International Journal of Mining Science and Technology 23 (2013) 213–219

Contents lists available at SciVerse ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Damage evolution law of coal-rock under uniaxial compression based on the electromagnetic radiation characteristics

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ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form 1 August 2012
Accepted 1 September 2012
Available online 28 May 2013

Keywords:
Electromagnetic radiation (EMR)
Acoustic emission (AE)
Uniaxial compression
Damage evolution

ABSTRACT

Based on electromagnetic radiation characteristics, the present research studied the damage evolution of rock under uniaxial compression. Besides, this research built the coal-rock damage evolution model considered residual strength. The applicability and accuracy of the model were verified through experiments. The results show that coal-rock damage evolution consists of four periods. The first period is from the beginning of compression to nearly 20% of the stress peak value, during which the damage variable changes stably about 0.1, and accordingly a few of electromagnetic radiation signals emerge. The second period is from about 20% to 70% of the stress peak value. The damage has stable development, and the parameter of electromagnetic radiation characteristics turns larger continuously with the increase of stress. The third period is when the damage has accelerated development, the coal-rock was broken which result from sharp increasing of the damage variable, meanwhile a great quantity of electromagnetic radiation signals emerge. The fourth period is after the coal-rock fracture, during which the damage variable corresponding to the parameter of electromagnetic radiation characteristics has a stable development. This research has great academic and realistic significance for further studies the electromagnetic radiation characteristics of coal-rock under loading and damage and the forecasting of coal-rock dynamic disasters.

1. Introduction

With the increase of mining depth, the intensity and rate of rock burst disasters are on the rise. It is still a major problem which confuses fields like mining safety and rock mechanics to forecast disasters of this kind. Based on electromagnetic radiation and acoustic emission feature during the fracture process of coal-rock, coal-rock dynamic disaster forecasting has been studied by some researchers with a certain amount of results gained [1–12]. Liu Baoxian and some other researchers studied the damage evolution law during fracture process of coal or rock by using AE feature of coal-rock under uniaxial compression [5–9]. He put forward a one-dimensional electromechanical coupling model of loaded coal-rock according to damage mechanics and statistics theory [13]. Sa studied the relationship between EMR counts and damage during coal-rock fracture process [14]. The electromechanical coupling model of coal-rock with gas on EMR memory effect was built under the circumstance of same confining pressure triaxial compression, and its rationality was proved. However, the damage evolution law of coal-rock in loading process represented in studies above was merely before the main fracture and that of the whole loading process, based on EMR signal feature, was rarely studied till now.

This paper mainly conducts experimental studies on coal-rock deformation damage and EMR feature under uniaxial loading circumstance. Based on verifying former theoretical models, the correspondence between EMR feature parameter and rock damage evolution while loaded was built. The residual strength was considered and the AE parameter was also compared and analyzed. The study results could provide basic evidence for further study on the damage evolution law of loaded coal-rock, coal-rock dynamic disaster evolution process and time effect mechanism. And it has important theory and practice significance for coal-rock break forecasting and coal-rock stability evaluation.

2. Acoustic-electric experimental study of the coal-rock uniaxial compression and damage

2.1. Experimental equipment and method

The acoustic-electric testing system of coal-rock uniaxial compression and damage consists of YAW series microprocessor control electricity–liquid servo pressure testing machine and CTA-1 acoustic-electric data acquisition and processing system. The

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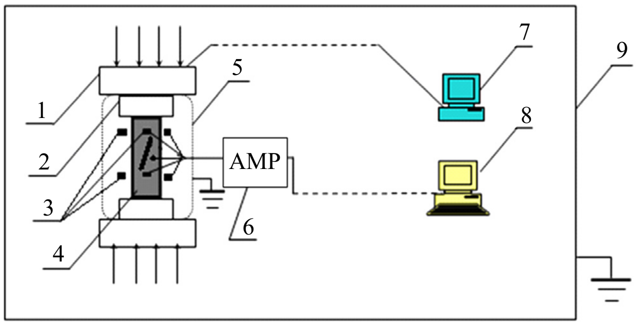
2095-2686/$ - see front matter © 2013 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.04.017



1. Pressure testing machine; 2. Insulated shim; 3. Acoustic-electric sensor;
4. Coal-rock sample; 5. Electromagnetic shielding net; 6. Front amplifier;

Fig. 1. Sketch map of experiment system.

whole experiment system is located in GP6 efficient electromagnetic shielding system, as shown in Fig. 1.

Coal-rock damage and EMR feature experiment was conducted by using this system. Counts and energy value of both EMR and AE signal generated in the process of loaded coal-rock uniaxial compression and damage were recorded by the CTA-1 acoustic-electric data acquisition and processing system. Parameters, like load, displacement and time, were automatically recorded by the YAW series microprocessor control electricity–liquid servo pressure testing machine.

