Research on Characteristics and Laws of Fracturing Dust Production in Deep Coking Coal with Similar Material Structure

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Abstract: The coking coal under the influence of the earth stress is easily broken in the mining process, the dust production is large, the particle size is small, and the dust is serious. Considering the characteristics of primary coal dust, the ratio of similar materials is determined by experiment of single axial compressive strength. By means of acoustic emission detection device, uniaxial compression test is carried out for the coking coal similar materials in different structural forms, and the characteristics of fracture development and dust production of the primary dust are studied. The experimental results show that: pulverized coal: gypsum: cement is 0.81:1:1 and 0.2:1:1 the compressive strength of similar materials is 3.5 mpa and 1.5mpa, which meets the test requirements. The regularity of structural pressure of similar material is shown, similar materials with smaller strength and heavy loading deformation, however, the fracture and fracture development, the primary dust production is large. When the axial pressure is low, the low-intensity similar coal test block is vulnerable to crushing deformation at the upper part, the lower high strength coal needs to be damaged when the force is larger.

1. Introduction
Coking coal has a large amount of dust in the mining process, small dust particle size and difficulty in collecting, which seriously endangers the safe production of coal mine[1-2]. In the process of coal body crushing, the primary dust of coal body is produced on the surface of the fracture, and with the increase and expansion of the crack in the coal body, fine particles and dust are produced[3-4].

Combining the fracture mechanism of brittle materials, the paper studies the influence of structure mechanics performance on the law of dust generation by using acoustic emission detection to detect the development of cracks in coal body and the formation and release process of dust nucleus during the fracture, and provides the theoretical basis for dusting in mining operations, in order to reduce the generation of coking coal dust.

2. Engineering background
Shandong JuYe coalfields Coal-based coking coal, the main coal seam (3 layers) of the main coking coal, coal thickness 4 ~ 6 m easily lead to dust hazards in the production process. Site monitoring data
and experiments show that the production process in the same coal seam at different positions in different parts of coking coal dust produced large differences, see Table 1.

| Number | Position     | Ash (Aad)/% | Water (Mad)/% | Volatile (Vad)/% | Fixed Carbon (FCad)/% | Axial Compression/MPa |
|--------|--------------|-------------|---------------|------------------|-----------------------|-----------------------|
| 1      | 3Lower Coal  | 6.51        | 0.33          | 25.41            | 67.76                 | 3.14                  |
| 2      | 3MiddleCol   | 5.52        | 0.57          | 23.71            | 70.20                 | 1.81                  |
| 3      | 3Coal Upper  | 6.70        | 0.68          | 23.65            | 68.97                 | 2.84                  |

As can be seen from Table 1, the coal seams in this area have high fixed carbon content and low water content. The same seam from bottom to top, the coal moisture, ash gradually increased, the larger the central fixed carbon content. Axial compression data show that the middle coal seam strength is only 1.81 MPa, lower and upper coal seam strength is higher. In this experiment, coal blocks were taken in different positions on the same working face and cut into square of 4 cm square. Then, the strength value of crushing time was tested with WYA-300 electro-hydraulic compression testing machine, and immediately screened. As shown in Figure 1, 2, Table 2.

| Number | Position     | Measuring pressure /MPa | Axial pressure crushing particle size mass ratio | Particle size characteristics |
|--------|--------------|-------------------------|-----------------------------------------------|-------------------------------|
|        |              |                         | <1mm/% | >1mm/% | D10 | D50 | D90 | Dav |
| 1      | 3Lower Coal  | 3.14                    | 11.80  | 88.20  | 11.78 | 59.68 | 107.03 | 59.23 |
| 2      | 3MiddleCol   | 1.81                    | 4.63   | 95.37  | 28.18 | 73.44 | 110.91 | 70.67 |
| 3      | 3Coal Upper  | 2.84                    | 8.03   | 91.97  | 11.68 | 59.00 | 107.62 | 58.93 |

As shown in Figure 1. The coal crushing, it can be seen with a large number of coal surface with small particles. The coal body is completely broken into loose granular powder particles with granular structure. Particle size is more uniform, Most particle size and broken powder of less than 5mm based. As can be seen from the micro-structure in Figure 2, the coal shows a large number of fine particles attached.

As can be seen from Table 2, After axial compression, the percentage of <1mm particles in the middle of crushed coal block after axial pressing was the lowest, only 4.63%. However, from the particle size distribution, the D10 particle size of the middle coal is the largest. After axial compression is mostly crushed coal.

3. Preparation of similar materials

3.1 Preparation and Experiment of Cylindrical Similar Material Sample

According to the principle of similarity, single factor analysis method was used to test the influence of the different ratio of pulverized coal, gypsum and white cement on the strength of similar materials. The results show that the similar materials of raw coal can be prepared with coking coal powder of 60...
~ 80 mesh as the aggregate and cement and gypsum as the binder, which can meet the basic requirements of the experiment for all indexes.

