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The Study Fracture Evolution of Coal and Rock Mass Under Hydraulic Fracturing

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Abstract

The hydraulic fracturing technology is the main technical means of coalbed methane. However, it is hard to describe the fracture formation mechanism and evolution law in the process of fracturing. It caused the present studies restrict the effective mining of coalbed methane. This article is mainly study the process of fracture cracking and extending based on the angle of energy. It introduces the theory of entropy to analyse the micro defect evolution under hydraulic fracturing, and builds up the evolution model of the micro fracture number, angle, length and opening based on the theory of entropy. Then it analyses the main controlling factors of the fracture evolution. It will provide a new research approach for the law of hydraulic fracturing evolution.

Key words: Entropy theory; Hydraulic fracturing; Damage evolution

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INTRODUCTION

The hydraulic fracturing has been widely used at home and abroad in the study of the coalbed methane development because of the characteristics of its economy, effectivity and perfect technology. In the study of fracture evolution, Huang Wenxi and Ding Jinli et al.[1] from Tsinghua University using the thick and thin cylindrical specimens and the soil materials studied the necessary conditions of specimens hydraulic fracturing. From the study of field test, M. K. Hubbert and D. G. Willis[2] focused on the problem of rock drilling hydraulic fracturing pressure, make sure that the direction of crack surface is always perpendicular to the minimum principal stress direction. Tsay[3] overcame the difficulties of the mesh regeneration in the finite element and used the numerical collection method combined with the crack opening displacement method predicting the fracture propagation rules successfully. M. M. Hossain and other scholars[4-6] used the method of elastic mechanics studying the influence of the fracture initiation and extend from the fracture pressure, direction of fracture and perforation under the two conditions of any orientation perforation or not perforation for wellbore. But under the process of hydraulic fracturing, there is no accurate and reasonable method to make a full description because of the complex of the fracture distribution and the different of strata stress distribution. It’s always been the bottleneck of coal and rock mechanical response and the system space distribution.

Comentropy is named by engineer Shannon in American bell telecom test in 1948. He made the entropy defined in the classical thermodynamics introduce to information theory as a measure of average information. It made entropy breakthrough the limitation of the thermodynamics and infiltrate into the different areas[7]. It is always accompanied by a certain energy conversion when we are in the process of rock mass hydraulic fracturing[8]. So this article will introduce the entropy change theory to the study of fracture initiation and propagation under hydraulic fracturing. It will build up the model of rock damage and fracture evolution under hydraulic fracturing in order to better reveal the fracture formation mechanism and process of coal rock. It will provide the reliable theory basis for optimizing construction parameters and fracturing process and improving the fracturing effect.

1. THE COMENTROPY DEFINITION OF COAL AND ROCK FRACTURING

Assuming the fracture is tension fissure. The growth of strain energy for any micro fracture is that,

$$Q_{F,j} = 2\int_0^a G_j dA. \quad (1)$$

Define,

$$\lambda_j = \frac{Q_{F,j}}{Q}. \quad (2)$$

Where: Q is the total strain energy of the system; $\lambda_j \geq 0$ (j = 1,2,...,n) is the distribution of strain energy in the system of the rock mass.

Define the comentropy function of system s_j is that[9],

$$S_j = -\lambda_j \ln \lambda_j \ (0 \leq \lambda_j \leq 1). \quad (3)$$

From the Figure 1, we can express the fracture behavior of rock mass fracturing process based on comentropy. In the Formula 3, the comentropy function will increase with the rise of λ_j from zero. When it reaches the top, it begins to decrease. When λ_j tends to 1, s_j tends to zero. As is shown by Figure 1, this change accords with the law of comentropy change in the process of fracture propagation.

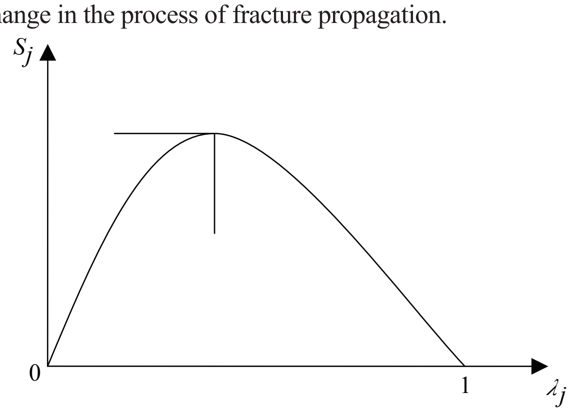

Figure 1
The Change Curve of Comentropy

The comentropy of any fracture propagation is that,

$$S_j = -\frac{2\int_0^a G_j \mathrm{d}A}{Q} \ln \frac{2\int_0^a G_j \mathrm{d}A}{Q}. \quad (4)$$

