Numerical modelling of rock cross-cut coal uncovering based on ANSYS

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Abstract

Outbursts of coal and gas could be induced by rock cross-cut coal uncovering. ANSYS is used to numerically simulate the stress, strain and energy of surrounding rock of roadway during the process of rock cross-cut coal uncovering. Modelling results show that there is a banding tension stress zone in roof and floor of roadway after excavation. Principal and shear stress concentration are formed in the upper and under area of the anterior heading face, which is symmetrically distributed between medial axis of roadway, while stress, strain and strain energy of overlying strata above the coal seam approximately keep invariant. The occurrence of the stress concentration in upper area of the anterior heading face could contribute to the instability and failure of coal and rock mass. The area with weak destruction-resisting ability is the most easily to be the releasing port of outburst and should be regarded as the key region in outburst prevention.

Keywords: Rock Cross-cut Coal Uncovering, Numerical Modelling, ANSYS, Stress Distribution

1 Introduction

Outburst of coal and gas is a complicated dynamic disaster in underground coal mining and can occur when certain conditions of ground stress, coal physical and mechanical property and gas pressure are met [1]. In China, outbursts of coal and gas mainly occur in the development of roadway and advance of mining face. The outburst intensity of rock cross-cut coal uncovering is the largest, having average intensity of 586.1 t. Over 80% of large-scale outbursts are induced by rock cross-cut coal uncovering [2].

In the past few decades, some attempts have been made to numerically model the outburst of coal and gas, such as a gas desorption and flow model by Paterson [3], an airway gas flow model by Otuonye and Sheng and a fracture mechanics model by Odintsev [4-5]. More recently, Xu et al. modelled outbursts with a simple finite element model, which coupled gas flow and the deformation and failure of solid [6]. The model also incorporated small scale variability in modulus and strength of coal to model heterogeneity. A model was proposed by Wold et al. to model the coal failure by using plasticity theory with softening mechanism and fragmentation is modelled with continuum damage mechanics [7]. Xue et al. developed a coupled simulator which could model the deformation and failure of a coal seam, adsorption and desorption of gas and flow of gas and water in coal to numerically simulate the initiation process of the outburst by linking and sequentially executing two numerical codes: FLAC^{3D} and COMET3 [8].

In terms of numerical modelling of rock cross-cut coal uncovering, rock failure process analysis code RFPA^{2D} was used to simulate the outburst in cross-cutting in steep coal seam containing gas [9]. Solid-gas coupling model RFPA^{2D}-Flow to numerically perform the instantaneous outburst induced by cross-cut driving and the whole process of micro-cracking, propagation, coalescence and ejection of coal and rock [10]. He used RFPA^{2D}-Flow to simulate the process of rock cross-cut coal uncovering of different gas pressure, coal strength and angle of coal seam [11]. The 6.20 outsized outburst mechanical process of Hongling coal mine was simulated by using finite element analysis software of ANSYS and Flac^{3D} [12].

Rock cross-cut coal uncovering is dangerous and has high-degree difficulty in technology [13]. The changes of physical and mechanical properties in coal and rock mass caused by rock cross-cut coal uncovering are the main factors inducing outbursts. To perform numerical modelling of the stress, strain and energy of roadway surrounding rock during the process of rock cross-cut coal uncovering could be instructive for mechanism study and outburst prevention.

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2 ANSYS modelling

ANSYS is a finite-element-method numerical software with the function of structure, fluid, electric field, magnetic field and electric field analysis. It is a commercial application code with powerful function and convenient operation and has the characteristics of data unification, powerful modelling, solving and nonlinear analysis function, automatic mesh generation, and friendly develop kit. Nowadays, it has been widely used in the field of aerospace, petrochemical industry, mechanical manufacturing, nuclear industry, railway, energy, defence and civil engineering.

To model the distribution of stress, strain and energy field during the process of rock cross-cut coal uncovering, in view of the influence of ground stress and original gas pressure, killing elements function module is used to simulate excavation. Structural statics module of ANSYS is used to perform the numerical modelling of rock cross-cut coal uncovering and the evolution laws of stress, strain and energy are revealed.

