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Fractal characterization for the mining crack evolution process of overlying strata based on microseismic monitoring technology

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ABSTRACT

In order to study the evolution laws during the development process of the coal face overburden rock mining-induced fissure, we studied the process of evolution of overburden rock mining-induced fissures and dynamically quantitatively described its fractal laws, based on the high-precision microseismic monitoring method and the nonlinear Fractal Geometry Theory. The results show that: the overburden rock mining-induced fissure fractal dimension experiences two periodic change processes with the coal face advance, namely a Small → Big → Small process, which tends to be stable; the functional relationship between the extraction step distance and the overburden rock mining-induced fissure fractal dimension is a cubic curve. The results suggest that the fractal dimension reflects the evolution characteristics of the overburden rock mining-induced fissure, which can be used as an evaluation index of the stability of the overburden rock strata, and it provides theoretical guidance for stability analysis of the overburden rock strata, goaf roof control and the support movements in the mining face.

1. Introduction

Under the disturbance of mining activity on the coal face, the coal mining width varies and the internal stress in the rock redistributes continuously. Thus, the overlying strata undergo different types of deformation and damage at various depths and new rock structures form constantly. Fissure development has an impact on the mechanical behavior of the rock, thereby controlling the permeation and movement of water and gas which, to some extent, controls the stability of the overlying strata [1]. Therefore, a study of the evolution laws of mining-induced fissures in the overburden rock is of great significance in managing overburden rock movement laws and achieving mine safety, etc.

To describe the characteristics of a mining-induced fissure quantifiably depends on the determination of a rational parameter that can reflect its self-similar laws – namely, its fractal dimension. Fractal Geometry, created by B.B. Mandelbrot, can describe the rock fracture network very clearly [2]. The fractal effect exists in any rock material, at a scale as small as the crystal sizes, or as large as the crack distribution and fractures of tens-of-kilometers (faults) [3]. There are fractal features from fissures in mining rock strata to the network distribution of fissure of mining rock strata [4]. Based on many similar material simulation experiments, Yu et al. [5,6] have studied the fractal distribution and the evolution laws of fissures in mining rock strata and propose the concept of a network of fractures in mined rock masses. Using numerical simulation, Liang et al. [7,8] believe that there exists a duality of structural pattern in the unstable failure of rock samples at the micro and macro level, namely, the 'self-similarity' of fractal theory. Gao et al. [9] adopted the digital panoramic borehole camera technique to study the fracture fractal laws of roof rock masses in the process of continuous mining-induced caving in unit blocks. Li et al. [10–12] have used physical experiments to study the fractal features of the porosity, acoustic emission and other parameters of porous medium coal–rock samples.

By using such methods as theoretical modeling, numerical simulation, simulation experiments and engineering inversion, the above-mentioned results make beneficial exploration of the movement law of the overlying strata, the distribution of fractures in mined rock masses and its applications in practical engineering. The formation of fractures by mining and their distribution is simulated using similar materials or numerical calculation methods, although the simplified model cannot reflect the virtual conditions of *in situ* rock. Although research into discontinuity measurement is conducted by CT, SEM and borehole methods, most research is

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based on laboratory experiment which means that the results are different from engineering rock masses and lack the real and dynamic reflection of the fractal law of fractures in engineering rock masses. An effective monitoring technique is required at engineering sites to dynamically locate, track and monitor the position and range of fractures in the overlaying strata. To quantitatively describe the study of the evolution features of fractures in mined overlying strata by non-linear mathematical methods should also be further improved.

It is advantageous to measure and research the fracture fractal dimension in terms of reflecting the original condition of the overlying strata more vividly by using the distribution of microseismic events. The reason is that microseismic monitoring technology can obtain the real condition of overlying strata fracturing in real time and provide the three-dimensional space location of micro-fractures. With the help of the high-precision microseismic monitoring method, the thesis further reveals the evolution process of the overburden rock mining-induced fissure. And, through non-linear fractal geometry theory, the distribution of mining-induced fissures can be described quantitatively.

