coal rock

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Abstract

The acoustic emission technique is used to research the deformation and the failure process, investigate the deformation and injury regularity, discuss the physical process of acoustic emission of the coal and gas outburst and reveal the evolution process and disaster mechanism of the coal rock dynamic disaster. In this paper, the relationship between the damage and the acoustic emission is researched to get the coal cock damage expression which is expressed by the acoustic emission cumulative value. Meanwhile, the quasi-static is used to analyze the evolution process of the coal rock's inner damage and describe the coal rock's single axis damage character. On the base of the coal rock unit damage model, the constitutive relationship of acoustic emission coal rock is studied, which is the theory analysis for the coal and gas outburst. It is very significant for the research of the coal and gas outburst mechanism and prediction.

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Keywords: coal and gas outburst; damage factors; acoustic emission; energy functional

1. Introduction

Coal and gas outburst is a manifestation of coal's large-scale destruction in the rule of the power. The acoustic emission can be used to predict the forced state of the coal and locate the force, which is an effective measure to predict the coal and gas outburst[1]. The acoustic emission is used to analysis the relationship between the stress and strain , and research the coal gas and coal rock's position and information. This technology has important theoretical significance and engineering value for People to understand the coal and gas outburst and drainage mechanism.

The acoustic emission technology of coal and gas outburst is a common testing method to judge the inner damage, but there is still some drawback. The basic parameter of the acoustic emission(event rate,

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energy rate) is closed related to coal rock's stability situation. It can basically reflect the destroyed situation of the coal rock. The acoustic emission event rate(or the energy rate) and the big event rate are the main basic to evaluate the stability of coal and gas outburst. The engineering geological condition of the coal is very complex. Because of the heterogeneity,there is the pressure difference between the coal rock's joint surface and the outlet [2]. The signal will be seriously influenced. The accurate is limited if we just use the acoustic emission event rate and big event rate to judge the coal and gas outburst. Sometimes, in the experimental investigation and the real life, there are abnormal changes on the coal rock acoustic emission, but the structure has not destruction. Meanwhile, there is not obvious information, but the structure is destroyed. These situations influence the reliability of the acoustic emission technology seriously and we must settle them.

2. The relationship between the damage variable and acoustic emission

The coal rock acoustic emission is the mini-sosie impulse during the destroying process of the coal rock. It is affected directly by the coal rock's inner crack or defect[3]. The damage is the result of the coal rock's inner defect, so it has direct influence to the evolution and the grown up of the coal rock's inner defect . Therefore, there is inevitable relationship between the damage and the acoustic emission. There is statistic rule of the acoustic emission, so we can establish the relationship between the damage and the acoustic emission.

If η is used to express the destroyed acoustic emission of the unite area, when the destroyed area is *dA,* the acoustic emission event rate $d\Omega$ is:

$$d\Omega = \eta dA \tag{1}$$

If the Ω_0 is the accumulated amount of the total destroyed area A_0, the η can be expressed as follows:

$$\eta = \frac{\Omega_0}{A_0} \tag{2}$$

So he destroyed area *dA* which is related to the strain dε can be expressed as follows:

$$dA = A_0 \phi(\varepsilon) d\varepsilon \tag{3}$$

ϕ (ε) is the statistic distribution function of the unit intensity, which is the Weibull distribution as follows:

$$\phi(\varepsilon) = \frac{m}{\alpha} \varepsilon^{m-1} \exp\left(-\frac{\varepsilon^m}{\alpha} \right) \tag{4}$$

m and α are all constants. We put the formula (2), (3) and (4) into the formula (1), and integral, the following can be gotten:

$$\frac{\Omega}{\Omega_0} = \frac{m}{\alpha} \int \left[\varepsilon^{m-1} \exp\left[-\frac{\varepsilon^m}{\alpha} \right] \right] d\varepsilon = 1 - e^{-(\frac{\varepsilon}{\alpha})} = D \tag{5}$$

The acoustic emission equipment is used to measure the waveform parameter of the acoustic emission wave. The formula (5) can be used to calculate the damage value of any time.

