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Fractal Evolution of a Crack Network in Overburden Rock Stratum

GUANGMING YU[a,*], HEPING XIE[b], JIANFENG ZHAO[a] and LUN YANG[a]

[a]*Liaoning Technology University, Liaoning Province, P.R. China;* [b]*Beijing Graduate School, China University of Mining and Technology, P.R. China*

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A quantitative description for the spatial distribution and the evolution of a crack network in mining rock stratum is one of the most difficult and fundamental problem in the subject of surface subsidence. In this paper, the physical models are employed to simulate the spatial distribution of a crack network. By using the fractal geometry, the self-similarity of spatial distribution of crack network is discovered. As a result, the conception of fractal crack network is proposed. Furthermore, the evolution of a crack network with the increasing of mining width is investigated. It is shown that (1) the spatial distribution of a crack network displays the fractal behavior, so, the fractal dimension can be used to describe quantitatively the evolution of the crack network, (2) the fractal dimension of the crack network increases with increasing of mining width, (3) the surface subsidence increases with the increasing of fractal dimension of crack network.

Keywords: Mining overburden rock stratum, Fractal crack network, Self-similarity, Mining width

1 INTRODUCTION

Underground coal mining causes rock stratum from underground to surface to be fractured and deformed. The fractured and deformed rocks will form a new structure, in which there exist numerous joints and cracks. To some extent, the stability and mechanical behaviors of rocks and fluid flow in rocks are controlled by their joints and cracks. So, to investigate the evolution of mining cracks has important significance for assessing the stability of engineering rocks, investigating fluid flow in fractured rocks and underground coal mining under the "water body" and predicting the surface subsidence (Liu, 1995). To quantitatively describe the spatial distribution of cracks is a good place to start all of further investigations. However, because of the extremely complex spatial distribution of cracks in rocks, it is impossible for us to quantitatively describe the spatial distribution by using the classical methods.

Fortunately, the fractal geometry introduced by Mandelbrot (1975, 1982) provides us a very effective tool to quantitatively describe an extremely

* Corresponding author. The postgraduation Department of Liaoning Technology University, Fuxin 123000, Liaoning Province, P.R. China. Fax: (+86 418)2828772. E-mail: Yugm@public.fx.ln.cn.

irregular object and discontinue phenomenon widely existing in nature. During the past two decades, increasing effort has been directed toward quantitative describing complex and irregular objects and phenomena by using the fractal geometry. For example, many attention has been devoted to applications of fractal geometry on the earth science, particularly to description for spatial distribution of microfractures, cracks, pores and faults in earth (Turcotte, 1986; Taksyuki, 1989; Xie, 1990; 1991; 1993; 1995).

As well known, during underground coal mining, cracks in overburden rocks will extend from underground to surface. The evolution of crack network in overburden rocks is mainly controlled by mining process. In this paper, the physical models are employed to investigate the evolution of crack network within the framework of fractal geometry. It is shown that the crack network expresses to be self-similar and the fractal dimension can be used as an indicator of the development degree of crack network.

2 DESCRIPTION OF EXPERIMENTS

As mentioned above, cracks in overburden rocks will develop gradually in the process of advancing of underground coal face. In this paper, the physical models are used to simulate this process, especially to reappear the spatial distribution and evolution process of cracks in overburden rocks.

The physical models must follow three theorems of simulation, i.e., the following detailed conditions of simulation:

geometrical condition $\alpha_l = l_m/l_p = 1:100$;
density condition $\alpha_r = r_m/r_p = 3:5$;
velocity condition $\alpha_v = V_m/V_p = \sqrt{\alpha_l} = 1:10$;
displacement condition $\alpha_s = \alpha_l = 1:100$;
conditions of strength, elastic modules and cohesion $\alpha_R = \alpha_E = \alpha_C = \alpha_l \cdot \alpha_r = 3:500$;
condition of fraction angle $\alpha_\varphi = R_m/R_p = 1:1$;
condition of applied force $\alpha_f = f_m/f_p = \alpha_g \cdot \alpha_r \cdot \alpha_l^3 = 0.6 \times 10^{-6}$;

TABLE I Volumetric component of simulated materials

Kind of materials	Proportion of matrix to cementing agent	Quarta sand : heavy spar : mica	Lime : gypsum
Rock	4 : 1	4 : 2 : 2	5 : 5
Coal	6 : 1	6 : 1 : 1	3 : 7

where the subscripts p, m present the prototype and the model, respectively.

In present research, sandstone, shale and coal are simulated. The physical models are composed of quarta sand, mica, heavy spar, lime, gypsum and borate with a certain component (as shown in Table I).

The physical models with the length of 0.7 m and the height of 0.5 m were used to simulate the coal mining process under a single rock strata with the uniaxial strength of 40 MPa. The experimental results with and the coal mining width L of 24, 40, 60 and 70 m are shown in Fig. 1(a), (d), (g) and (j) respectively.

