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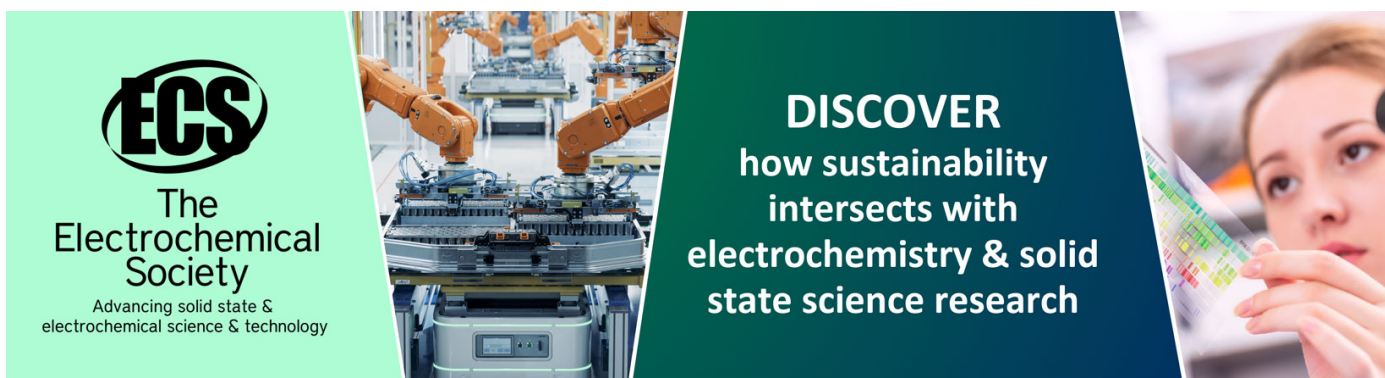
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Research on Determination Method of Gas Drainage Radius Based on Elastoplastic Softening Model

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Abstract. Based on the elasto-plastic softening model and the theory of gas seepage, this paper establishes the calculation model of the gas pressure and the pumping time of the coal around the mining. The COMSOL Multiphysics simulation software is used to simulate the gas pressure of the surrounding coal Distribution with time. According to the basic parameters of the 3[#] coal seam in the mine, the simulation results show that the effective sampling radius is 1.5m and the model is 1.6m, and the error is small within the allowable range. Based on the elastic - plastic softening model, the mining radius can provide the basis for the design of mine coal mining and drainage, improve the efficiency of gas extraction and ensure the safety of mine production.

1. Introduction

Pre-extracted coal seam gas through layer drilling is one of the important measures to control mine gas disaster [1~3], therefore, reasonable drainage hole drainage radius is the key to ensure the effect of gas disaster control. The coal seam gas extraction radius is measured on site, and a small number of boreholes are used as the investigation holes. There are occasional errors and large errors. If multiple sets of boreholes are measured, the engineering quantity will increase significantly, and the test results will be larger in different areas of the same coal seam. Randomness and blindness, this coal seam gas extraction radius inspection method restricts the mine outburst prevention and gas control work to a certain extent.

With the development of computer technology and numerical simulation software, it is a feasible method to determine the coal seam gas extraction radius by numerical calculation analysis technology. A corresponding physical model is proposed for studying the characteristics of coal body. Combined with the model of coal bed gas seepage, numerical analysis software is used to numerically calculate the coal seam extraction radius. It is generally simple to assume that the coal body is an ideal elastic model to consider the gas flow in the coal body. However, for the particularly soft coal seam, this idealized assumption can quantitatively analyze the coal body seepage process, but the actual error with the site is large.

During the construction process of pre-drilling through the layer, micro-cracks must be formed in the coal seam, especially in the high-stress soft coal seam, the strength parameters of the coal body will be significantly reduced in the nonlinear deformation stage [4~5]. Therefore, this paper assumes that the



coal body is an elastic-plastic softening model. A fluid-solid coupling model for the dynamic change of coal strength parameters, permeability and porosity with the increase of plastic deformation is proposed, which can be used to analyze effective drainage radius of boreholes in soft coal seams. The research results can provide reference for the optimal arrangement of mine drainage drilling.