2.1 MODEL DEVELOPMENT

Simulation test of rock cross-cut coal uncovering based on 8# coal seam of Luling coal mine, Huaibei, China, mining area was conducted [14]. The model development and parameter determination of numerical modelling are based on the simulation test.

2.2 PHYSICAL MODEL AND UNIT DIVISION

Geometry size of physical model is shown in Figure 1. Three-dimensional model which is divided into 6 layers including coal seam and the columnar section of coal seam is shown in Figure 2, where the angle of coal seam is 18.44°. The 6 geological strata presented in Figure. 1 are generated based on physical model, as is shown in Figure 3.

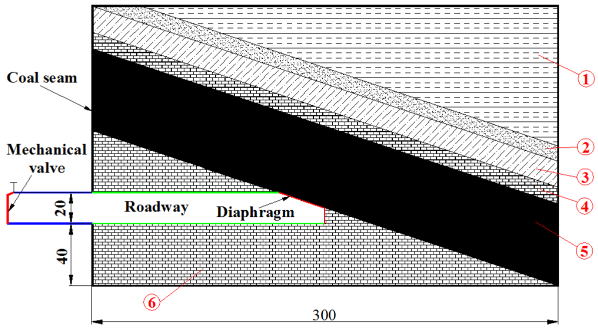


FIGURE 1 Geometry size (cm)

Numbering	Thickness / mm	Columnar section	Lithology
1	36		Siltstone
2	10		Mudstone
3	16		Limestone
4	10		Siltstone
5	50		Coal seam
6	78		Mudstone

FIGURE 2 Columnar section of coal seam

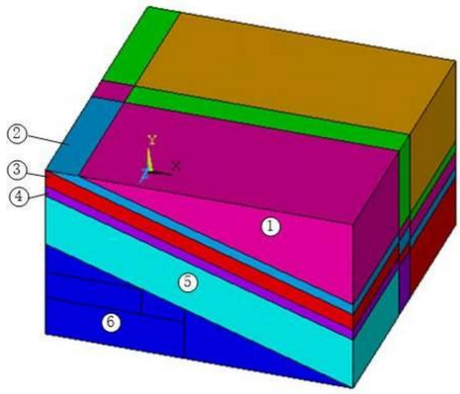


FIGURE 3 Geometric model

Strata of the model are numbered as 1～6# from top to bottom. Rock and coal are assumed to be elastic during the process of excavation Elastic modulus and Poisson ratio of coal and rock mass in these substrata are shown in Table 1. Finite element model obtained by mapping mesh generation is shown in Figure 4.

TABLE 1 Parameters of coal and rock mass

	Elastic modulus / Pa	**Poisson ratio**
Coal seam	9.5×10^{9}	0.350
Stratum 1	1.56×10^{10}	0.290
Stratum 2	1.04×10^{10}	0.238
Stratum 3	1.68×10^{10}	0.200
Stratum 4	9.8×10^{9}	0.225
Stratum 5	9×10^{9}	0.280

