Study on the coal gas pressure dynamic distribution law ahead of tunnelling

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Synopsis

During mining, the stress in the coal face varies, and, at the same time, the gas flows from the coal body into the excavation, which will cause the gas pressure to change continuously. Assuming the coal gas content of the coal to be constant, and applying the law of energy conservation, the influence of stress concentration on the gas pressure was analysed. It was found that the stress is proportional to the gas pressure. Finally, as a result of analysis and the law of gas flow, the gas pressure dynamic distribution ahead of tunnelling was modelled, and the mechanism by which blasting induces outburst was explained by making use of the model.

Keywords: gas pressure, stress concentration, excavation, tunnel.

Introduction

In the unmined coal seam, the gas pressure is equal in every direction[1,2]. During the course of mining, a pressure gradient is established in the direction of the face advance. This pressure gradient is the source of outbursts. It plays a leading role in the initiation and development of the outburst[3,7]. Therefore, it is very important to understand the distribution of gas pressure ahead of tunnelling, and a lot of scholars have researched it from different viewpoints[8,9]. But two problems are not considered in their studies: one is that stress causes plastic deformation of the coal, with a consequent drop in the permeability and resultant change in the gas pressure distribution. Another is that the very fact that gas will flow into the excavation will reduce the gas pressure in the coal, and one needs to know how the pressure will change with time. Therefore, author studied the gas pressure ahead of tunnelling from these two aspects.

Influence of stress concentration to gas pressure

The quantity of gas that can be contained in one tonne of coal in the original stress state can be computed by[1]:

$$X_1 = \left(\frac{V_1 p_1 T_0}{T_1 p_0 \xi_1} - \frac{abp_1}{1+bp_1} e^{n_1(t_0-t_1)}\right) \frac{100-A-W}{100\times(1+0.31W)} \quad [1]$$

In formula 1:
V_1—void volume in one tonne coal, m³/t
p_1—gas pressure, MPa
T_0—absolute temperature at standard conditions (273K)
p_0—atmospheric pressure at standard conditions (0.101325MPa)
T_1—absolute temperature of gas, K
ξ_1—gas condensation coefficient
e—natural logarithm, e =2.718
t_0—temperature of lab, °C
t_1—temperature of coal, °C
n_1—coefficient, $n_1 = \frac{0.02}{0.993+0.07\,p_1}$
a, b—adsorption constants for coal, m³/t, MPa^{-1}
A, W—ash and moist in coal, %
X_1—coal gas content in original stress state, m³/t.

The quantity of gas that can be contained in one tonne of coal in the stressed state is given by:

$$X_2 = \left(\frac{V_2 p_2 T_0}{T_2 p_0 \xi_2} - \frac{abp_2}{1+bp_2} e^{n_2(t_0-t_2)}\right) \frac{100-A-W}{100\times(1+0.31W)} \quad [2]$$

Subscript '2' denotes that parameters are those for the stressed state.

Because $0.993>>0.07p_1$, $n_1 \approx n_2$, the gas content is constant before and after being stressed. If the temperature of the coal is also reasonably constant, then:

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$$\frac{V_1 p_1 T_0}{T_1 p_0 \xi_1} - \frac{abp_1}{1+bp_1} e^{n_1(t_0-t_1)} \frac{100-A-W}{100\times(1+0.31W)} \approx \frac{V_2 p_2 T_0}{T_2 p_0 \xi_2} - \frac{abp_2}{1+bp_2} e^{n_1(t_0-t_1)} \frac{100-A-W}{100\times(1+0.31W)} \quad [3]$$

The stress analysis of coal ahead of tunnelling is shown in Figure 1. x is the thickness of coal, y is the height of the tunnel, z is the width of the tunnel, and σ_x, σ_y, σ_z are the stresses in three directions (x, y, z) normal to each other. Three linear strains will result, ε_x, ε_y and ε_z, which are calculated as follows[10]:

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \sigma_z)] \quad [4]$$

$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_z + \sigma_x)] \quad [5]$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)] \quad [6]$$

In these formulae:
μ—Poisson modulus
E—Elastic modulus, GPa.
The strain in the z axis is 0, and then:

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \mu\sigma_x + \mu\sigma_y)] \quad [7]$$

$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_x + \mu\sigma_x + \mu\sigma_y)] \quad [8]$$

If temperature variations and angular strain of coal are neglected, applying the conservation of energy, Formula [9] may be obtained.

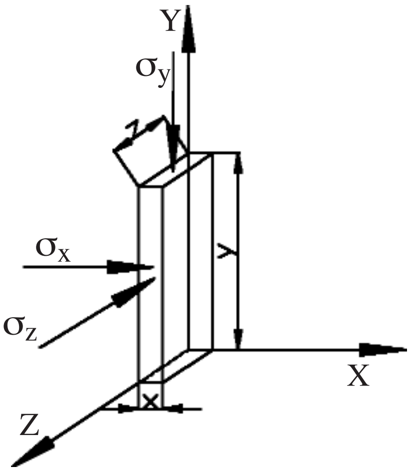

Figure 1—Sketch map of coal stress

$$(y - \frac{(V_1-V_2)xyz\rho}{xz})xz\varepsilon_y\sigma_y + \frac{(V_1-V_2)xyz\rho}{xz}xz\sigma_y + \frac{1000xyz\rho(V_1\frac{p_1T_0}{p_0T_1} - V_2\frac{p_2T_0}{p_0T_2})}{22.4}L_v = -\sigma_x\varepsilon_x xyz + \frac{1000p_2T_0}{22.4p_0T_2}xyz\rho V_2\overline{C}(T_2-T_1) + \Delta W \quad [9]$$

