FINE CHARACTERIZATION AND GROUTING SIMULATION OF BOREHOLE FRACTURE DEVELOPMENT IN BURNT ROCK

by

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Burnt rock, as a special rock characterized by highly developed internal fractures, provides excellent spatial conditions for the storage of groundwater resources. However, due to the mining disturbance in the working face of the coal seam, the internal fractures of the burnt rock layer will further develop to generate a large number of macroscopic fractures. If these fractures expand to the working face of the coal seam, it will bring safety problems to coal seam mining. Therefore, this study first conducted a detailed identification of borehole fractures in burnt rock, constructed a fracture distribution model, and analyzed the development of fractures in the burnt rock layer. Second, grouting simulations of the burnt rock mass with fractures were performed to examine the stress field distribution of the burnt rock mass under different grouting pressures. It is concluded that for regions with uniformly distributed fractures, a grouting pressure of 2.0 MPa is more effective, while the areas with non-uniformly distributed fractures require a grouting pressure of 2.5 MPa.

Key words: *burnt rock, fracture identification, grouting simulation*

Introduction

Spontaneous combustion of coal seams has occurred in large areas such as Xinjiang, Shaanxi, Inner Mongolia, and Gansu in China. The combustion of coal seams causes changes in rock structure, mineral composition, physical properties*, etc.*, forming a special type of rock known as burnt rock [1-3]. The development of internal fractures in burnt rock provides excellent water storage capacity, providing favorable spatial conditions for the storage of groundwater [4-6]. However, since burnt operation aquifers are often associated with coal seams, high intensity mining of the coal seam working face induces numerous macro-fractures within the burnt rock, which gradually connect with the working face of the coal seam, threatening the safe operation of the coal mine [7, 8]. Therefore, analyzing the morphology and distribution characteristics of fractures in burnt rock layers is vital for understanding the mechanical properties of the burnt rock layer, designing roadway support for the working face of the coal

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seam, enhancing grouting efficiency, and preventing and controlling floods, which can provide a guarantee for the safe and efficient operation of the mine.

This study is based on 360° panoramic borehole videos recorded at the working face of the coal seam. First, the internal structure of the surrounding rock was observed and the distribution of fractures was recorded. Then, the fracture parameters were identified and quantitatively characterized with the help of image processing software ImageJ and modelling software RHINO. Finally, the RS2 software was used for grouting simulation analysis of borehole surrounding rock with fractures, and the grouting effects under different pressures were analyzed and compared.

Fracture identification in burnt rock boreholes

Fractures in images were characterized by two major features of low grayscale and high linearity. Therefore, the threshold segmentation algorithm was applied for fracture identification, with the threshold adjusted based on the clear lines appearing in the binary image and by comparing it with the visual image for accurate characterization [9]. The ImageJ software was used for image processing to obtain fracture characterization images and measure fracture parameters. The measured joint occurrence and density data were grouped by spatial orientation intervals, and a rose diagram was created to characterize the joint tendency and number at various depths within the borehole, as shown in fig. 1. The analysis revealed that fractures were most concentrated at a depth of approximately 39 m, with azimuths ranging from 0°-300°.

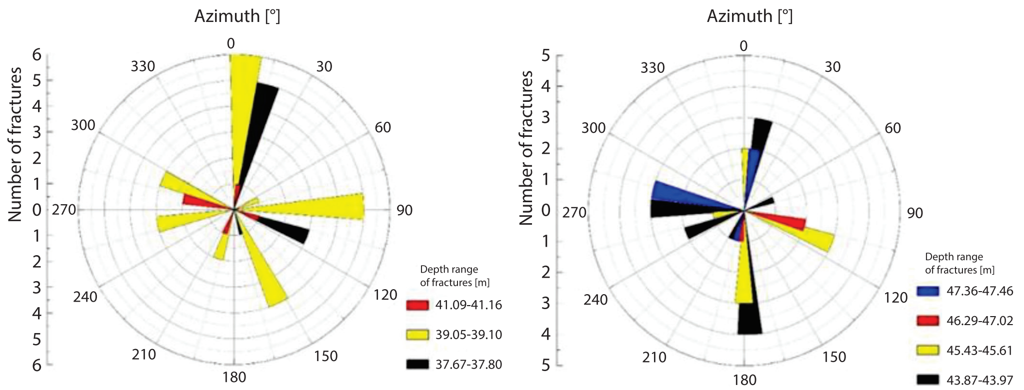

Figure 1. Rose diagram of fracture azimuth at different depth ranges

Fracture pole density cloud diagrams provide an intuitive representation of fracture development and dominant orientations, as shown in fig. 2. The scatter points in these diagrams are determined by the intersection of the fracture dip vectors originating from the diagram's center, with the projection sphere. The radial values correspond to fracture dip angles, with points on the outer perimeter indicating a dip of 0° and the center representing a dip of 90° increasing progressively towards the center). Angular values represent fracture azimuths. The diagram shows a concentration of fractures with azimuths around 10° and dips ranging between 15° and 30°, forming the dominant structural surface.