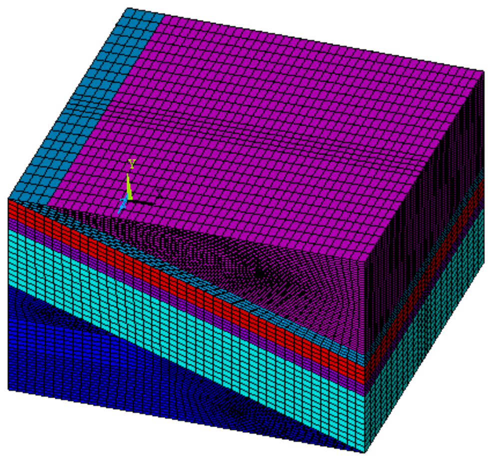


FIGURE 4 Finite element model

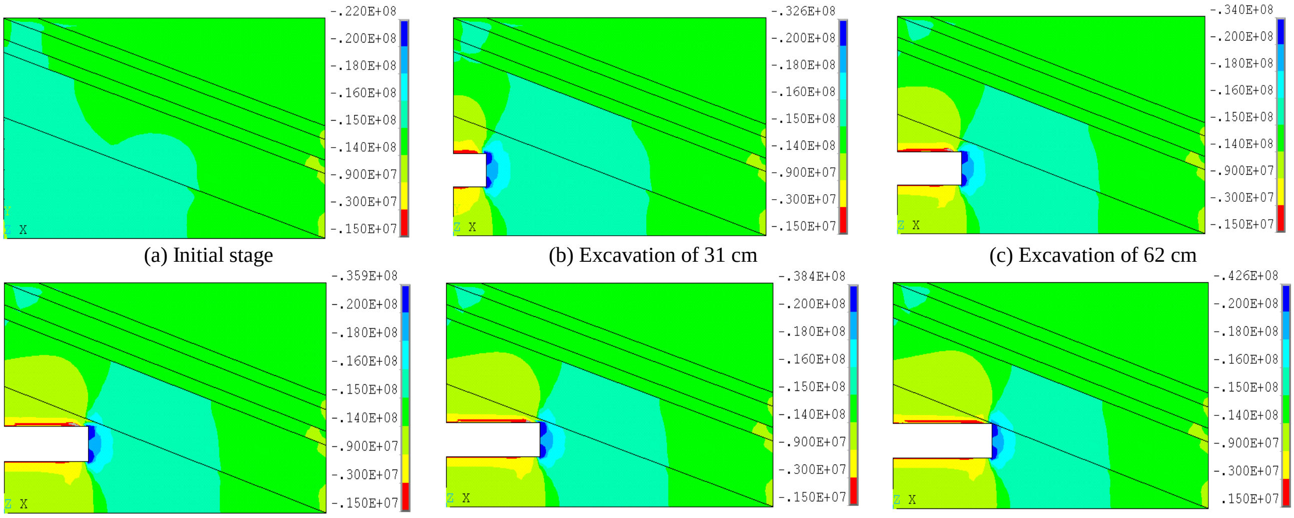
2.3 LOAD AND RESTRICTION

Vertical stress of 15 MPa is applied at the top boundary of the model to simulate the ground stress and gas pressure of 1 MPa is equivalent to nodal force of the coal seam which acts on upper and lower planes and components of the nodal force in the direction of X and Y are 2467220 Pa and 7399520 Pa, respectively. Planes of left and right sides, bottom, front and rear of the model are imposed restriction in the direction of X, Y and Z, respectively. Killing elements multiply stiffness of selected units by a quite small coefficient (generally 10-6), so the influence of stiffness could be neglected for further solving process and the simulation of excavation could be realized.

3 Simulation Results

3.1 STRESS DISTRIBUTION

The major principal stress and shear stress are main factors influencing destruction of coal-body and outbursts. The modelling of the distribution of major principal stress and shear stress is useful to arrest the law of stress field of surrounding rock during the process of rock cross-cut coal uncovering.