For the energy and material exchange with the outside world, and the condition of fracture evolution is ordered, the comentropy of hydraulic fracturing system is the lowest. From Formula 4, we can find the condition of fracture initiation for any facture is that,

$$\frac{\partial S_j}{\partial \sigma_j} = 0. \quad (5)$$

Assuming the fracture evolution relatives to the rock mass characteristics surrounding the fracture and the speed of evolution. Define the stress intensity factor K of the fracture dynamic evolution is that,

$$K = k_1 \cdot K_{D,i} + k_2 \cdot K_{v,i} \cdot K_I. \quad (6)$$

Where,

$$\begin{cases} K_{D,i} = f(w,a,\sigma) \\ K_{v,i} = g(v) \end{cases}, \quad K_I = p_i\sqrt{\pi a}, \quad p_i = \delta\left(p_b + G_f\right) - \sigma_\theta. \quad (7)$$

Where: $K_{D,i}$ is the damage function of the fracture growing; $K_{v,i}$ is the fracture dynamic growth rate function; K_I is the static stress intensity factor of fracture growth; k_1, k_2 are both the dimensionless impact factors of $K_{D,i}$ and $K_{v,i}$; v is the dynamic wave velocity of fracture growth; v_e is the surface wave velocity of rock; p_i is the effective stress of the fracture surface; p_b is the fracturing pump pressure; G_f is the gravity of the fracturing fluid; σ_θ is the circumferential stress of fracture.

At the moment, the relationship between the extend strain energy release rate G of any micro fracture and the stress intensity factor K is that,

$$G = \left[k_3 \frac{1-\nu^2}{E} + k_4 \frac{V^2 \beta_1}{2EV_2^2 D(V)}\right] K^2. \quad (8)$$

2. THE EVOLUTION MODEL OF COAL AND ROCK FRACTURING PARAMETERS

2.1 The Evolution Model of Micro Fracture Bifurcation Number

Assuming the rock has m natural fractures and the energy released promotes new micro fractures in the process of loading. When fracturing pump i stage loading, the number of micro fractures is that,

$$N_{m,i} = \left[F_1 - 1\right] \cdot N_{m,i-1} + F_2(\sigma) \cdot \left(\sum_{i=1}^{i-1} N_{m,i} - N_{m,i-1}\right) \cdot \rho_{m,i-1}. \quad (9)$$

Where,

$$\rho_i = \frac{N_{m,i}}{\sum_{i=1}^{i} N_{m,i}}, \quad F_1 = \frac{s_{m,i} - s_{m,i-1}}{s_{m,i}}, \quad F_2(\sigma) = \frac{1}{(1-D)} \frac{\ln\sigma}{\ln\sigma_c}. \quad (10)$$

Where: $N_{m,i}$ is the evolution number of micro fracture; ρ_i is the density of micro fracture; F_1 is the relative increment of comentropy in the process of fracture evolution, stand for the survival status of fracture evolution; $F_2(\sigma)$ is the impact ability of the fracturing load stress, dimensionless; σ is the load stress of hydraulic fracturing; D is the damage variable of rock mass.

By arrange,

$$N_{m,i}=\left[F_1-1\right]N_{m,i-1}+\frac{1}{(1-D)}\frac{\ln\left(\delta p_{m,i}-\sigma_\theta\right)}{\ln\sigma_c}\cdot\left(\sum_{i=1}^{i-1}N_{m,i}-N_{m,i-1}\right)\frac{N_{m,i-1}}{\sum_{i=1}^{i-1}N_{m,i}}. \tag{11}$$

For the i stage loading, the evolve number of micro fracture is that,

$$N_{m,i}=\left[\frac{s_{m,i}-s_{m,i-1}}{s_{m,i}}-1\right]N_{m,i-1}+\frac{1}{(1-D)}\frac{\ln\left(\delta p_{m,i}-\sigma_\theta\right)}{\ln\sigma_c}\cdot\left(\sum_{i=1}^{i-1}N_{m,i}-N_{m,i-1}\right)\frac{N_{m,i-1}}{\sum_{i=1}^{i-1}N_{m,i}}$$

$$=-\frac{s_{m,i-1}}{s_{m,i}}N_{m,i-1}+\frac{\ln\left(\delta p_{m,i}-\sigma_\theta\right)}{(1-D)\ln\sigma_c}\cdot\frac{\sum_{i=1}^{i-2}N_{m,i}}{\sum_{i=1}^{i-1}N_{m,i}}N_{m,i-1}. \tag{12}$$

The Formula 12 is the standard evolution model of coal rock micro fracture number.