Fracture modelling in burnt rock boreholes

Parameters such as depth, dip, width, length, and azimuth of fractures in each group were obtained through image identification, and the 3-D spatial distribution model of borehole fractures was established using RHINO software. The comparative analysis of the overall model revealed that fractures were most prominent at a depth of approximately 39 m. Future construction work should prioritize grouting reinforcement of the surrounding rock at this depth, as illustrated by the fracture model diagram shown in fig. 3.

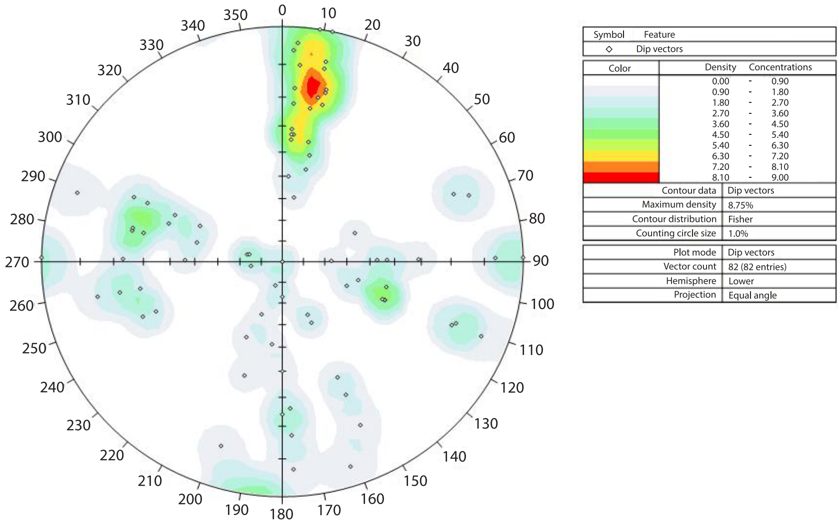

Figure 2. Fracture pole density cloud diagram

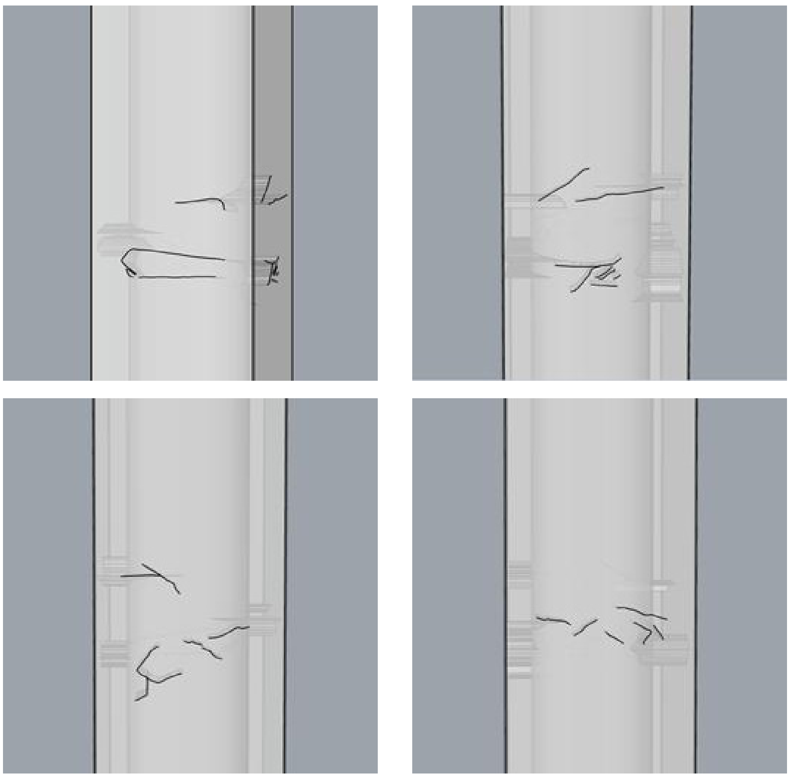

Figure 3. The 3-D spatial distribution effect diagram of fracture groups

Grouting reinforcement simulation study for burnt rock boreholes

The finite element software RS2 was employed for grouting simulation. Based on the fracture identification results, 2-D plane models at various depths were developed. The dimensions of the 2-D rock plane were 8 m × 8 m, with a borehole of 100 mm diameter at the center. Fractures on the borehole wall expand laterally from the edge into the center of the rock, with an expansion range of approximately 1 m.

To simulate the natural joint structure within the rock as accurately as possible, a method involving the addition of a random fracture network was adopted, which was achieved by adding a Voronoi (or Thiessen polygon) fracture network after importing the initial geometric model [10]. The mesh was discretized using six-node triangular elements, and material properties, loads, and boundary conditions were set during the preprocessing stage. The geometric model and pre-processing set-up used for simulation are shown in fig. 4.