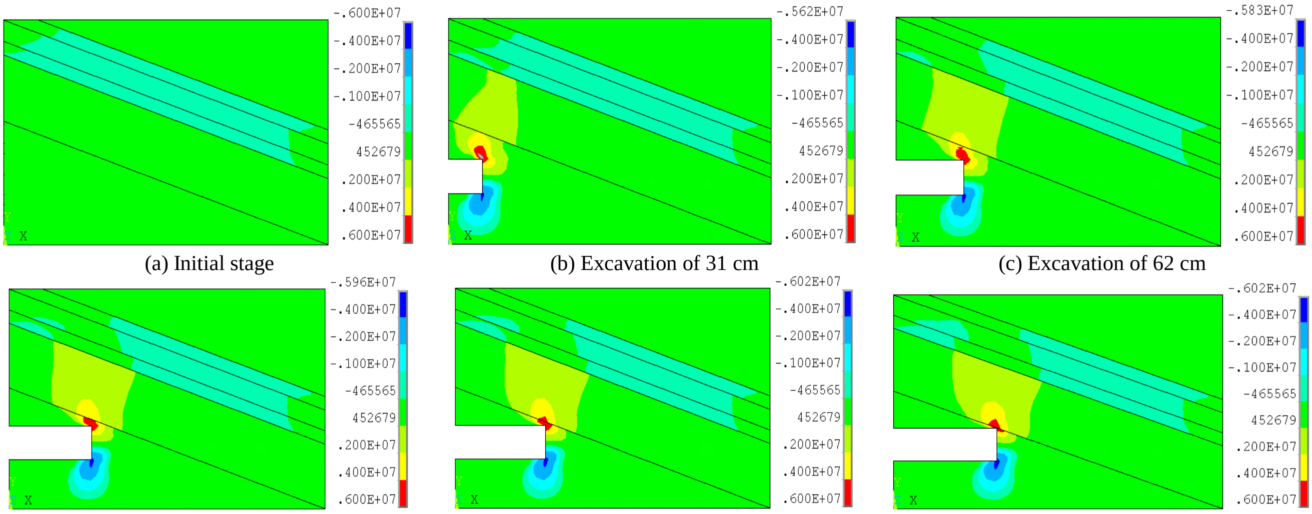
(a) Initial stage (b) Excavation of 31 cm (c) Excavation of 62 cm

(d) Excavation of 77.5 cm (e) Excavation of 85.25 cm (f) Excavation of 93 cm

FIGURE 5 Major principal stress distribution during excavation process

During excavation process, large deformation generates in the surrounding rock of roadway. The stress of surrounding rock is redistributed and the influential area is expanded constantly from surrounding area to the far field of country rock with the advance of headway. There is a banding tension stress zone in roof and floor strata of roadway after excavation. The major principal stress in roof and floor strata decreases and it is proportional to the distance from roadway. An umbrella-shaped stress-concentrated area is formed in the coal and rock mass before the heading face and moved forward with the advance of heading face and change little during excavation process. A major principal stress concentration region is formed in the upper and under area of the anterior heading face, which is symmetrically distributed between medial axis of roadway.

As shown in Figure 6, shear stress concentration regions in opposite direction are formed in the upper and under area of the anterior heading face and moved forward with the advance of heading face. The concentration of shear stress has significant influence on the upper area of the anterior heading face and extends from rock to coal seam. Therefore, that shear stress in coal seam increase and the influence area has an increasing tendency with the advance of heading face.



(a) Initial stage (b) Excavation of 31 cm (c) Excavation of 62 cm

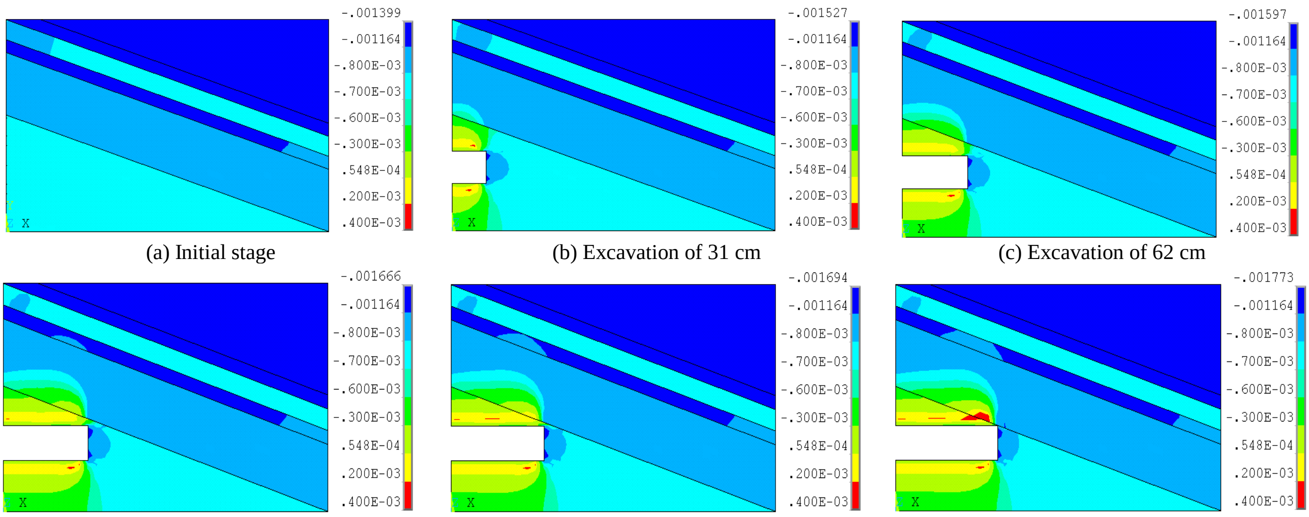
(d) Excavation of 77.5 cm (e) Excavation of 85.25 cm (f) Excavation of 93 cm

