A study of the failure characteristics of partings in thick coal seams during fully mechanized caving in the Wobei coal mine

Fully mechanized caving is a common practice in mining thick coal seams in China. The characteristics of parting failures affect the stability and cavability of the top coal. In this paper, based on the geological conditions of and partings in a production site in the Wobei mine, the characteristics of parting failures on the front of a working face are calculated using elasticity theory and the cavability of the coal seam and the parting are obtained. Based on the theory of a cantilever beam under a uniformly distributed load, the cantilever length and the conditions under which a parting at the back of a working face fractures are calculated. These results are combined to obtain the characteristics of parting failures in thick coal seams during fully mechanized caving in the Wobei mine. In addition, this provides basic parameters for improving the top coal caving ratio of a working face.

Keywords: *Fully mechanized caving; parting; top coal; failure*

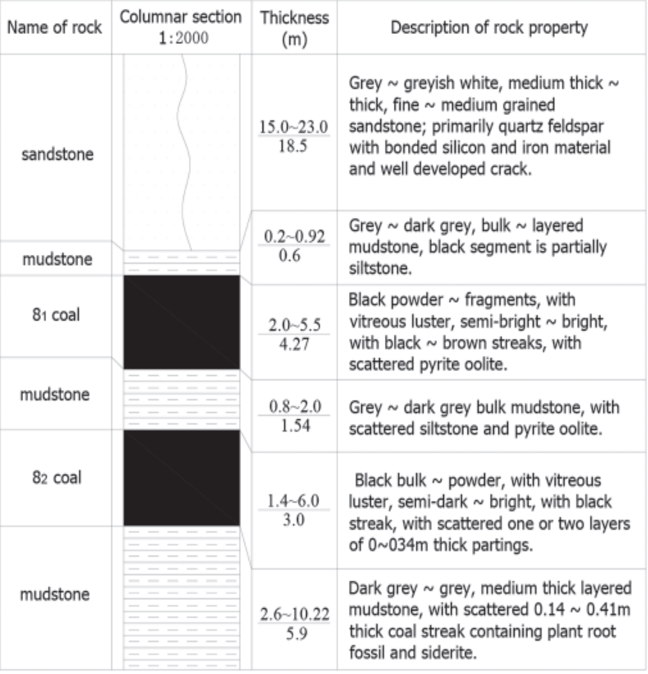
1. Introduction

The characteristics of parting failures in thick coal seams during fully mechanized caving affect the stability and cavability of the top coal [1-3]. During the fully mechanized caving of a thick coal seam with a parting, the lumpiness of fractured top coal varies considerably. During the coal caving process, it is not uncommon for only a small fraction of top coal to be excavated or for it to be very difficult for top coal caving to proceed. Large chunks of hard coal or gangue can block or form a balance darch on top of a coal caving opening, which makes top coal caving more challenging and reduces the top coal recovery [4-5]. Inadequate top coal fracturing means that during the fully mechanized caving of thick coal seams with partings, top coal has unique fracture characteristics [6].

2. Overview of the geological and production conditions of fully mechanized caving surface 8102 in the Wobei mine

Working face 8102 in the Wobei mine is the primary working face in the Huaibei Mining Group; its inclined length is 109.4m, and its strike length is 560m. No.8 coal is mined from its coal seam, which is separated by a layer of 0.8–2. 0m thick mudstone partings in 81coal (2.0–5.5m thick, 4.27m on average) and 82 coal (1.4–6.0m thick, 3.0m on average). The overall average thickness is 8.81m.

The hydraulic support in the middle of working face is model ZF6800-19/38. The support at the face end support is model ZFG7360/21.5/34H. The coal mining equipment is model MG300/700-WD. The mining height range of the support is 1.9–3.8m.The coal cutting height of the mining machine is in the range from 1.7 to 3.2m. Because of the bearing performance of the support, the coal cutting height of the mining machine and the stability of the support, this layer is mined together with the floor of the 82 coal. The working face's average coal cutting height is 2.7m, its coal caving height is 6.11m and the working face's mining-to-caving ratio is 1:2.26. An overall view of a columnar section of the coal seam's top and floor is shown in Fig.1.