2. Theoretical analysis

For the fluid-solid coupling mathematical model in coal seam, the following assumptions are made: 1) gas-bearing coal rock is regarded as strain softening model; 2) gas-bearing coal body is saturated by unidirectional gas; 3) gas seepage in coal body is isothermal and obeys Darcy's law [6]; 4) gas adsorption and desorption conforms to Langmuir equation [7].

2.1. Mechanical Model of Soft Coal

This paper assumes that the coal body conforms to the elastic-plastic softening model. In the elastic stage, the strain of the element is only elastic strain ε_e . When the element yields, the strain of the element consists of elastic strain ε_e and plastic strain ε_p . Plastic strain can be divided into plastic shear strain ε_{px} and plastic tensile strain ε_{pt} .

Hooke's law in the form of principal stress and principal strain is expressed as follows:

$$\begin{cases} \Delta \sigma_1 = \alpha_1 \Delta \varepsilon_1^e + \alpha_2 (\Delta \varepsilon_2^e + \Delta \varepsilon_3^e); \\ \Delta \sigma_2 = \alpha_1 \Delta \varepsilon_2^e + \alpha_2 (\Delta \varepsilon_1^e + \Delta \varepsilon_3^e); \\ \Delta \sigma_3 = \alpha_1 \Delta \varepsilon_3^e + \alpha_2 (\Delta \varepsilon_1^e + \Delta \varepsilon_2^e) \end{cases} \quad (1)$$

The shear yield function of strain softening model is as follows:

$$f_x = \sigma_1 - \sigma_3 N_\varphi + 2c \sqrt{N_\varphi} \quad (2)$$

$$N_\varphi = \frac{1 + \sin \varphi}{1 - \sin \varphi} \quad (3)$$

The tensile yield function is:

$$f_t = \sigma_t - \sigma_3 \quad (4)$$

In the formula, f_x is the shear yield function, f_t is the tensile yield function, σ_1 is the first principal stress, σ_3 is the third principal stress, c is the cohesive force, φ is the internal friction angle, N_φ is the function of the internal friction angle, σ_t is the tensile strength.

The shear plastic potential function is based on the uncorrelated flow rule, and the tensile plastic potential function is based on the correlated flow rule. The shear plastic potential function is:

$$g_x = \sigma_1 - \sigma_3 N_\varphi \quad (5)$$

The tensile plastic potential function is:

$$g_t = -\sigma_3 \quad (6)$$

2.2. Coal Strength Parameters and Porosity and Permeability Change Model

When the coal body enters the stage of strain softening, the relationship between the stress, plastic strain and the strength parameters of coal body is very complex. In this paper, the simplified treatment is made, in the stage of softening, the strength parameters of coal body are reduced linearly according to the yield stage.

$$C = \begin{cases} C_0 \left[1 - \frac{(1-\eta) \varepsilon_p}{\varepsilon_1^p - \varepsilon_e} \right] & (0 \leq \varepsilon_p \leq \varepsilon_1^p) \\ \eta C_0 & (\varepsilon_p \geq \varepsilon_1^p) \end{cases} \quad (7)$$

In the formula: η is the residual coefficient, that is, the ratio of the minimum strength coefficient to the original strength coefficient, which can reflect the softening degree of the strength parameter of the coal after strain softening. ε_e is the total elastic strain in the elastic phase, and ε_1^p is the total plastic strain at the junction of the softening phase and the residual stress phase.

Generally, with the drilling of the borehole, the stress of the coal body is redistributed, and the stress in the coal body around the borehole increases. When the stress increases beyond the ultimate strength of the coal body, plastic deformation occurs, and the peak of the concentrated stress is far from the borehole wall. The stress on the hole wall area of the coal body is gradually reduced, and finally lower than the original stress, that is, the coal body near the wall of the drill hole is relieved of pressure, and the closer to the hole wall, the greater the degree of pressure relief. The inside of the stress concentration ring is the pressure relief zone. The residual stress of the coal body in this area is less than the original stress. In this area, the coal body is destroyed during the stress concentration phase, plastic deformation occurs, cracks occur, and the porosity and penetration of the coal body The rate has increased accordingly.