FIGURE 6 Shear stress distribution during excavation process

3.2 STRAIN DISTRIBUTION

The strain distribution of surrounding rock during the process of rock cross-cut coal uncovering is present in Figure 7.

The strain of roof and floor strata changes with the development of roadway. It increases at first and then decreases with the distance from roadway and the strain direction changes as well. Strain concentration area moves forward and the influential area in coal seam enlarges with the advance of heading face. There is a strain concentrated region in the upper and under area of the anterior heading face and it is symmetrically distributed between medial axis of roadway. However, overlying strata strain of coal seam almost keeps invariant.



(a) Initial stage (b) Excavation of 31 cm (c) Excavation of 62 cm

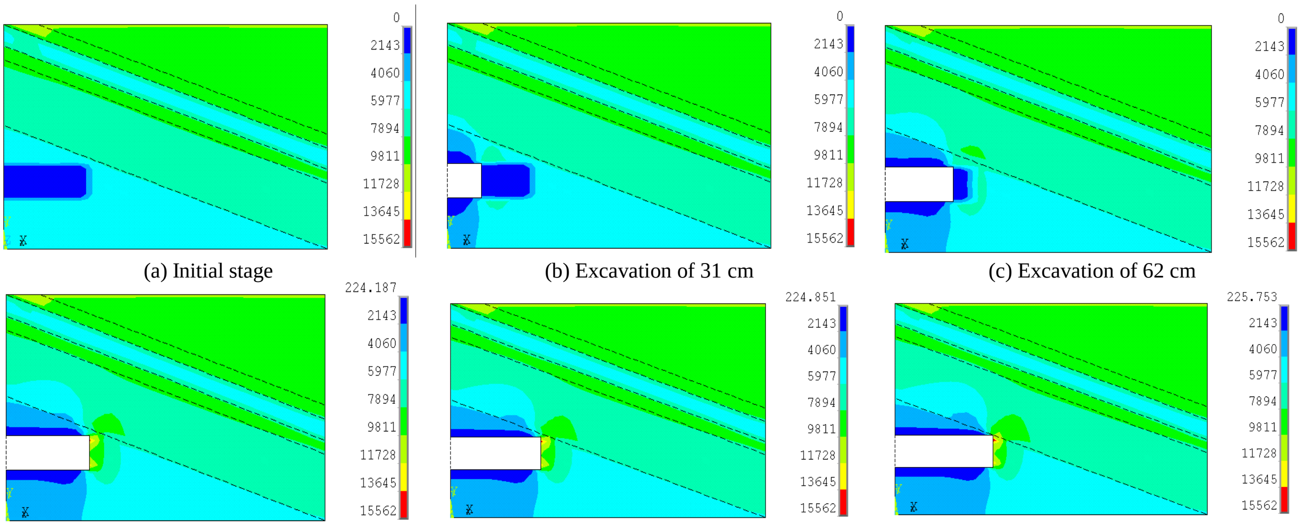
(d) Excavation of 77.5 cm (e) Excavation of 85.25 cm (f) Excavation of 93 cm

FIGURE 7 Strain distribution during excavation process

3.3 ENERGY DISTRIBUTION

The distributions of stain energy of initial state and excavation process are obtained by the function of Element Table and shown in Figure 8.