Name of rock	Columnar section 1:2000	Thickness (m)	Description of rock property
sandstone		15.0~23.0 18.5	Grey ~ greyish white, medium thick ~ thick, fine ~ medium grained sandstone; primarily quartz feldspar with bonded silicon and iron material and well developed crack.
mudstone		0.2~0.92 0.6	Grey ~ dark grey, bulk ~ layered mudstone, black segment is partially siltstone.
81 coal		2.0~5.5 4.27	Black powder ~ fragments, with vitreous luster, semi-bright ~ bright, with black ~ brown streaks, with scattered pyrite oolite.
mudstone		0.8~2.0 1.54	Grey ~ dark grey bulk mudstone, with scattered siltstone and pyrite oolite.
82 coal		1.4~6.0 3.0	Black bulk ~ powder, with vitreous luster, semi-dark ~ bright, with black streak, with scattered one or two layers of 0~034m thick partings.
mudstone		2.6~10.22 5.9	Dark grey ~ grey, medium thick layered mudstone, with scattered 0.14 ~ 0.41m thick coal streak containing plant root fossil and siderite.

Fig.1 Lithology synthesis histogram of 8 coal roof and floor

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3. Mechanical analysis of the stability of a parting at the front of the working face

Outside the peak abutment pressure area at the front wall of a coal seam with a parting, a parting in the top coal is in an essentially elastic state. Even if the parting is in the peak abutment pressure area or the roof control area, due to the parting's great strength and hardness, as the load of top coal above the support gradually increases, the top coal becomes plastic under the abutment pressure. This acts as a buffer cushion for the parting and ensures that the parting in the top coal is relatively complete and in an elastic state. A small parcel of material in the parting can be viewed as an elastic medium. According to physical equation for the spatial state of stress,

$$\varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \mu\left(\sigma_1 + \sigma_2\right)\right],$$

and if $\sigma_2 = \sigma_3$, then,

$$\varepsilon_3 = \frac{1}{E}\left[\left(1-\mu\right)\sigma_3 - \mu\sigma_1\right]$$

and

$$\varepsilon_3 = -\mu\frac{\sigma_c}{E}.$$

The following equation is obtained by substituting equation(3) into equation (2):

$$-\mu\frac{\sigma_c}{E} = \frac{1}{E}\left[\left(1-\mu\right)\sigma_3 - \mu\sigma_1\right]$$

After consolidation, when the parting medium reaches its ultimate failure state, the formula for the elastic cracking stress is as follows:

$$\sigma_1 = \sigma_c + \frac{1-\mu}{\mu}\sigma_3,$$

where σ_1, σ_3 are the parting's vertical stress and lateral stress, respectively, in MPa, σ_c is the parting's unidirectional compressive strength in MPa and μ is the parting's Poisson's ratio.

Equation (5) shows that a parting's elastic cracking stress increases with the unidirectional compressive strength, σ_c, and the lateral stress, σ_3.This equation can be converted to

$$\sigma_1 = \sigma_c + (\frac{1}{\mu} - 1)\sigma_3.$$

Similarly, the elastic cracking stress of the top coal in the front of a coal wall in an elastic state is

$$\sigma_1' = \sigma_c' + (\frac{1}{\mu'} - 1)\sigma_3',$$

where σ_1', σ_3' are the top coal's vertical stress and lateral stress, respectively, in MPa, σ_c' is the top coal's unidirectional compressive strength in MPa and μ' is the top coal's Poisson's ratio.

When there is a parting, these values are set as follows on the basis of actual field data:

$\sigma_c = 18MPa$, the Poisson's ratio is $\mu = 0.3$, the stress concentration coefficient is $K = 3$, the bulk density of the overlying strata is $\gamma = 2500KN/m^3$ and the burial depth is $H = 550m$.

The calculation shows that $K\gamma H = 41.25MPa$ and $\sigma_1 = 36MPa$.

When there is a parting, the calculation shows that under mining stress, the parting's peak abutment pressure exceeds its elastic cracking stress. The parting's fracture extends and penetrates, the overall strength deteriorates and early fracture occurs in the form of an irregular block.