The gas seepage in the coal body obeys Darcy's law, that is, the porosity and permeability of the coal body determine the gas seepage characteristics of the coal body.

The data show that in the elastic phase, the microcracks inside the coal body do not expand substantially, that is, the permeability and porosity of the coal body change little. When the coal body enters the stage of plastic deformation, the microcracks inside the coal body begin to expand, resulting in an increase in coal permeability and porosity. According to a similar treatment method as described above, when the coal body enters the strain softening stage, the permeability and porosity of the coal body increase linearly.

$$C = \begin{cases} C_0 \left[1 + \frac{(\eta' - 1) \varepsilon_p}{\varepsilon_1^p - \varepsilon_e} \right] & (0 \leq \varepsilon_p \leq \varepsilon_1^p) \\ \eta' C_0 & (\varepsilon_p \geq \varepsilon_1^p) \end{cases} \quad (8)$$

In the formula: η' is the residual coefficient, that is, the ratio of the minimum strength coefficient to the original strength coefficient, which can reflect the softening degree of coal strength parameters after strain softening.

When the element yields, the strength coefficient, coal permeability and porosity of the element are calculated in each iteration step according to the plastic strain of the element, the strength reduction relationship and the strengthening relationship. Then the strength parameters and seepage related parameters of the unit are updated into the next iteration step, so that the cycle can reflect the gas seepage process under the plastic deformation mechanical characteristics of coal.

3. Engineering background and numerical model

3.1. Engineering Background

Taking No. 3 coal seam of Sangshuping Coal Mine as engineering background, the average thickness of No. 3 coal seam is 3.0m, the hardness is soft, the gas pressure is high, and the permeability is poor, which belongs to the difficult-to-extract coal seam. The main measure of mine outburst prevention is pre-drainage of cross-layer boreholes in floor roadway. Therefore, the simulated cross-layer boreholes pass through the horizontal coal seam vertically and bear the gravity of overlying rock vertically. In order to understand the change and influence range of gas pressure in coal seam during drainage more intuitively and clearly, a three-dimensional model is established.

Assuming that the coal body range is far larger than the research scope, considering the boundary effect, the model is set to $20\text{ m} \times 20\text{ m} \times 3\text{ m}$ coal body. In the model, the drilling hole is located in the center of the model, the diameter of the drilling hole is 94 mm, the surrounding boundary and the gas pressure of the coal body are the original gas pressure of the coal seam, and the negative pressure of the drilling hole is 25 kPa.

Before calculating the effective extraction radius of 3[#] coal seam in coal mine, field measured gas pressure of 3[#] coal seam is 1.3 MPa, permeability coefficient of coal seam is $0.0221\text{ m}^2/(\text{MPa}^2\cdot\text{d})$, porosity is 0.0950, coal bulk density is 1.42 t/m^3 , original gas content is $12.32\text{ m}^3/\text{t}$, corresponding to $7.42\text{ m}^3/\text{t}$ at 0.74MPa.

3.2. Model Numerical Solution and Result Analysis

The multi-physics coupling analysis software Comsol Multiphysic was used to perform this time value simulation analysis. The Darcy seepage module and the solid mechanics module in the software are selected, and the coefficients of the partial differential equations in each module are adjusted, and the fluid-solid coupling relationship is embedded in the equation, and finally the coupling calculation is performed in the solver.

Simulate the cloud pressure distribution of the coal seam under the conditions of single-layer drilling for 3 months, 6 months and 9 months, as shown in Figure 1. The small black circle in Figure 1 is the effective extraction radius corresponding to the drilling hole under the corresponding extraction time, and the black large circle is the influence radius of the drilling extraction under the corresponding extraction time; with the increase of the extraction time, the original gas pressure of the coal seam is reduced. The area of the area is increased, that is, the influence range of the extraction drilling is gradually increased, but regardless of the extraction time, the gas pressure less than 0.74 MPa is only a small range of the range of drilling drainage.