3. The theory model of acoustic emission coal rock's damage

Many researches indicate that the essence of the coal rock's destroying is that the inherent drawback (such as the tiny hole of the surface) is pulled. The microcosmic rupture is the destroyed result of the stretching[4].

According to the damage factor *D*, when *D*=0, there is no damage situation, which is referenced situation. When *D*=1, the coal rock is completely damaged and can't afford any pulling stress. When *D* is between 0 and 1,the coal rock will not be completely fractured.

In the real life, the coal rock usually has initial damage D_0. It will attract stress-strain when it's been pulled, which is decided by the modulus *E*. *E* (which is smaller than the initial modulus E_0)is the temporal modulus, $E=E_0(1-D)$. So the elastic energy is:

$$U = E(1-D)\varepsilon^2 / 2 \tag{6}$$

ε- the strain; *D*-the damage variable according to the acoustic emission.

When the damage happens, *D* is the temporal variable expressing the damage level. According to the thermodynamics relation, the damage of the coal rock can be gotten:

$$\left(\frac{\partial U}{\partial \varepsilon}\right)_D = E(1-D)\varepsilon = E\varepsilon(1-\frac{\Omega}{\Omega_0}) = \sigma \tag{7}$$

From the formula (7), the acoustic emission accumulation is the direct reflection of the coal rock damage degree. For the fixed adjoining rock system, the level of the acoustic emission can attract different damage model, which can be used to detect the change of the energy and judge the type of the coal and gas outburst.

For the defective unit, when the stress is out of the destructive intensity, the defective can be activated. The distribution of the defective is usually the Weibull distribution of double parametric(Jaeger and Cock,1969).

$$n(\varepsilon) = k\varepsilon^m \tag{8}$$

$$n'(\varepsilon) = km\varepsilon^{m-1} \tag{9}$$

n(ε)-the defect number which can attracted when the pull strain is smaller or equal to the ε;

K，m-the material character of the fragmentation, constant;

n′(ε)-the defect's variance ratio because of the strain.

When the pull strain is added by dε, the new defect number is:

$$dn = n'(\varepsilon)d\varepsilon \tag{10}$$

Because of the damage, the material's strain of *D* percent has been released. We suppose defect damage is an acoustic emission number, the acoustic emission number is:

$$dN = (1-D)n'(\varepsilon)d\varepsilon \tag{11}$$

Put the formula (9) into the formula (11),

$$dN = km(1-D)\varepsilon^{m-1}d\varepsilon \tag{12}$$

Considering the defect distribution and the various random factors r(ε), from the formula (12), the accumulated acoustic emission number N is:

$$N = r(\varepsilon)\int_{\varepsilon_0}^{\varepsilon} km(1-D)\varepsilon^{m-1}d\varepsilon \qquad (13)$$

ε_0-the strain of the material's initial damage. r(ε) is a random value between 0 and 1. So the acoustic emission changing ratio is:

$$N'(t) = \frac{dN}{dt} = r(\varepsilon)km(1-D)\varepsilon^{m-1}\frac{d\varepsilon}{dt} \qquad (14)$$

The formula of (13) and (14) are the theory model of the acoustic emission. It proves that the number and the changing ration of the acoustic emission are decided by the damage factors, instantaneous strain and the strain speed. It also has relation with the material character(inherent default, the size of the material, and the homogeneous degree).

4. The Destruction Instability Criterion of Damaged Coal

We can put the coal body of different scales into a unit. The according of dividing unit is on the basis of joints, fault and physical properties (such as elastic modulus E) in coal body. The whole model can be irregular; the divided units can also be irregular. Take one of the units V, see figure 1, the damaged model of coal unit.