Figure 1 shows that, along with the advancing of coal face (i.e., the increasing of mining width), the crack network in overburden rocks extend to a relatively large area, in other words, all coal mining steps cause a new crack network to be produced continuously. As a result, the crack network in overburden rocks become more and more complex.

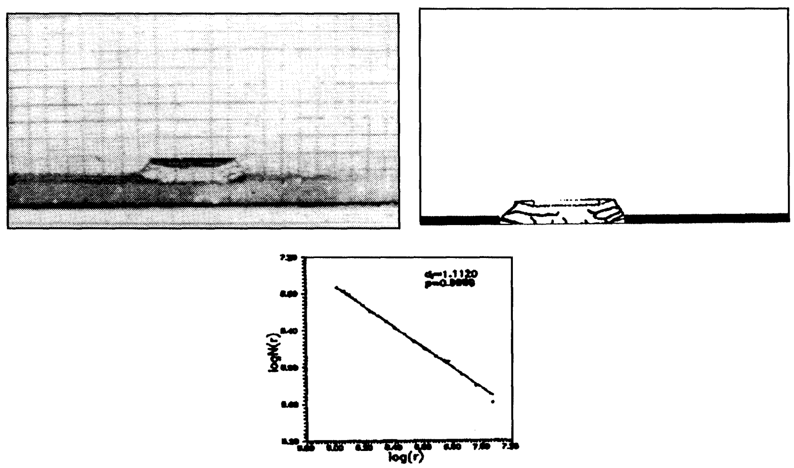
3 EVOLUTION OF CRACK NETWORK DURING COAL MINING

3.1 Estimation of Fractal Dimension of Crack Network

Although fractal dimension can be used as an indicator of complication of formation, extension and spatial distribution of crack network, how to estimate fractal dimension? In general, estimation of fractal dimension can be grouped into 2 categories, the first one being derived from purely geometrical requests, the second one being related to information theory. In this paper, the first method is used to estimate the fractal dimension of crack network. Firstly, let us choice a square grid with a certain box size to cover the crack network. Then count the number of boxes needed to cover crack network. Decreasing the box size (i.e., scale) must give a large increase in the number of boxes needed to cover crack network. Repeat this process, then the following relation can be obtained:

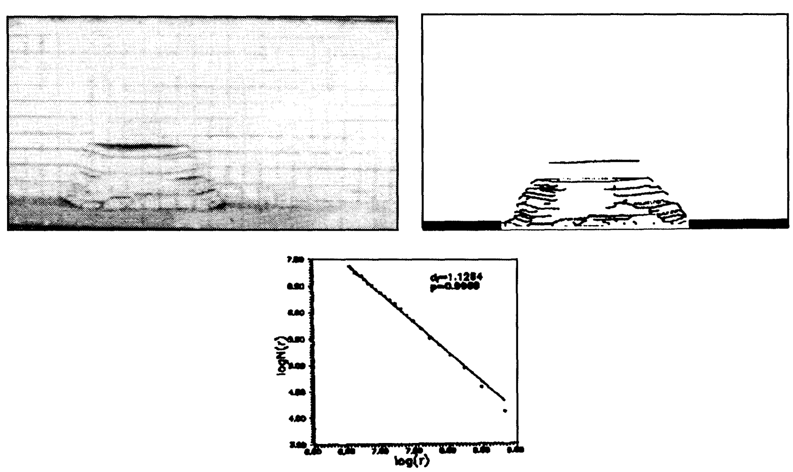
$$N(r) \sim r^{-D}, \tag{1}$$

where $N(r)$ is the number needed to cover the crack network, r is the measurement scale, D is the fractal dimension. If the spatial distribution of