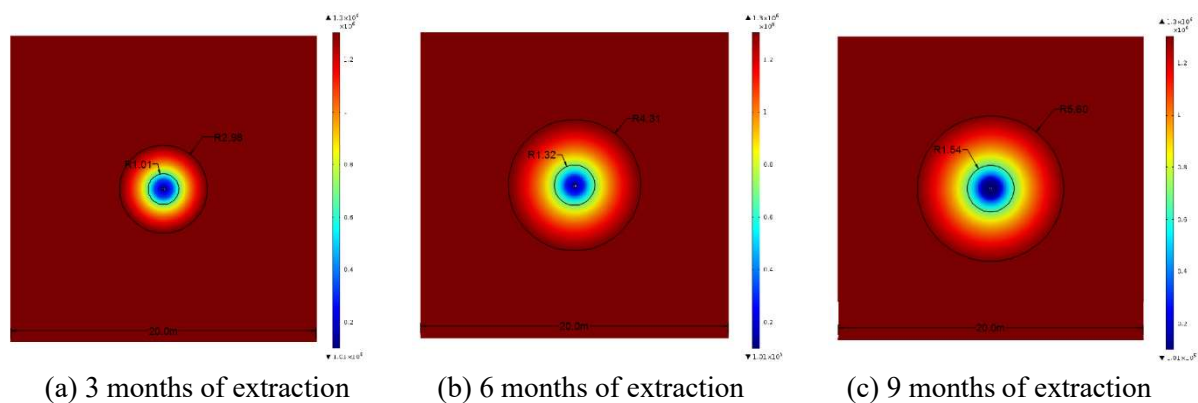


Figure 1. Cloud pressure distribution around the borehole at different extraction times

The gas pressure of the coal seam on the boundary of the borehole to the boundary of the model is monitored. The pressure distribution on the monitoring curve of different extraction time is shown in Fig. 2. Since the coal body near the wall of the borehole is destroyed during the stress concentration phase, plasticity occurs. Deformation produces tiny cracks, and the porosity and permeability of the coal body increase correspondingly. The gas seepage velocity in this area is faster. From the gas pressure distribution curve, the gas pressure in the vicinity of the pore wall is significantly reduced.

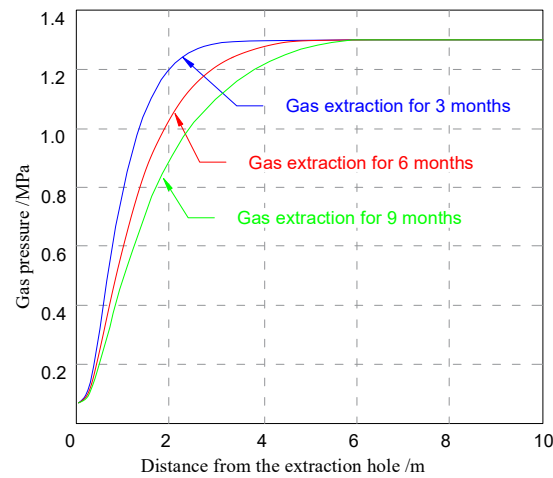


Figure 2. Pressure distribution around the borehole at different extraction times

After 3 months, 6 months and 9 months of extraction, the gas pressure in the range of 1.01 m in the drilling radius, 1.3 m in the drilling radius and 1.6 m in the drilling radius is reduced to 0.74 MPa or less. As the extraction time increases, the drilling extraction radius increases, but the increased speed decreases.

4. Extraction radius site inspection verification

At the site of Sangshuping Coal Mine, the flow simulation method was used to investigate the gas extraction radius and the numerical simulation results were compared and verified. Investigate the hole spacing of 6m, the hole diameter of the hole is 94mm, a total of 16 holes are arranged. Gas drainage data is recorded using a gas extraction online monitoring device. The original gas content of the survey area is $12.32 \text{ m}^3/\text{t}$, and the residual gas content of the extraction target is $7.42 \text{ m}^3/\text{t}$. Assuming that the pre-extraction area is a square area with a side length L of 100m, the extraction area needs a total amount of gas Q_c according to the formula. (9) Calculated, the total amount of coal seam gas that needs to be extracted in the pre-drainage area is 208740 m^3 .

$$Q_c = L^2 h \gamma (W - W_{0.74}) \quad (9)$$

In the formula: h is the thickness of the coal seam, m; γ is the bulk density of the coal seam, t/m^3 .

