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Fractal analysis of acoustic emission parameter series of coal with different properties under uniaxial loading

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Fractal analysis of acoustic emission parameter series of coal with different properties under uniaxial loading

Huiming Yang[1, 2]

[1.] State Key Laboratory of Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing, 400037, China

[2.] Chongqing Research Institute of China Coal Research Institute, Chongqing, 400037, China

Abstract. In order to study acoustic emission (AE) evolution characteristics of coal with different mechanical properties in failure process, uniaxial compression experiments of coals from 4 mines were carried out to analyse fractal feature of AE time series by G-P algorithm. The results indicate that AE parameter series of all 4 different coals have fractal feature, and the fractal dimension value of coal with different properties go through a process of "first rise, then fall". The change of AE fractal dimension value can reflect the cracking evolution in coal failure process, which is closely related with the failure phase. The continuous decline of AE fractal dimension can be viewed as a precursor of impending failure of coal, which could provide theoretical basis for the AE pre-warning model establishment of coal dynamic disaster.

1. Introduction

With the increase of coal mining depth, stress-dominant coal and gas outburst disasters are increasing, and that has gradually became one of the main problems blocking coal mining safely and effectively. Under deep condition, the in-situ stress in coal and rock mass increases significantly, and the outburst hazard causing effect of it becomes more prominent, that leads to frequent occurrence of coal and gas outburst in the case of "low gas content". Acoustic emission[1] (AE) monitoring method is a kind of monitoring and early warning method which can reflect the stress change and stability status of coal or rock mass, and is one of the important development directions of effective monitoring and early warning of stress-dominant outburst disasters[2-4].

The key of AE monitoring and early warning technology is AE precursor information of coal and rock material instability. The analysis of AE parameter characteristics of coal or rock failure process and precursory information mining of instability are the important methods of early warning model establishment of rock mass instability and disasters. So far, the study of AE characteristic mainly focuses on occurrence frequency, energy, spatial distribution, source parameters and some modern mathematical analysis of AE activity [5]. Such as, Mogi [6] conducted the rock failure test and found that AE activity occurred four patterns in turn with loading process: weak, sporadic or small, gradually increasing with the load increase, a sharp increase near rock failure. Zhang [7] found the "relatively quiet period" phenomenon that AE events rate declined before the failure of coal (rock), and viewed it as the precursory characteristic of rock failure. Jiang [8] found the *b* value decreased when the failure was approaching, so the continuous decline of b value can be used as a precursor of rock failure. Yin [9] studied the feature of intension distribution of AE during the process of rock failure under uniaxial compression, and found that the continually declining of fractal value was the premonitory feature of rock failure. Zhang [10] found that dominant-frequency of AE signal had a mutation before the rupture of rock. Kong [11] found that AE fractal dimension can reflect the evolution and propagation of cracks in the loading process. Gao [12] found that all the dry, natural and saturated coal samples had the fractal characteristics, and the fractal dimension value of AE presented the phenomenon of rising, drop and maximal value

Most of the above studies are based on single coal-rock material. It is rare to study the AE characteristics of coal with different properties. In this paper, experimental study is taken as the main means to analyze the fractal dimension evolution characteristics of AE parameters sequence in failure process of coal from 4 mines, to explore AE precursor information of coal instability to provide the theoretical basis for the AE pre-warning model establishment of coal-gas dynamic disaster.

2. Experiment materials and equipment

2.1. Experiment coal specimens

The test coal specimens were taken from 4 coal mines with outburst risk and different bursting liabilities. According to the standard method of coal specimen making, the coal is processed into the standard specimen of Φ50mm × 100mm along the vertical bedding direction, and of which the non-parallelism are less than 0.05mm. It is found that all coal specimens have primary joint fissure structure, and obviously which in bursting liability coals are significantly less than which in outburst coal.

2.2. Experiment equipment

The loading equipment of coal failure testing used TAW2000 computer controlled tri-axial testing machine, the device can offer 2000KN maximum axial pressure which can conduct uniaxial and tri-axial loading test. AE monitoring equipment using 2-channel AE monitoring equipment which produced by Beijing Shenghua technology company, the type of sensor is SR150N and its' frequency ranges from 22KHz to 220KHz. According to the waveform characteristics of AE in coal failure process, sampling rate is set to 1MHz and the threshold is set to 50dB, settings of acquisition time parameters are optimized, shown in table 1. AE monitoring system employ dual-channel for data acquisition, two AE sensors are arranged symmetrically on sides of the coal specimen. Sensor and coal specimen coupled with vaseline in contact face and fixed with tape. Test specimen loading test and AE monitoring system was shown in figure1.