![Figure 3. Coking coal standard specimen.](image1)

![Figure 4. Samples of similar materials of coking coal.](image2)

### 3. 2 Preparation of similar material samples

After verifying the feasibility of using similar materials for acoustic emission research, a sample of similar material assembly was prepared. Specific combinations are divided into Single-layer easily broken coking coal samples of similar materials, double-layer of soft-hard coal samples of similar materials, and three-layers of hard - soft - hard coal similar material sample.

| Number | Combination Style | Raw materials and ratio | Size (mm) | Loading method and speed |
|--------|-------------------|-------------------------|-----------|--------------------------|
| 1      | Single layer      | 0.8:1:1                 | 100×150×150 | Displacement loading 0.6mm/min |
| 2      | Double layer      | 0.8:1:1                 | 50×150×150  | Displacement loading 0.6mm/min |
|        |                   | 0.2:1:1                 | 50×150×150  | Displacement loading 0.6mm/min |
|        |                   | 0.2:1:1                 | 30×100×200  | Displacement loading 0.6mm/min |
| 3      | Three layers      | 0.8:1:1                 | 40×100×200  | Displacement loading 0.6mm/min |
|        |                   | 0.2:1:1                 | 30×100×200  | Displacement loading 0.6mm/min |
|        |                   | 0.2:1:1                 | 30×100×200  | Displacement loading 0.6mm/min |
| 4      | Three layers      | 0.8:1:1                 | 40×100×200  | Displacement loading 0.6mm/min |
|        |                   | 0.2:1:1                 | 30×100×200  | Displacement loading 0.6mm/min |

![Figure 5. Sample of similar material of fragile coking coal.](image3)

### 4. Fracturing Experiment and Process Analysis of Coking Coal Similar Material

In the condition of uniaxial compression, the acoustic emission of brittle materials such as coal often occurs during the destruction process. Brittle materials such as coal are damaged due to external forces, and their internal strain energy is quickly released through the form of elastic waves. Due to the uneven distribution of internal stress and the combination of different specimens, the transition from
unstable high energy to stable low energy state occurs. In this process, the relaxation process will be produced, and the activity of the specimen reflects the activity of the micro damage of coal. On the macroscopic view, the fracture of the specimen and the production of the fine particle dust. The experiment adopts the mining stress test system developed by Shandong University of Science and Technology and the US acoustic emission detection system. The displacement loading speed is 0.6 mm/min. The damage evolution process of coal and rock can be analyzed by detecting the characteristics of acoustic emission, ringing count rate and energy counting rate. The fracture modes, stress-strain characteristics and acoustic emission characteristics of soft hard coal samples under uniaxial compression in different combinations were studied. And The influence of different coking coal combinations on mechanical behavior, fracture development and dust production characteristics of samples were analyzed[5-6].

4.1 Analysis of dust production characteristics of single layer similar material under uniaxial compression.

Combined with the stress strain curve and acoustic emission counting statistics, it can be found that the homogeneous and uniaxial fracture process can be divided into four stages: initial compaction stage, elastic stage, plastic deformation damage and excessive deformation stage[7]. The pressure law of similar material structure shows that in the axial compression of single material similar material, the middle part is the weak link of material, the crack development is obvious, the primary dust develops outward from the central area of X, and the low strength similar coal specimen has obvious fissure development and the amount of dust produced is larger.

The crack shape of rock and concrete under plane stress of different stress states, as shown in Figure 6. The density, configuration and shape of the crack have an important relationship with the stress ratio. Each crack is generally formed on the plane perpendicular to the maximum principal stress direction, and the damage is anisotropic. Anisotropy in rock mechanics is mainly due to the existence of fracture and weak surface structures. By analyzing the microscopic phenomena of coal compression process, the damage mechanism can be summarized as follows: The first is the formation of micro-cracks in the interface between the internal particles of the similar material and the interior of the cement material; After the stress increases, these micro cracks gradually extend and expand, and connect into macro cracks. The damage of mortar keeps accumulating, cutting off the connection with aggregate, and losing the bearing capacity gradually because of the destruction of the integrity of concrete.
4.2 Analysis of dust production characteristics of double layered similar material under uniaxial compression

As shown in Figures 8, the experiments of double-layer axial compression at different intensities indicate that:

![Figure 8. Development curves of axial compression crack and acoustic emission of double layered specimens](image)

According to the relationship between the parallel bedding strain-loading time and the AE ring count-time curve of the soft-hard coal similar material sample assembly, and the relationship between the AE energy number and the loading time[8-10], it can be analyzed:

The process of axial compression is shown in Figure 8. The counting rate and the energy counting rate of the acoustic emission ringing at 0 to 65 s showed an increasing trend, and the energy count increased in the vicinity of 65 s, and the corresponding specimen was cracked. With the increase of load, the ringing count rate and energy counting rate of 65 s ~ 180 s acoustic emission continue to increase, and micro cracks and micro pores in coal begin to appear and develop. When loading to 180 s, the count rate of acoustic emission ringing and the number of energy counting rate begin to increase greatly, and the cracks in the samples of similar materials expand and connect with each other.