The number of holes required to control the $L \times L$ area is n :

$$n = \frac{Q_c}{Q_d} \quad (10)$$

The drilling radius of the through-hole drilling is r :

$$r = \frac{L}{2\sqrt{n}} \quad (11)$$

The average amount of gas per day of the single borehole in the test area was monitored. The amount of boring of the gas in the borehole was reduced by a negative exponential law. The fitting relationship between the volume of the gas extracted by the borehole and the time is shown in Fig. 3.

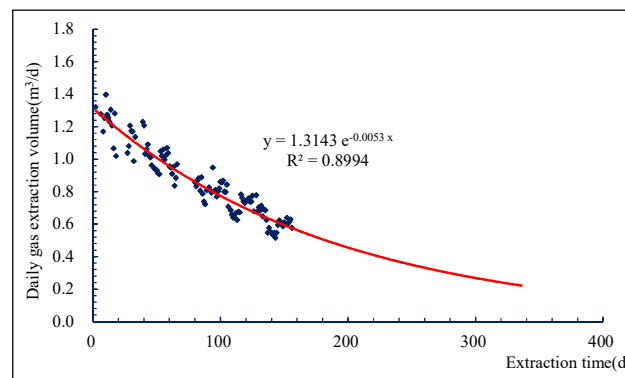


Figure 3. Fitting map of gas attenuation of drilling day

The borehole gas extraction attenuation negative exponential curve can effectively represent the single hole extraction gas law of drilling, and the drilling fitting radius can be calculated according to the integral calculation of the extraction attenuation negative exponential curve formula.

$$Q_d = \int_0^t 1.3143 e^{-0.0053t} dt = \left(\frac{1.3143}{0.0053} - \frac{1.3143}{0.0053} e^{-0.0053t} \right) \quad (12)$$

According to the average single hole extraction gas attenuation fitting function, the total amount of single borehole extraction for 90d, 180d and 270d drilling can be integrated. Combining equations (10) and (11), the measured extraction radius of the flow method is calculated. The comparison between the numerical solution results and the field test results is shown in Table 1.

Table 1. Comparison of numerical simulation results and field test results

Extraction time(d)	Flow method on-site inspection of extraction radius r(m)	Numerical simulation of the extraction radius(m)	error (%)
90d	1.06	1.01	4.7
180d	1.35	1.32	2.2
270d	1.50	1.54	2.7
limit	1.72	/	/

Comparing the numerical simulation results with the field investigation results, the results of numerical simulation results of coal seam gas drainage radius based on strain softening model and the results of field investigation are small. According to the measured results, the numerical simulation results are corrected according to the proportional coefficient method to achieve more accurate and reliable results. Collecting the basic parameters of coal seam gas in different areas can make a reasonable calculation of the gas extraction radius in different areas of the same coal seam, reduce the investigation workload of the extraction radius, and provide a basis for the coal mine drainage drilling design and construction schedule, to achieve a targeted, The purpose of precise governance.

5. Conclusion

(1) Based on the elastoplastic softening model of coal body, the coal body strength during the plastic deformation stage of the coal body is reduced, and the permeability and porosity of the coal body around the borehole wall are correspondingly increased. The numerical simulation software Comcol Multiphysics was used to simulate the distribution law of coal gas pressure under different extraction time, and the relationship between extraction time and extraction radius of 3[#] coal seam in Sangshuping

Coal Mine was obtained. The longer the extraction time, the larger the extraction radius, but as the extraction time continues to increase, the extraction radius only slowly increases.

(2) The effective extraction radius of 3[#] coal seam gas in Sangshuping Coal Mine was investigated by gas drainage flow method. The effective extraction cavities corresponding to 90d, 180d and 270d were 1.06m, 1.35m and 1.50m respectively.

(3) The numerical simulation of the elastoplastic softening model proposed in this paper determines that the extraction radius method is suitable for softer coal seams. This method can accurately determine the extraction radius under the premise of reducing the site inspection work, and has guidance for improving the gas drainage effect of coal seams. significance.

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