Table 1. Time parameter settings of acoustic emission acquisition

Parameters	Time Settings[μs]
Peak definition time (PDT)	150
Hit definition time (HDT)	300
Hit lockout time (HLT)	500

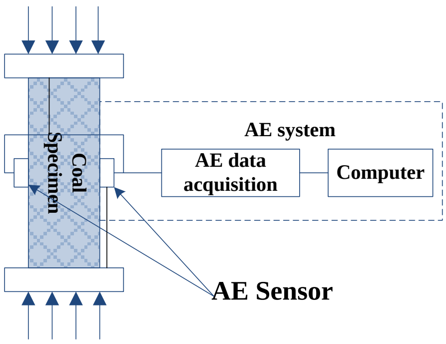


Figure1. Block diagram of AE test system in laboratory

3. Fractal characteristics of AE parameter sequence

3.1. Calculation method of fractal dimensions

Fractal theory was proposed by Mandelbrot [13] in the mid-1970s, and Xie H.P.[14] combined damage mechanics with fractal geometry to create a new field called rock fractal theory. Fractal dimension is a quantitative description of fractal characteristic, which's main calculation methods include Hausdorff dimension, information dimension, box dimension and correlation dimension, etc. Due to the relatively extensive use of correlation dimension, G-P algorithm was used in this paper to calculate the correlation dimension to analyze the evolution characteristics of AE parameter sequence.

The AE signal can be viewed as a one-dimensional time series, which can be treated to series set with capacity *n*

$$X=\{x_1,x_2,\dots,x_n\} \tag{1}$$

Firstly, take the previous m elements as a *m*-dimensional phase space point ($m<n$)

$$X_1=\{x_1,x_2,\dots,x_m\} \tag{2}$$

Then, after shifting of the element to construct the second phase space point

$$X_2=\{x_2,x_3,\dots,x_{m+1}\} \tag{3}$$

And so forth, construct the No.N (n-m+1) phase space points, namely

$$X_N=\{x_{n-m+1},x_{n-m+2},\dots,x_n\} \tag{4}$$

The correlation function w for a set of N points in phase space is given by this formula:

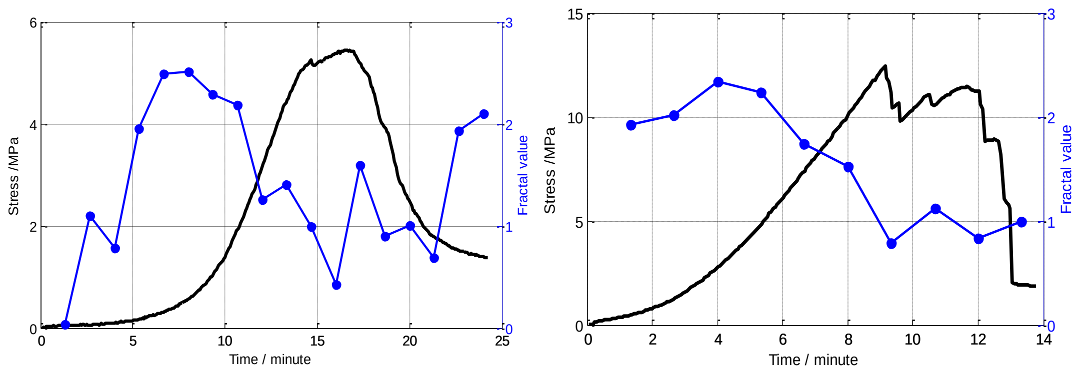
$$w(r(k))=\frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}H\left[r(k)-\left|X_i-X_j\right|\right] \tag{5}$$

Where H is the Heaviside function, $H(x)=\begin{cases}1, & x>0\\ 0, & x\le 0\end{cases}$, *r(k)* is a given scale function.