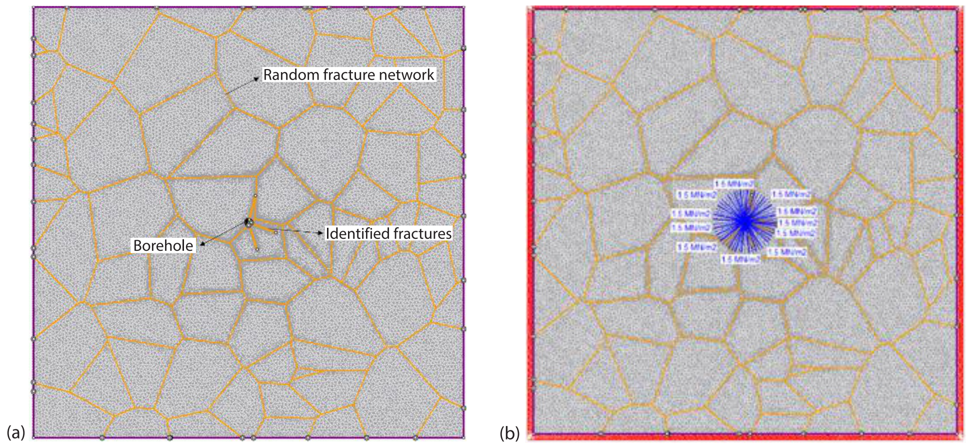

Figure 4. Geometric model (a) and pre-processing model (b)

The stress field responses of burnt rock with fractures under different grouting pressures were analyzed. Based on the depth range of borehole fractures and empirical formulas, grouting pressures of 1.5 MPa, 2.0 MPa, and 2.5 MPa were selected for simulation.

The distribution of maximum principal stress σ1 around the borehole under different grouting pressures is shown in fig. 5, and the following observations were made:

– Grouting alters the stress distribution around the borehole, and increased grouting pressure leads to a more uniform stress distribution within the surrounding rock.
– For fractures uniformly distributed around the borehole wall, such as those in fracture Group 2, a circular stress redistribution zone forms around the borehole under low grouting pressure. As the grouting pressure increases, this zone expands radially outward.
– At a grouting pressure of 1.5 MPa, the maximum principal stress distribution around the borehole does not improve significantly, with an average value of approximately 4.7 MPa, exceeding the tensile strength of the rock and creating plastic failure zones.
– Grouting pressures of 2.0 MPa and 2.5 MPa improve the stress distribution, reducing the average maximum principal stress around the borehole to approximately 3.3 MPa.

The values of the maximum principal stresses were basically the same for the two grouting pressures, and the difference lies in the more uniform stress field at 2.5 MPa compared with that at 2.0 MPa.

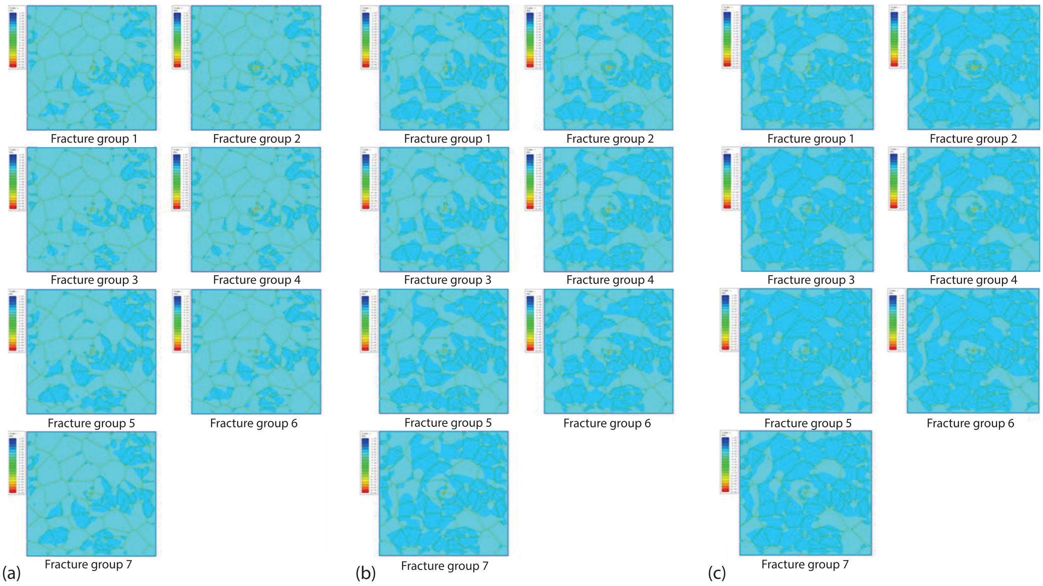

Figure 5. The distribution of maximum principal stress around borehole under different grouting pressures; (a) 1.5 MPa, (b) 2.0 MPa, and (c) 2.5 MPa

Conclusion

Based on the fracture observation results, this study characterized borehole fractures, established a spatial distribution model, and analyzed the grouting effects of burnt rock under different pressures. The key conclusions are Borehole fractures were characterized and they were most concentrated at a depth of approximately 39 m, with fractures having azimuths of around 10° and dips ranging between 15° and 30° forming dominant structural surfaces. Grouting pressures of 2.0 MPa and 2.5 MPa improved the stress distribution within the rock mass. A pressure of 2.0 MPa is more effective for uniformly distributed fractures, while a pressure of 2.5 MPa is required for non-uniformly distributed fractures.

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