When there is soft coal above the parting, these values are as follows:

$\sigma_c' = 5MPa$, the Poisson's ratio is $\mu' = 0.4$, the stress concentration coefficient is $K = 3$, the bulk density of the overlying strata is $\gamma = 2500KN/m^3$ and the burial depth is $H = 550m$.

The calculations shows that $K\gamma H = 41.25MPa$ and $\sigma_1' = 36MPa$.

The calculation for soft coal shows that $K \cdot \gamma \cdot H > \sigma_1'$, i.e., when the peak abutment pressure exceeds the elastic cracking stress, the parting's fracture extends and penetrates, the overall strength decreases and early fracture occurs in the form of an irregular block.

The analysis shows that the parting's elastic cracking stress normally exceeds the elastic cracking stress of the top coal, i.e., $\sigma_1 - \sigma_1' > 0$.

Comparing the peak abutment pressure with the elastic cracking stresses of the parting and soft coal can reveal whether the parting fractures. However, it is rather difficult to describe the size of the crack. Because partings and soft coal have fixed uniaxial compressive strengths, the concept of a cracking coefficient is introduced; this coefficient is the ratio of the peak fore poling pressure to the uniaxial compressive strength,

$$i = \frac{K\gamma H}{\sigma_c} \text{ and } i' = \frac{K\gamma H}{\sigma_c'},$$

where i is the cracking coefficient of the parting and i' is the cracking coefficient of soft coal.

When peak abutment pressure, $K\gamma H$, is 41.25MPa, a parting containing hard coal is chosen for study. The values of the uniaxial compressive strength, σ_c and the cracking coefficients of hard coal, i, and soft coal, i', are shown in Fig.2 and Fig.3.

Fig.2 and Fig.3 show that the cracking coefficients of partings in hard coal, i, and soft coal, i', are strongly correlated with the compressive strength; their relationship is exponential. A parting normally has $\sigma_c = 30MPa$. When $\sigma_c = 30MPa$,, the parting's cracking coefficient, i, has a maximum value of 2.29, which means that as the uniaxial compressive strength of hard coal increases, i decreases. The closer it is to the maximum value, i.e., the larger i is, the greater the effect of a fracture in the parting. Soft coal normally has $\sigma_c > 10MPa$. When $\sigma_c = 10MPa$, the cracking coefficient of soft coal, i', has a minimum value of 4.13, which means that as the uniaxial compressive strength of soft coal decreases, i' increases. The further it is from the minimum value, the greater the effect of fracturing the soft coal.