4.3 Analysis of dust production characteristics of three-layer similar material sample under uniaxial compression

Combined with the actual situation of coking coal in southwestern Shandong, according to the force conditions of the coal seam, the three-layer briquette specimens were specially selected in a hard-soft-hard combination to test the fracture development process and its laws. The experimental process and test parameters are shown in figure 9.

![Figure 9  Acidic emission monitoring data of three-layer sample](image)

According to the curve of strain-loading time and AE ring count-time, and the relationship between AE energy number and loading time, it can be analyzed:

(1) When the upper indenter touches the sample, the particulates on the contact surface and the interface between the soft and hard coal are broken, and some of the initial weak acoustic emission signals are captured, due to the smaller compressive strength of the central “soft coal” sample. The pores in the middle are first compacted.

(2) At t=47s, there was a strong crack propagation event. The ring count-time changed significantly and increased sharply at t=65s. The elastic energy accumulated in the sample was suddenly released, the soft coal specimen in the middle of the sample occurred macro fracture. At the same time,
the macro cracks were also found in the hard coal samples. However, because of their high hardness and rigidity, the fracture surfaces were sparse and failed to produce dust.

(3) Continuous loading stage, The internal coal seam rupture surfaces are rubbed against each other, and the acoustic emission activity of the similar material sample assembly is intense and the strain value increases. Finally, the bifurcated cracks in the coal have completely penetrated to form a large main crack.

(4) Then continue loading, the sample enters the stage of excessive destruction. During this stage, the ringing count of acoustic emission didn’t decrease significantly. When the peak stress is reached, the acoustic emission signal is relatively large, which indicates that there are a large number of internal cracks in the coal, and it is maintained for a long time. This indicates that the microcracks in the coal are fully developed at this stage, forming many large cracks and cracks. Faces are rubbed against each other, and dust develops at this stage. As a result, coal’ s acoustic emission activity is intense, its carrying capacity is continuously declining, and its strain is rapidly increased. It shows that the micro cracks in the coal are fully developed, forming many large cracks, friction between the fracture surfaces, and the dust development at this stage, so the acoustic emission activity of coal is violent. Bearing capacity has been decreasing and strain has increased dramatically.

5. Conclusion
Aiming at the problem of deep crushing of coking coal and producing dust. Designed acoustic emission testing experiments for similar material combinations of coking coal with different degrees of softness and hardness, studied the crack generation process of different combinations, and the development of cracks and the impact on the production of cracked dust. The conclusions of this paper are as follows:

(1) The uniaxial fracturing process of single-layer coking coal similar materials can be divided into four stages: initial compaction stage, elastic stage, plastic deformation failure, and excessive deformation stage. Dust generation occurs mainly in the plastic and excessive deformation stages.

(2) In the process of uniaxial compression of similar material of double or triple coking coal, the position where the macroscopic crack appears first and the collapsed particle is always located at the interface between similar materials of soft coal and similar materials of hard coal, and the degree of damage of similar material of soft coal is higher, that is, dense nuclear sources of dust, resulting in a larger amount of dust. For the different loading directions: parallel to the bedding direction, the fissure extends along the bedding direction, and the dust core is concentrated; the fracture of the specimen is extended in all directions, and the dust source is dispersed.

References
[1] Rahman, M. H., et al. (2015). Study of Thermal Conductivity and Mechanical Property of Insulating Firebrick Produced by Local Clay and Petroleum Coal Dust as Raw Materials. Procedia Engineering105: 121-128.
[2] Zhao, R., et al. (2003). Study on co-pyrolysis of coking-coal, plastic and dust. Environmental Science24(5): 28-33.
[3] Feng, Z., et al. (2012). An experimental study on the correlation between the elastic wave velocity and microfractures in coal rock from the Qingshui basin. Journal of Geophysics & Engineering9(6): 691.
[4] Zhao, L.Q., Feng, J.W.(2018). Interrelationship Study Between Rock Mechanical Stratigraphy and Structural Fracture Development,Journal of Shandong University of Science and Technology(Natural Science),2018,37(1):35-46.
[5] Xu, J., et al. (2009). Rock fatigue damage evolution based on acoustic emission. Journal of University of Science & Technology Beijing31(1): 19-24.
[6] Moradian, Z. A., et al. (2010). Evaluating damage during shear tests of rock joints using acoustic emissions. International Journal of Rock Mechanics & Mining Sciences47(4): 590-598.
[7] Tang, L., et al. (2015). Experimental study of mechanical characteristics of skarn under one-dimensional coupled static and cyclic impact loads. Journal of Central South University.

[8] Cai, M., et al. (2007). Back-analysis of rock mass strength parameters using AE monitoring data. International Journal of Rock Mechanics & Mining Sciences 44(4): 538-549.

[9] Liu, B., et al. (2009). Study on damage evolution and acoustic emission character of coal-rock under uniaxial compression. Chinese Journal of Rock Mechanics & Engineering 28: 3234-3238.

[10] Vilhelm, J., et al. (2008). Application of autocorrelation analysis for interpreting acoustic emission in rock. International Journal of Rock Mechanics & Mining Sciences 45(7): 1068-1081.