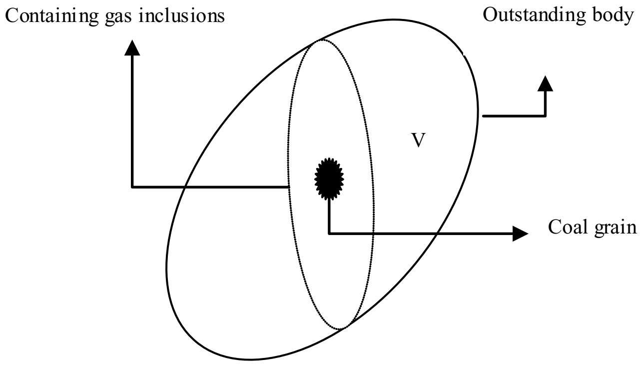

Fig1 unit damage model of the coal rock body

The judge of the equilibrium stability of deformation system generally adopts Dirichlet standards, the criterion think that when the total potential energy of system is very minimum, the balance system is stable, when the total potential energy is maximum, the balance system is unstable. Assumed the functional of the total potential energy be Π, according to the variation principle:

$$\delta\Pi = 0 \qquad (15)$$

- The having type is the conditions of potential energy functional having limit value, but also the necessary condition of balance system. When δ2Π>0, the functional of potential energy has minimum, the balance system is stable, when δ2Π<0, the functional of potential energy has great value, the balance system is unstable, when δ2Π=0, the different of the high order variation is considered the critical state of transition from stable to unstable. So the criterion of coal and gas outburst is the condition of coal and rock containing gas balance which is in critical stable and the unstable equilibrium state, that is:

$$\delta\Pi = 0 \quad \delta^2\Pi \geq 0 \tag{16}$$

- Type (16) is the value terms of minimum potential energy in elastic-plastic stability theory, but also the balance condition of deformation system, when the system is in balance, the type is automatically satisfied. When coal is saturated by gas, the mathematical expressions of the reactive force A, the deformation potential energy U and the gas potential energy E are as follows:

$$A = \iiint_v \{F\}^T \{u\} dv + \iint_s \{T\}^T \{u\} ds$$

$$U = \iiint_v \{\sigma'\}^T \{\varepsilon\} dv = \iiint_{v_e} \{\varepsilon\}^T [D_e]\{\varepsilon\} dv_e + \iiint_v \{\varepsilon\}^T \left[D_p\right]\{\varepsilon\} dv_p \tag{17}$$

$$E = \iiint_v P dv$$

- In formula: {ε}— The strain of coal and rock under the effect of the mass strength {F}, the surface force {T} and the pore pressure {P};
- {u}— The displacement;
- $[D_\varepsilon]$— Elastic matrix, the effect of the injury defined by acoustic emission is considered in the matrix;
- $[D_p]$— Plastic matrix; considering the coal and rock deformation system is only composed by the elastic zone and the plastic soften region;
- V_e— The volume of coal in the elastic zone;
- V_p— The volume of coal in the plastic zone;
- s.v— the total area and the total volume of coal and rock deformation system in discussion.
- Among them, the total volume of system is the sum of the volume of the elastic zone and the volume in the plastic zone:

$$V = V_e + V_p \tag{18}$$

- So, the total potential energy functional of system can be expressed as:

$$\prod = U - A - E \tag{19}$$

- Put Formula (17) into $\delta\Pi=0$、$\delta^2\Pi\geq0$ and get:

$$\delta^2\Pi = \iiint_{v_e} \{\delta\varepsilon\}^T [D_e]\{\delta\varepsilon\} dv_e + \iiint_{v_p} \{\delta\varepsilon\}^T \left[D_p\right]\{\delta\varepsilon\} dv_p \geq 0 \tag{20}$$

- Under the effect of stress and gas pressure, if the deformed coal doesn't get into peak intensity, the instability damage will not happen. Only a part of coal and rock start to be destroyed coal and get into the peak intensity deformation stage, the type just may be satisfied, the equilibrium condition of deformation system just may become unstable. So a part of coal and rock deformed after getting into the peak intensity is the necessary condition that the equilibrium condition of deformation system becomes unstable, it is also the necessary condition of coal and gas outburst, at the same time, to make the above formulas are completely satisfied, it not only need a certain volume of part of coal and rock go into the deformation stage after the peak intensity, but also need the second absolute value is greater than the absolute value of the first item, the two conditions are both together to satisfy the above type, make the equilibrium conditions of coal and rock deformation system unstable, which leads to the occurrence of coal and gas outburst.
- Coal and rock instability damage is not only relevant to the stress state, but also relevant to the physical and mechanical properties; $[D_e]$ and $[D_p]$ are respectively on behalf of the change degree of the carrying capacity of coal and rock with increasing deformation. In one-dimensional cases, $[D_e]$ and $[D_p]$

respectively express the slope of stress-strain curve before and after intensity. So the brittle of local strain softening medium is easy instability, otherwise not easy instability, and when the stiffness of surrounding rock is small, it is easy instability, when the stiffness is great, it is not easy instability, this is consistent to the results of stiffness comparing standard.