In formula 9:
p—coal density, t/m³
ΔW—change in the elastic strain energy, J
L_V—latent heat of gas, J/mol
$\overline{C}$—heat capacity, J/mol.
From Formula [3] and formula [9], Formula [10] may be obtained.

$$[\frac{V_1p_1T_0}{T_1p_0\xi_1} - \frac{abp_1}{1+bp_1}e^{n_1(t_0-t_1)}\frac{100-A-W}{100\times(1+0.31W)} - \frac{abp_2}{1+bp_2}e^{n_2(t_0-t_2)}\frac{100-A-W}{100\times(1+0.31W)}]\times \frac{1000xyz\rho(L_v - \overline{C}T_1)\xi_2}{22.4} + xyz\varepsilon_y\sigma_y - \frac{1000xyz\rho V_1p_1T_0}{22.4p_0T_1}L_v - xyz\sigma_x\varepsilon_x + \frac{1000xyz\rho p_2T_0}{22.4p_0}V_2\overline{C} + \Delta W + (V_1-V_2)(1-\varepsilon_y)xyz\rho\sigma_y \quad [10]$$

An analytic solution for the gas pressure may be obtained from Formulae [7], [8] and [10], but it is very complex, and the relation between gas pressure and stress is not obvious. Therefore, firstly, we assume typical parameters for the coal, then find the gas pressure by numerical computation. Finally, from the variation of gas pressure as the conditions are varied, we obtain an indication of the relation between gas pressure and stress.

The main parameters are shown in Table I.

Then the gas pressure p_2 may be calculated for the assumed values of the parameters for any choice of σ_y and V_2. In the example below, the gas pressure is calculated for six values of the stress, as shown as Table II.

As Table II shows, the gas pressure increases with increasing stress. During mining, the coal stress is bigger than original stress, so the gas pressure in the coal is higher than before mining.

Table II

Relation of gas pressure and stress in coal

σ_y (MPa)	15	16	17	18	19	20
V_2 (m³/t)	V_1	$0.9V_1$	$0.8V_1$	$0.7V_1$	$0.6V_1$	$0.5V_1$
p_2 (MPa)	1.209	1.465	1.741	2.044	2.388	2.797

Table I

Main parameters of coal

Parameters	p_1 (MPa)	T_1 (K)	C (J/mol)	L_v (J/mol)	A (m³/t)	b (MPa⁻¹)	E (GPa)	z (m)	Y (m)	x (m)	V_1 (m³)
Value	1.2	300	60	8000	25	1	10	3	3	0.01	$0.1xyz$

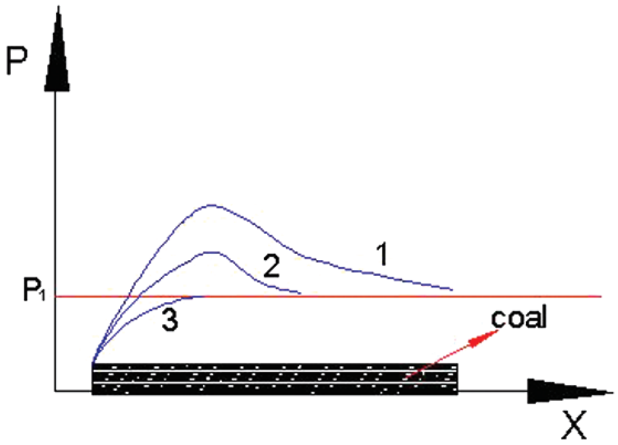

Figure 2— Sketch map of coal gas pressure after being affected by mining

Coal gas pressure dynamic distribution law in the front of a heading

If there were no mining, coal stress and gas pressure would both be constant. After mining, the stress on the coal first increases, and then returns to its original value[11]. According to above analysis, gas pressure will also first increases, and then decreases to original gas pressure, as illustrated in Figure 2.

In Figure 2, there are three gas pressure curves. Curve 1 shows the instantaneous gas pressure curve during the concentration of stress caused by mining. Because gas flows from the coal seam into the airway, the gas content of the coal reduces, and the gas pressure (especially in area of stress concentration) will also reduce. Eventually, the gas pressure curve will be shown as curve 3. Curve 2 is an illustrative intermediate gas pressure curve.

Discussion

The outburst of gas is the result of mining[12]. Generally, an outburst occurs after a disturbance such as, especially, blasting. For example, 52% of outbursts occur soon after blasting[13]. Ahead of tunnelling, the gas pressure distribution is very close to curve 3 in Figure 2. After blasting, coal in the destressed zone is removed, and the tunnel is extended. The point of maximum stress moves close to the face, and the gas pressure distribution approaches that of curve 1 in Figure 2. The gas pressure and pressure gradient in curve 1 are both higher than in curve 3, and therefore the risk of outbursts is higher after blasting.

Conclusions

- We have developed an expression linking the gas pressure to the stress on the coal during mining for a range of coal and mining parameters, assuming the coal gas content constant and the law of energy conservation.
- Several sets of gas pressure, stress and hole cubage were computed numerically, and the result indicates that gas pressure is proportional to stress.
- During mining, coal stress and gas pressure both increase, and then decrease to the original levels, but because gas flows from the coal seam into the airway continuously, gas pressure (especially in area of stress concentration) will decrease. The pressure distribution will finally be very close to curve 3 in Figure 2.
- The gas pressure and pressure gradients after blasting are both bigger than before blasting, and the risk of outbursts increases. Blasting is a very important factor that induces outbursts.

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