With the excavation of roadway, the strain energy of roof and floor strata changes and changed areas enlarge and move forward. Strain energy of rock strata is proportional to the distance from roadway and strain energy of coffin corner in anterior heading face shows an uneven distribution because of the boundary effect. There is a concentrated area of strain energy in the upper and under area of the anterior heading face and the strain energy in upper area of heading face is larger than that of other areas. While, strain energy of overlying strata of coal seam almost keeps steady.



(a) Initial stage (b) Excavation of 31 cm (c) Excavation of 62 cm

(d) Excavation of 77.5 cm (e) Excavation of 85.25 cm (f) Excavation of 93 cm

FIGURE 8 Strain energy distribution during excavation process

3.4 STRESS CHANGE IN COAL SEAM

The 5 paths parallel to the horizontal boundaries of coal seam are numbered as path 1～5 from the bottom up and downward tilt direction of coal seam is the positive direction, as is shown in Figure 9. The stress change of coal seam could be caused by the stress change of path point during excavation process. Path 1 is arranged along the nether boundary line of rock and coal and other paths are parallel to path 1 and vertical distance of each path is 10 cm.

As is shown in Figure 10, stress of the coal seam changes during the excavation process and stress change of coal seam area nearer to the roadway is more obvious. Stress of coal seam over the excavated area decreases and the minimum stress is in path 1 and followed by path 2 and stress decreasing zones move forward with the with the advance of heading face. There is a stress-increasing area of a certain distance from the starting point. When the excavation distance is 77.5 and 93 cm, the stress-increasing areas are at the distance of 80-120 and 100-140 cm respective.

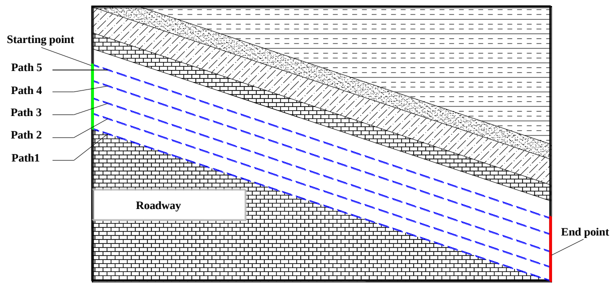
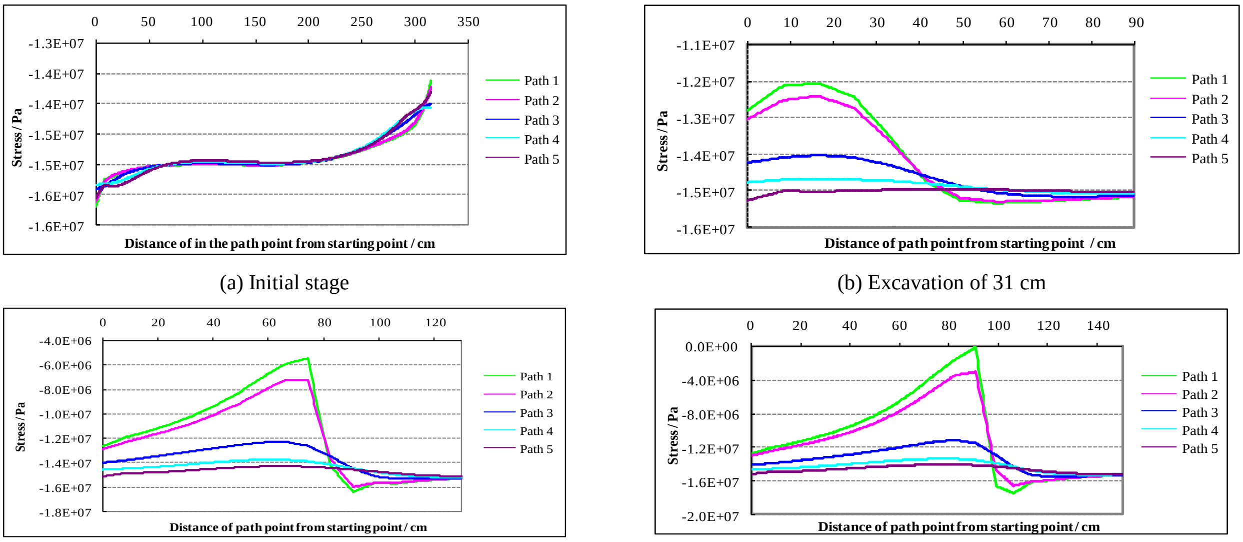