- For coal and gas outburst, the strain {ε} is from the effective stress on coal body, namely is due to the combined effect of stress and porosity gas pressure. Coal and rock medium material properties matrix $[D_e]$ and $[D_p]$ are both influenced by gas fluid, so the occurrence of coal and gas outburst is not a factor which plays a leading role, also not the result of the comprehensive effect of stress and the gas simple composition, but the dynamic instability damage phenomenon happened under the interaction and mutual influence of each factors.
- The coupling of Coal and gas leads to the decrease of coal effective stress; and also make the coal peak intensity decrease, so the necessary conditions of coal instability damage more likely to be meet. At the same time, the coupling effect also makes the slope of stress-strain curve small before the peak intensity, that $[D_e]$ decreases. And make brittleness degree increase after the peak intensity, that $[D_p]$ increases, thus that promotes the type to be meet, and instability damage, therefore, the gas is helping to coal and gas outburst.

5.Conclusion

- Based on the traditional damage mechanics, the method of acoustic emission is adopted to define the damage variables of coal and rock in this paper, and formed acoustic emission theory considering damage, and then discusses the mechanism of coal and gas outburst considering damage, formed the criterion of coal and gas outburst. The conclusions are as follows:
- The acoustic emission of loading coal rock is closely related with deformation fracture process. The results show that the destruction of coal and rock material is the result of the micro damage accumulation of internal representative volume element, the acoustic emission events can reflect the damage degree of coal and rock;
- Acoustic emission counts and acoustic emission rate mainly depends on damage factor, transient strain and strain rate, and also closely related with the material properties (inherent defect sum, material scale, homogeneous degree and so on);
- The acoustic emission activities of coal and rock reflect damage evolution process in coal and rock, the occurrence of coal and gas outburst is not a factor which plays a leading role, also not the result of the comprehensive effect of stress and the gas simple composition, the gas is helping to coal and gas outburst.

References

[1] Yu Shouwen, Feng Xiqiao. Damage mechanics [M]. Beijing: Tsinghua University Press, 1997.67~83.

[2] Qin Yueping. The research on theory and test on the damage and dynamic of coal and rock [D]. Beijing: China University Of Mining And Technology, 2003.

[3] Shan Nalin, Chen Zhiping, Liu Yunzhen. Engineering geology exploration [M]. Beijing: Metallurgical Industry Press, 2006, 183-192.

[4] Qin Yueping, Zhang Jinfeng, Wang Lin. Preliminary discussion on theoretical model of rock damage mechnaics[J]. Chinese Journal of Rock Mechanics and Engineering, 2003, 22(4):646-650.

[5] Cao Shugang, Liu Yanbao, Zhang Liqiang. Study on characteristics of acoustic emission in outburst coal[J]. Chinese Journal of Rock Mechanics and Engineering, 2007, 26(1):2795-2799.

[6] Manthei. Moment tensor evaluation of acoustic emission[J]. Construction and Building Materials, 2001, 15(5):297-309.

[7] Shiotani T. Detection and evaluation of AE waves due to rock deformation[J]. Construction and Building Materials, 2001, 15(5):235-246.

[8] Zou Yinhui, Zhao Xusheng, Liu Sheng. Research on sound transmitted continued prediction technology for coal and gas outburst[J]. 2005, 33(6):61-64.

[9] D A Beck, B H G Brady. Evaluation and application of controlling parameters for seismic events in hard rock mines [J]. International journal of Rock Mechanics and Mining Sciences, 2002, 39(5):633-642.

[10] Ji Hongguang, Zhang Tiansen, Zhang Zhiyong, Cai Meifeng. Analysis on the acoustic emission parameters for nondestructive testing[J]. Nonde Structive Testing, 2001, 23(7):289-291.