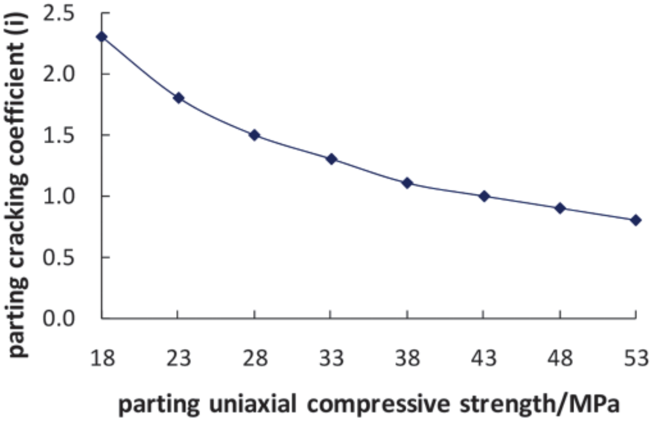

Fig.2 Curves of rupture coefficient i change with compressive strength

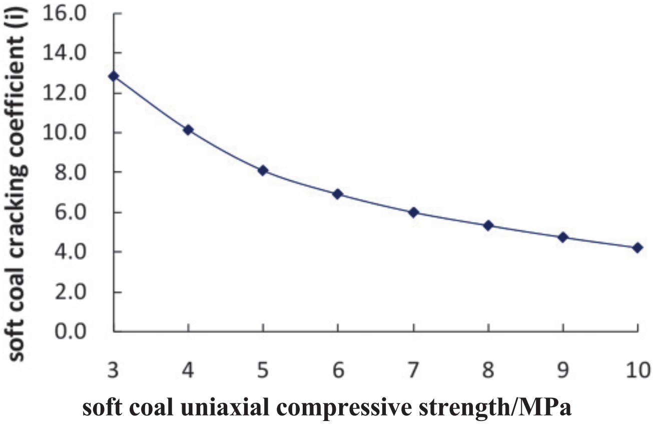

Fig.3 Function curves of soft coal rupture coefficient i' change with compressive strength

The stress concentration coefficient, K, of the caving working face of the top coal is normally set to between 2 and 3. This shows that at identical burial depths, when the stress concentration coefficient is set to another value, the cracking coefficients of the parting, i, and of soft coal, i', are also linearly related to the corresponding compressive strengths, which demonstrates that there is an exponential relationship. A larger value of fracturing coefficient i means that the effect of a fracture in the parting and the cavability of the top coal are better; a larger value of fracturing coefficient i' that the effect of a fracture in the parting and the cavability of the soft top coal are also better.

When the peak fore poling pressure, $K\gamma H$, and the soft coal cracking coefficient, i', are fixed, a smaller value of i'–i means that there is a smaller difference between the lumpiness of the fracture in the parting and the soft coal, which provides a better fracturing effect. Fractures develop and penetrate both; subsequently, the deformation at the top of the roof control area grows. This mechanical change process results in fractures in the parting and the top coal being similarly lumpy. When the parting cracking coefficient, i, is fixed, a larger value of i'–i means that fractures in the parting and the soft coal are similarly lumpy, which indicates abetter fracturing effect. Otherwise, the lumpiness of fractures varies significantly, and the top coal's cavability decreases. A parting with a very lumpy fracture is more likely to form an arch at the coal caving opening during the drawing process and to block the normal flow of top coal. In addition, due to the wide range of lumpiness, the speed of the flow is unbalanced, which is unfavorable to the drawing process and reduces top the coal recovery.

Based on the geological and parting conditions of the production site in the Wobei mine, partings have great strength and are hard to crack and cantilever beam structures are likely to form at the backs of working faces.

4. A cantilever beam model for fractured and unstable partings under uniformly distributed loads

When a parting is surrounded by a weaker coal seam at the front of a coal wall, it is in a triaxial stress state. When the working face moves forward and the parting is at the top of the roof control area, the lower top coal develops a fracture and sinks, and the upper top coal separates from the roof when the parting deforms [7-9]. At this point, the parting can be modeled as a cantilever beam. Because the former roof has not yet fractured, i.e., it has not developed a rotary deformation and has not generated significant pressure on the soft top coal, the mass of the upper top coal is modelled as a uniformly distributed load. Thus, the mechanical model shown in Fig.4 is defined. The width of the beam (the parting) is set to b=1mand analyzed using the mechanics of materials [7].

According to the mechanics of materials, fixing one end of a cantilever beam restricts the translation and rotation of that end section. Therefore, a vertical reaction force, F_{RA}, and a reaction torque, M_A, are present at the fixed end. To analyze the stress state of the cantilever beam, the coordinate system

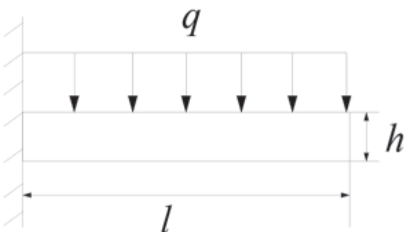

Fig.4 Stress state of a stratum of gangue under uniform load

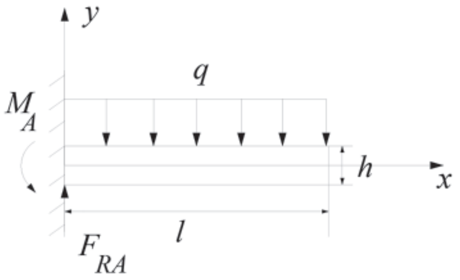

Fig.5 Sketch map of mechanics computation model

shown in Fig.5 is defined.