FIGURE 9 Arrangement of path in the coal seam



(a) Initial stage (b) Excavation of 31 cm

(c) Excavation of 77.5 cm (d) Excavation of 93 cm

FIGURE 10 Stress change of path in the coal seam

4 Discussion of results

During the excavation process, stress of surrounding rock is redistributed and stress concentration region is formed. When stress exceeds the strength limit of rock, surrounding rock of cross-cut would yield large deformation which extends from surrounding rock to deep rock mass. As the strength of rock is much higher than that of coal, when the heading face is far from the coal seam, stress of rock and coal and gas pressure accumulated in the coal could not crack the rock between heading face and coal seam, which bears the stress mainly. However, with the advance of the heading face, the strata thickness turns thin so that the stress affordability decreases and stress of rock and coal and gas pressure accumulated in the coal could crack the rock and this may induce the occurrence of outburst.

As rock has high stress affordability and its permeability is much lower than coal, so before uncovering the coal, motion quantity between coal and rock is small and gas accumulated in the coal releases little as well as stress of rock and coal, as a result, there will be large stress and gas pressure gradient. This can be the important factor of inducing outburst of coal and gas. At the moment of uncovering the coal, lateral stress of the uncovering area releases suddenly and the state of three dimensions of applied force turns to two dimensions. Unbalanced forced state causes rapid failure of coal and rock and this is an important factor inducting outburst.

The existence of the principal and shear stress concentration region formed in the upper and under area of the anterior heading face accumulates high strain energy and contributes to the instability and failure of coal and rock mass. The upper area with high stress is the nearest to coal seam and its destruction-resisting ability is weak. If there is, a large amount of gas accumulated in the coal, outburst is potential to occur under the disturbance of mining and the upper area is the most easily to be the releasing port of outburst.

5 Conclusions

The stress, strain and energy of roadway surrounding rock during the process of rock cross-cut coal uncovering could be numerically simulated by ANSYS and the simulation results could be regarded as the analysis basis of physical and mechanical property of surrounding rock during the process of rock cross-cut coal uncovering.

Stress field distribution of coal and rock mass is relatively uniform before excavation and a banding tension stress zone is formed in roof and floor strata after excavation. A principal and shear stress concentration area is formed in the upper and lower area of the anterior heading face and it is symmetrically distributed between medial axis of roadway and stress change of coal seam area nearer to the roadway is more obvious, while the changes of stress, strain and strain energy of overlying strata are unapparent.

Gas accumulated in the coal is difficult to release before uncovering the coal and lateral stress of the uncovering area releases suddenly after uncovering the coal. There would be large stress and gas pressure gradient at the moment of uncovering the coal. Hence, rock cross-cut coal uncovering could easily induce outburst of coal and gas.

The concentrations of the principal and shear stress formed in the upper area of the anterior heading face could contribute to the instability and failure of coal and rock mass and the upper area with high stress is the nearest to coal seam and its destruction-resisting ability is weak. The upper area is the most easily to be the releasing port of outburst and should be regarded as the key region of outburst prevention.

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