(a) Physical model(L=24m) (b) Crack network

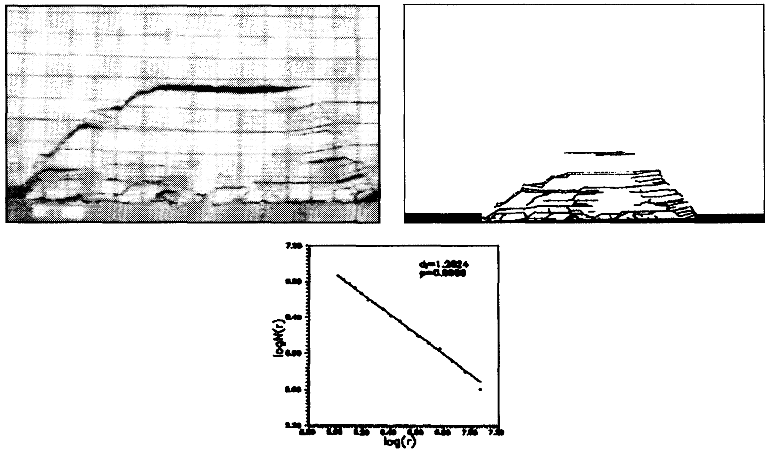
(c)Log-log plot



(d) Physical model (L=40m) (e) Crack network

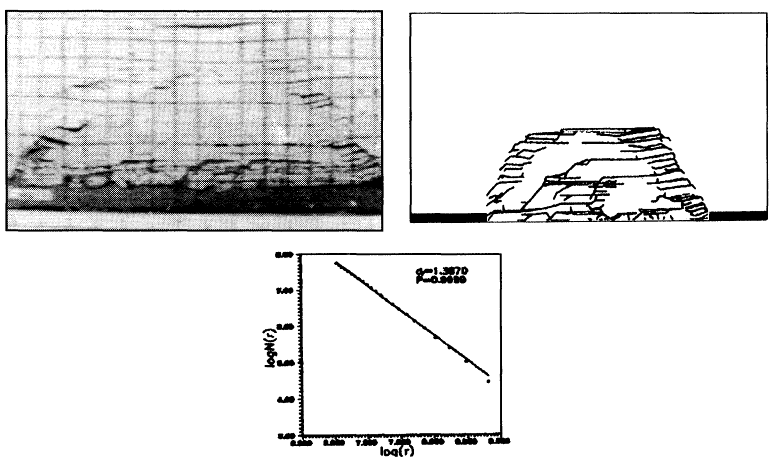
(f)Log-log plot

FIGURE 1(a)–(f)



(g) Physical model (L=60m) (h) Crack network

(i)Log-log plot



(j) Physical model (L=70m) (k) Crack network

(l)Log-log plot

FIGURE 1(g–l)

FIGURE 1 Evolution of crack network in mining overburden rocks during coal mining.

cracks is a fractal, $N(r)$ and r will fall on straight line in log–log plot. The slope of straight line is equal to $-D$.

In this paper, a special program called Fractal. For (Chen, 1995) is used to estimate the fractal dimension of crack network. Firstly, scan the pictures of experimental results (as shown in Fig. 1(a), (d), (g) and (j)); secondly, recognize these pictures and form pictures containing only cracks (as shown in Fig. 1(b), (e), (h) and (k)); then this program can count automatically the numbers of boxes in different scales and export the calculated results (as shown in Fig. 1(c), (f), (i) and (l) and Table II).

TABLE II Increasing of fractal dimension and subsidence with increasing of mining width (m)

	24	40	60	70
Fractal dimension	1.1120	1.1264	1.2624	1.3870
Related parameter	0.9999	0.9999	0.9999	0.9999
Maximum subsidence (mm)	274	758	1008	1094

3.2 Evolution of Fractal Dimension with the Mining Width

Figure 1(c), (f), (i) and (l) show that there exists a good linear relations between $N(r)$ and r in log–log plot. It is indicated that the spatial distribution of cracks express fractal behavior.

According to Table II, the regression relation between fractal dimension D and mining width L can be given by

$$D = 0.000172432L^2 - 0.0102654L + 1.2596, \quad (2)$$

where D is the fractal dimension of spatial distribution of crack network in mining overburden rocks and L is the mining width.

Figure 1(c), (f), (i) and (l) and Eq. (2) show that along with increasing of coal mining width L, the spatial distribution of crack network appears to be relatively more complex, and the fractal dimension of spatial distribution increase (Yu, 1998a,b; 1999).

3.3 Regression Relations between Surface Subsidence and Mining Width

During coal mining, the surface subsidence also increases. According to Fig. 2 and Table II, the regression relation between maximum subsidence and mining width can be given by

$$S_{\max} = -0.368L^2 + 51.89L - 751.43, \quad (3)$$

where $S_{\max}$ is the maximum surface subsidence (mm).

4 CONCLUSION

In this paper, the physical models are employed to investigate the spatial distribution of cracks in mining overburden rocks during underground coal mining. The research results indicate that

(1) the spatial distribution of crack network in overburden rocks appears to be statistically self-similar;
(2) the statistically self-similar fractal dimension of crack network in mining rocks can be used as a quantitative indicator of development degree of cracks in the process of coal mining. The more the mining width, the greater the fractal dimension. The regression relation between fractal dimension and the mining width can be given by Eq. (2);
(3) along with the advancing of coal face, the surface subsidence increases. There exists a regression relation (as shown in Eq. (3)) between the maximum surface subsidence and mining width. So, there must be a certain relation between the surface subsidence and the fractal dimension.

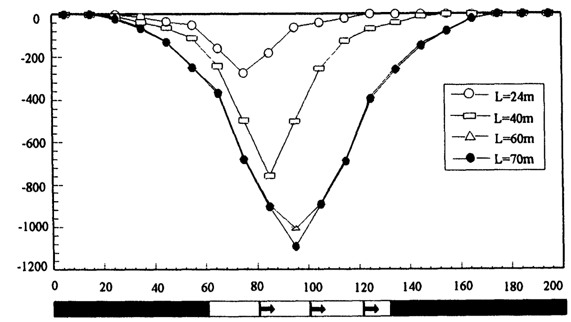


FIGURE 2 Surface subsidence under the condition of different mining width.

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