The balance equations $\sum F_y = 0$ and $\sum M_A = 0$ lead to $M_A = \frac{1}{2} q l^2$ and $F_{RA} = q \times l$.

Diagrams of the parting's bending moment and the shear force on it are obtained from the above formulae and shown in Fig.6 and Fig.7.

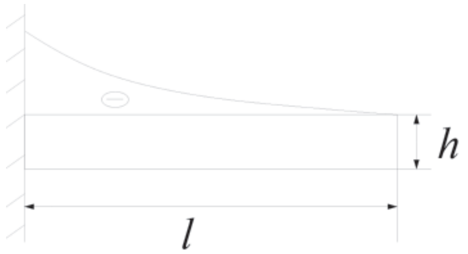

Fig.6 Moment of a stratum of gangue subjected to uniform load

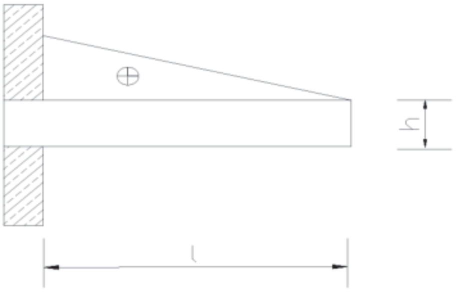

Fig.7 Shear of a stratum of gangue under uniform load

According to the mechanics of materials, the relationship between the tensile stress and bending moment of a cantilever beam is

$$\sigma = \frac{6M_A}{h^2} = \frac{3ql^2}{h^2}.$$

The diagrams of the bending moment and the shear stress show the following:

(1) The maximum negative bending moment occurs at the border between the parting and the coal wall. The border is subjected to the maximum tensile stress and is a dangerous surface. The maximum tensile stress is

$$\sigma_{\max} = \frac{6M_A}{h^2} = \frac{3ql^2}{h^2}.$$

Because $q = q_{top\ coal} + q_{parting}$, the above equation becomes

$$\sigma_{\max} = \frac{6M_{\max}}{h^2} = \frac{3\left(\gamma_{\text{parting}} h + \gamma_{\text{top coal}} h_{\text{top coal}}\right) l^2}{h^2}.$$

(2) The maximum shear stress occurs at the border between the parting's central axis and the coal wall. It is

$$\tau_{\max} = \frac{3}{2} \cdot \frac{Q}{A}.$$

That is,

$$\tau_{\max} = \frac{3ql}{2h} = \frac{3l\left(\gamma_{\text{parting}} \mathrm{h} + \gamma_{\text{top coal}} h_{\text{top coal}}\right)}{2\mathrm{h}}.$$

Because rock has lower tensile and shear strengths, according to equations 13 and 15, when the cantilever beam is relatively short, its shear stress should be analyzed to determine whether it fractures. The following analysis primarily focuses on the situation in which the beam fails when the tensile stress exceeds the rock's tensile strength.

According to equation 13, the tensile stress increases with the cantilever drawing pace land as the thickness of the parting, h, decreases. This shows that, when the parting is thinner and has a larger cantilever drawing pace, it is more likely to become damaged. Therefore, to damage the parting, the thickness should be minimized and the cantilever drawing pace should be maximized. The minimum parting thickness and the maximum cantilever drawing pace are analyzed below:

When $\sigma_{max} = R_t$, according to equation 13,

$$R_t h^2 - 3\gamma_{\text{parting}} l^2 h_{\text{parting}} - 3\gamma_{\text{top coal}} h_{\text{top coal}} l^2 = 0.$$

Solving this equation and consolidating the units provides the parting's minimum thickness,

$$h = \frac{3l^2\gamma_{\text{parting}} + \sqrt{9l^4\gamma^2_{\text{parting}} + 120 l^2 \gamma_{\text{top coal}} h_{\text{top coal}} R_t}}{2R_t},$$

where $\gamma_{parting}$ is the density of the parting in kg/m^3, $\gamma_{top\ coal}$ is the density of the top coal density in kg/m^3, $h_{top\ coal}$ is the thickness of the top coal in the parting in m and R_t is the tensile strength of the parting in MPa.