2.2 The Evolution Model of Micro Fracture Bifurcation Direction

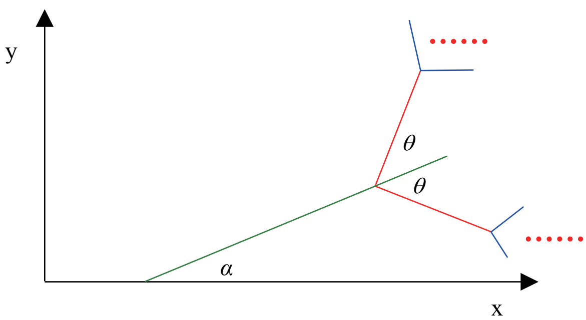

Figure 2
The Bifurcation Characteristics of Fracture

The schematic diagram of bifurcate fracture, the stress intensity factor is that,

$$K_i=G_i(\theta,\frac{b}{a})p_i\sqrt{\frac{\pi(a+b\cos\left(\alpha+(i)\theta\right))}{2}}. \tag{13}$$

Where: $G_{3A}(\theta,b/a)$ is the stress intensity factor coefficient before the micro fracture bifurcates.

Introduce the Formula 4 is that,

$$S_i=-\frac{2\int_0^a G_i dA}{Q}\ln\frac{2\int_0^a G_i dA}{Q}. \tag{14}$$

According to the Formula 13, we can find the relationship between comentropy and bifurcation point is that,

$$S_i=-\frac{2\int_0^a\left[k_3\frac{1-\nu^2}{E}+k_4\frac{V^2\beta_1}{2EV_2^2D(V)}\right]\left[G_i(\theta,\frac{b}{a})p_i\sqrt{\frac{\pi(a+b\cos\left(\alpha+(i)\theta\right))}{2}}\right]^2dA}{Q}$$

$$\cdot\ln\frac{2\int_0^a\left[k_3\frac{1-\nu^2}{E}+k_4\frac{V^2\beta_1}{2EV_2^2D(V)}\right]\left[G_i(\theta,\frac{b}{a})p_i\sqrt{\frac{\pi(a+b\cos\left(\alpha+(i)\theta\right))}{2}}\right]^2dA}{Q} \tag{15}$$

For any bifurcation stage, it need satisfy that,

$$\frac{\partial S_i}{\partial\theta_i}=0. \tag{16}$$

The Formula 16 is the model of fracture bifurcation angle based on comentropy.

3. CASE STUDY

Choose a coal block of Hegang Dongxing coal mine. Its basic parameters are the following. The maximum horizontal main stress s_H is 32 MPa. The minimum horizontal main stress s_h is 28.5 MPa. The formation pressure P_0 is 11.4 MPa. The modulus of elasticity E is 2,800 MPa. The critical damage strength s_c is 30 MPa. The fluid compressibility factor a is 0.8. The poisson's ratio is 0.20. The porosity of fracture and substrate are boss 0.15. The fracturing fluid density is 2.16 g/cm^3. The fracturing fluid velocity is 4.0 m^3/min. The hole radius is 0.12 m. The angle of internal friction is 0.35.

3.1 The Influence of the Hole Fracture Evolution With the Net Fluid Pressure

The Figures 3-6 are the relation charts about the net fluid pressure influent the micro fracture growing number, length, opening and bifurcation angle. As is shown by these charts, with the net fluid pressure increasing, the micro fracture growing number, length and opening are all have a certain degree of increase. But the micro fracture bifurcation angle has a degree of decline. According to the analysis of calculation condition, the first bifurcation angles are almost between 50° and 60°.