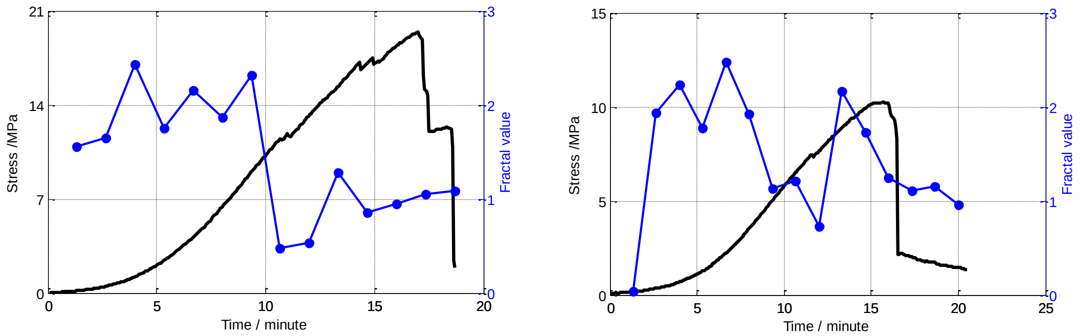
For each given scale *r(k)*, it corresponds to value *w (r (k))*, and mark *w(r(k))* as *W(k)*. Thus, for *g* scales, we would get *g* coordinate points (*ln W(k), ln r(k)*) in the logarithmic coordinate system, where *k = 1, 2, ..., g*. Then, make a regression of these g coordinate points. When the regression result indicates a straight line, it shows that the AE data series has the fractal characteristic, and the slope of the regression line is the correlation dimension value *D*.

3.2. AE fractal characteristics of coal specimens with different properties

The calculation algorithm of fractal dimension was compiled by Matlab software, and the correlation dimension value (phase space dimension *m=4*)of the AE event rate time series of different coal specimens were calculated by the algorithm, the curve are shown in figure 2.



(a) outburst risk coal specimen (b) weak bursting liability coal



(c) strong bursting liability coal (d) strong bursting liability coal

Figure 2. The stress curve and AE correlation dimension value under uniaxial compression

As shown in figure 2, the fractal correlation dimension curves of coal specimens with different properties are different, but curves evolution trends of all coal specimens have some similarity. Fractal evolution can be mainly divided into several stages: Firstly, the fractal dimension value increases gradually in the initial fissure compression and elastic deformation stage. Secondly, in yield deformation stage the fractal dimension value decreases gradually by fluctuation. Then, the fractal dimension value decreases to be the lowest in the sharp cracking phase. On the whole, the fractal characteristic curves of coal specimens with different properties go through a process of “first rise, then fall", and the decline stage appears in the severe damage stage of coal.

3.3. Discussion

AE activity is the external representation of the internal damage evolution of coal material, so the correlation dimension of AE time series parameters can reflect the evolution of the internal fracture activity. In initial loading stage, micro-cracks, which widely distributed in coal in different quantities and scales, will be closed or expanded with the increase of the load. Therefore, in this stage, the internal rupture activity in coal is dispersive and disorderly, and the correlation dimension of AE will appear as a fluctuating rising curve. With further increase of loading, the internal cracks of coal are further expanded, converged and the damage localization zone that control the failure of coal is gradually formed. The damage distribution and pattern in specimen has been gradually changed from dispersed and disorderly cracking to localized and ordered fracture. Therefore, AE correlation dimension in this stage began to reduce gradually. In the vicinity of the peak stress of coal, the internal cracks were rapidly expanding and converging into macro-fracture. The failure activity of coal was dominated by the localized fracture, while AE correlation dimension of this stage decreased rapidly. The change of AE correlation dimension reflected the evolution of crack propagation in coal, which is the external representation of the coalescence of crack propagation. Therefore, correlation dimension continuously decline can be viewed as a precursor of impending failure of coal.

4. Conclusions

(1) AE parameter series of all coal with different property have fractal feature. On the whole, the fractal characteristic curves of coal specimens with different properties go through a process of "first rise, then fall", and the decline stage appears in the severe damage stage of coal specimen.

(2) The change of AE correlation dimension reflected the evolution of crack propagation in coal, which is the external representation of the coalescence of crack propagation. The failure process of coal is a gradual damage changing process from dispersed and disorderly cracking to localized and ordered fracture.

(3) The continuous decline of AE correlation dimension can be viewed as a precursor of impending failure of coal, which could provide theoretical basis for the AE pre-warning model establishment of coal dynamic disaster.

Acknowledgments
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