Equation 16 shows that when the parting has a fixed cantilever drawing pace, *l*, its thickness is less than the minimum thickness, *h*, and its support is subjected to cyclic loading, the structure quickly fractures into pieces with the desired caving lumpiness and falls, which facilitates top coal caving. The lumpiness of the fracture does not affect top coal caving, and the cavability is good. When the parting's thickness is greater than the minimum thickness, the fracture is lumpy, and a cantilever may be formed. Interconnections create an isolation zone for the top coal that stops the top coal from falling in time and results in poor top coal cavability.

When the parting's thickness, *h*, is fixed, the positive stress at the maximum cantilever drawing pace reaches the ultimate tensile strength, and the parting fractures and becomes damaged. According to equation 16, the parting's maximum cantilever drawing pace is

$$l = \sqrt{m} = \sqrt{\frac{9{h_{\text{parting}}}^2 R_t}{120\gamma_{\text{coal}} h_{\text{coal}} + 18 h_{\text{parting}} \gamma_{\text{parting}}}} .$$

According to the diagram of the geological columnar section of working face 8102 in the Wobei mine, the thickness of the parting is between 0.8 and 2.0m, and the thickness of the top coal is between 2.0 and 5.5 m. According to the Huaibei mining group's Wobei coal mine's 8 coal's top floor physical and mechanical property test report, the relevant parameters for the coal and the parting are as follows: the parting's tensile strength is between 0.1 and 1.50 MPa with an average of 0.8 MPa, the bulk density is $\gamma_{\text{parting}} = 25000 N / m^3$ and the bulk density of the top coal is $\gamma_{\text{top coal}} = 13000 N / m^3$. These parameters are substituted into the equations to calculate the maximum cantilever drawing paces of partings with different ultimate thicknesses. The relationship between the top coal thickness and the parting's maximum cantilever drawing pace is obtained and shown in Fig.8.

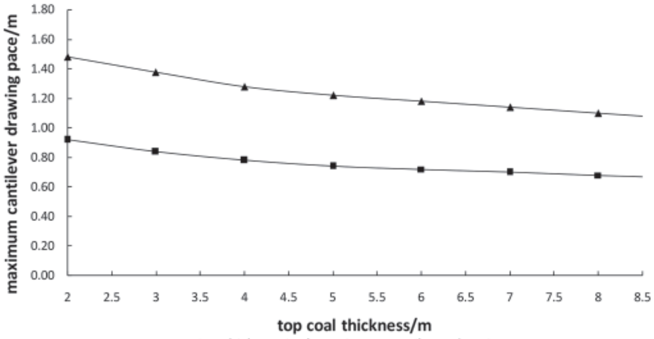

Fig.8 Relationship of maximum cantilevered pace of a stratum of gangue and top coal thickness under uniform load

Fig.8 Shows the following:

1. When the thickness of the parting is fixed, the thickness of the top coal increases, the maximum cantilever drawing pace decreases, and when the thickness of the top coal thicknesses, as the thickness of the parting increases, the maximum cantilever drawing pace increases.
2. The thicknesses of the parting and the top coal are two major factors that influence the parting's maximum cantilever drawing pace. Of the two, the thickness of the parting has more significant impact. When the thickness of the top coal is fixed, the cantilever drawing pace is of a parting that is 2 m thick is double that of a parting that is 0.8m thick. When the thickness of the parting is fixed, parting cantilever drawing pace decreases less significantly as the thickness of the coal top increases.
3. The maximum cantilever drawing pace of the parting in working face 8102 parting is between 0.5 and 1.6m.

Conclusions

In the Wobei mine, the maximum cantilever drawing pace of the parting in working face 8102 is between 0.5 and 1.6 m. In addition, a well-developed fracture in the parting and the damage due to cyclic loading of the support and to the pressure on the parting's abutment accelerate fracture of the parting. Therefore, the parting in working face 8102 has an insignificant impact on the cavability of the top coal, which reflects the field situation.

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