In order to compare the loaded rock damage EMR data with AE data, the data acquisition system connected in terms of the following way: Paths 2 and 6 connected with AE sensors, and their main frequencies were 51.76 and 20 kHz; Paths 5 and 8 connected with EMR sensors with 53 and 5 kHz as their main frequencies. The switching rate of the acquisition system was set as 500 ksps.

The experimental rock samples were taken from proof rocks of Groove 3 in Anzi area of Changgouyu Coal Mine, and the rock samples were fine sandstone. Chunks of rock were made into standard samples of 50 mm × 100 mm, and planeness error of two end faces was below 0.02 mm. The samples were strictly sifted: (1) samples with obvious or visible fractures on surface were removed from the samples; (2) samples with unqualified size or planeness were also thrown out from the samples. Rock samples were surely selected from the same surface of one rock block in order to ensure the comparability of experimental results. Three samples were finally selected from those qualified ones to conduct this experimental study, and were numbered as 1#, 2#, and 3#.

The EMR sensors were arranged on the same height parallel with long axis direction of the sample. The distance between end of sensors and surface of the sample was 1–2 cm. Each end face of the sample was separated with the pressure testing machine by piece of insulated shims in order to prevent signals from transferring. The AE sensors were fixed and coupled with the sample using paper tape, and vaseline was coated on the probe and contact part to ensure coupling effect. Besides, it is necessary to ensure that the EMR or AE sensors keep certain distance with top and end faces of the sample in order to decrease the influence of them.

Control mode using the force was adopted in the process of experiment. The pressure testing machine would not stop until the sample, which was loaded by a loading rate of 1000 N/s, be damaged and stay in stable residual deformation phase.

2.2. Experimental results and analysis

Experimental results of sample 1# are shown in Figs. 2–5. The results show that: (1) EMR and AE signals all exist through the process of rock loading. Generally, the counts and energy value of acoustic or electric signals would heighten with the increasing of load and deformation rates. The EMR and AE become active unusually when the pressure value gets near to the peak, and reach the maximum around the pressure peak; (2) there is a sharp increase of accumulation curve of the EMR and AE counts (energy) before the main fracture of the rock. This feature can be applied to forecast rock fracture efficiently; (3) the counts and energy value of EMR in the residual deformation phrase are greater than those of AE. It is possibly because friction between fragments after rock fracture causes amounts of EMR signals.

3. Coal-rock damage model based on EMR feature parameters

The damage of coal-rock materials loaded is mainly about the emergence, expanding and sudden breakage of their inside crack. When cracks emerge and expand, burst damage would form if part of elastic energy which reserved inside suddenly released. EMR generated because of damage when coal-rock loaded anisotropism. It is caused by anisotropic speed changing deformation when coal-rock loaded [15]. There are two forms: one is Coulomb field caused by charge (or quasi-electrostatic field), and the other is EMR caused by speed changing activity of charged particle.

Damage is the process of material or structure degradation and breakage caused by defect of micro-structure under the effect of external loading circumstance [16]. According to coal-rock damage EMR micro deformation mechanism, loaded coal-rock EMR is a phenomenon that radiate electromagnetic wave outward which caused by damage deformation of inside structure micro-structure defect. Therefore, there must be certain correspondence between the EMR and the damage deformation degree of coal-rock [17].

According to the continuous damage mechanics theory, a damage deformation model could be built as Eq. (1):

$$\sigma = E(1-D)\varepsilon = (1-D)\sigma_e \tag{1}$$

where E is the young modulus of elasticity; ε the strain; σ_e the effective stress; and D the damage parameter.

In uniaxial stress circumstance, D represents the rate of micro-crack (micro-hole, micro-defect) inside material elementary volume; $D = 0$ represents complete material without any damage; and $D = 1$ means damage of volume element.

3.1. Damage evolution model based on EMR counts value

Based on analyzing the correspondence between the EMR and the coal-rock damage deformation degree, Nie provided the relative equation of the uniaxial compression coal-rock damage variable D and the EMR accumulative counts value ($\Sigma N, N_m$), while the intensity of each volume element was supposed to obey Weibull distribution [18–20]. Eq. (2) is as follows:

$$D = \frac{\Sigma N}{N_m} \tag{2}$$

where ΣN is the EMR accumulative counts value when damage time reaches t; and N_m the accumulative counts value when coal-rock entirely damaged.

Substitute Eq. (2) into Eq. (1), the coal-rock damage deformation EMR coupling model under uniaxial circumstance was obtained as follows:

$$\sigma = E\varepsilon\left(1 - \frac{\Sigma N}{N_m}\right) \tag{3}$$

where $\sum N$ is the EMR accumulative counts value when strain reaches ε. The meanings of other parameters are as mentioned above.