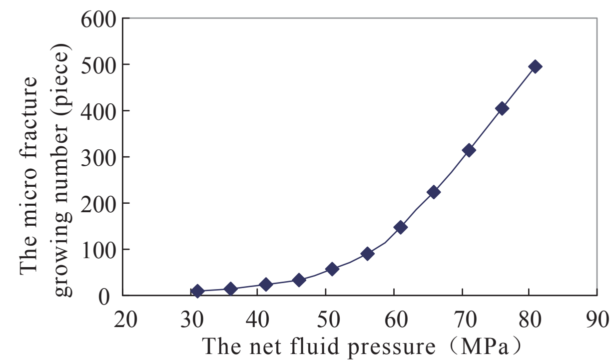

Figure 3
The Chart of Micro Fracture Growing Number

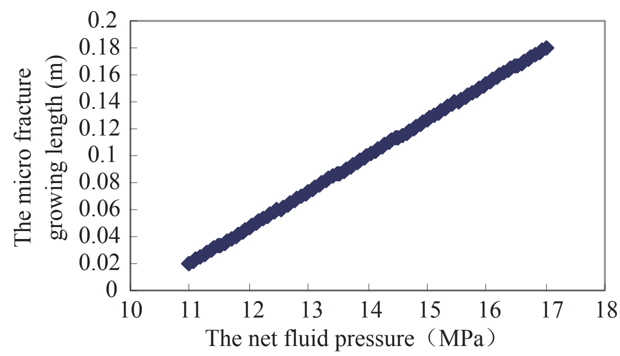

Figure 4
The Chart of Micro Fracture Growing Length

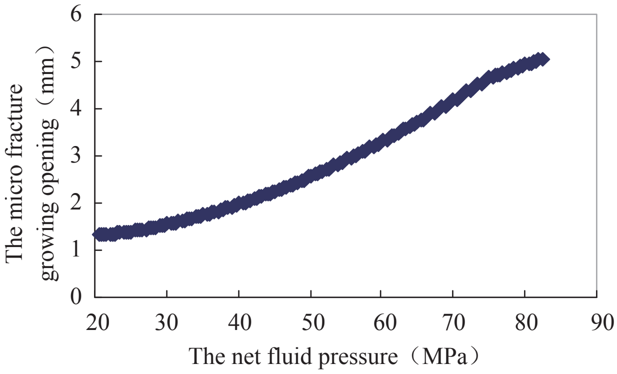

Figure 5
The Chart of Micro Fracture Growing Opening

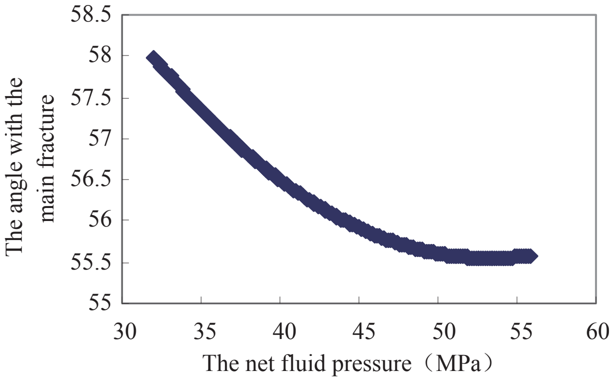

Figure 6
The Chart of the Angle With the Main Fracture

CONCLUSION

In this passage, we have built up the evolution model of micro fracture number, angle, length and opening based on the theory of entropy according to analyse the fracture evolution law in the process of hydraulic fracturing. It provides the theoretical foundation for the fracture evolution rules.

For the geologic parameter of one block of Dongxing Coal mine and combine the theoretical models have been finished, we analyse the main controlling factors of fracture damage evolution under hydraulic fracturing. Then we get the curves of relationship between micro fracture evolution number, angle, length, opening and the net fluid pressure, the modulus of elasticity, the poisson's ratio.

Following the increasing of the net fluid pressure, the micro fracture growing number, length and opening are all increasing, and the bifurcation angle becomes lower. The first bifurcation angles are almost between 50° and 60°, and the micro fracture largest opening is 5.061 mm. Following the increasing of the modulus of elasticity, the micro fracture growing length, opening and bifurcation angle are all declining. Following the increasing of the poisson's ratio, the micro fracture growing length and opening are both having a certain degree of decrease, and the bifurcation angle becomes larger.

REFERENCES

[1] Ding, J. S., Tang, Q. M., & Gong, Y. M. (1994). Using water seepage force model to study the character of saturated soil load. *Chinese Journal of Geotechnical Engineering*, (1), 33-37.

[2] Hubbert, M. K., & Willis, D. G. (1957). Mechanics of hydraulic fracturing. *Trans AIME*, *210*, 153-168.

[3] Tsay, R. J., Chiou, Y. T., & Chuang, W. L. (1999). Crack growth prediction by manifold method. *Journal of Engineering Mechanics*, *125*(8), 884-890.

[4] Hossain, M. M., Rahman, M. K., & Rahman, S. S. (2000). Hydraulic fracture initiation and propagation: roles of wellbore trajectory, perforation and stress regimes. *Journal of Petroleum Science and Engineering*, *27*, 129-149.

[5] Zhang, G. Q., & Chen, M. (2009). Complex fracture shapes in hydraulic fracturing with orientated perforations. *Petroleum Exploration and Development*, *36*(1), 103-107.

[6] Jiang, X., Chen, M., & Zhang, G. Q. (2009). Impact of oriented perforation on hydraulic fracture initiation and propagation. *Chinese Journal of Rock Mechanics and Engineering*, *28*(7), 1321-1326.

[7] Jaynes, E. T. (1982). On the rationale of maximum entropy methods. *Proceedings of IEEE*, *70*, 939-952.

[8] Deng, G. Z., & Zhu, W. S. (1997). The basic characteristics of rock mass nonlinear unloading and the entropy change. *Journal of Xi'an Mining Institute*, *17*(4), 332-335.

[9] Xu, C. H., & Ren, Q. W. (2004). Criterion of entropy catastrophe of stability of surrounding rock. *Rock and Soil Mechanics*, *25*(3), 437-440.