2. Fractal theory in rock mechanics

In 1983, B.B. Mandelbrot's *Fractal Geometry in Nature* marked the birth of fractal science [13] and since then fractal geometry has been widely used in rock mechanics. In China, the academician Xie H.P. was the first to apply fractal theory to the rock engineering field. He created the "Fractal-Rock Mechanics" theory [14], proving that coal and rock were detachable in the whole process from micro-fracture to destruction. He also proposed the consideration of fractal effects and their influence in the process of analyzing and solving rock mechanics problems. The quantitative description of a fractal is the fractal dimension D_f. The common dimensions are the similarity dimension, box dimension, Hausdorff dimension, information dimension and correlation dimension [15]. So far, the fractal theory has produced many research results in many aspects of rock mechanics, including: fracture and damage, statistical strength, evolution features of rock micro-crack damage, joint mechanics behavior, explosion fragmentation prediction, rockburst, etc. [16].

At present, there are six methods for fractal dimension measurement of rock fracture geometric construction, and amongst them the box dimension method is the most common [6]. The method involves the use of a circle of certain radius R or a square of certain side length R to cover a fracture curve or the distribution area of a fracture structure. For the grid of side length R, select a series of dimension $1/R$, and count the trace coefficient or the number of blocks falling on, and intersecting with, relevant cells. Therefore, the packing density of the trace (or block) of each cell of dimension $1/R$ is:

$$N(R) = \frac{\sum_{i=1} \frac{x_i}{x_{\max}}}{R} \tag{1}$$

Type: x_i-number of the traces or blocks within the i cell; $x_{\max}$-the maximum value of density in i cell.

A series of data from R and $N(R)$ can be obtained through the use of the above results. If the distribution of mining-induced fissures has fractal characteristics, the following relation [17,18] must be applied to the two:

$$D = \lim_{R\to 0} \frac{\lg\ N(R)}{-\lg\ R} \tag{2}$$

Analyzing the data from the logarithm of the above relation, the result is:

$$\sum_{i=1} \frac{x_i}{x_{\max}} = \frac{\lg\ N(R)}{\lg\ (1/R)} = -\frac{\lg\ N(R)}{\lg\ (R)} \tag{3}$$

Comparing the above relations, the result is:

$$D = \sum_{i=1} \frac{x_i}{x_{\max}} \tag{4}$$

In practical applications, only a limited number of them R can be taken. Taking a series of them R, $N(R)$ and then taking the slope of the straight line with double logarithmic coordinates, the slope is the fractal dimension D.

3. Mining crack monitoring of overlying strata

3.1. Monitoring the conditions of regional geology and exploitation

Fracture development and numerous faults can be seen in Huainan Xinzhuangzi mine C13. The coal seam thickness is 2.1–12.0 m, with an average of 6.16 m, of which 62,113 working surface comes to about 860 m. The elevation of the upper bound is −590 m, and the elevation of the lower bound is −665 m with an average trend of about 120 m. The C14 coal seam is unstable, and can be classified as an outburst coal seam. The thickness of the coal seam is 0.4–1.3 m, with an average thickness of 0.8 m. C15 coal seam has a thickness of about 0–0.8 m, and is unstable. The 62,114 working surface comes to 900 m, the elevation of the upper bound is −569 m, the elevation of the lower bound is −650 m, the mining height is 1.5 m, and the average trend length is about 145 m. In addition, the C15 and C13 group coal seams are highly prone to outbursts, and the first mining protective layer C14 groove protects C15 and C13, and the monitoring region of mining conditions is shown in Fig. 1.

3.2. Monitoring scheme design

After full consideration of the extraction scheme in the monitoring area, mining planning and degree of difficulty of installation, three seismic acquisition instruments and two seismic acquisition instruments are used respectively in the working surfaces of 62,113 and 62,114. Five acquisition instruments are connected with a total of 30 channel sensors. After connecting the instruments in series, the signal is transferred to the host computer on the surface, thus forming the microseismic monitoring system [19], as shown in Figs. 2 and 3.

3.3. Analysis of monitoring results

During the microseismic monitoring period, micro-crack distribution in the process of real-time caving of the overlying strata is

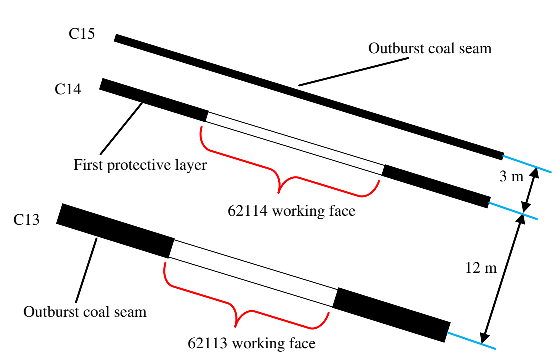

Fig. 1. Mining conditions of monitoring area.