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Original scientific paper

An Experimental Study on the Interaction Law of the Pore Gas Pressure and Stress in Gassy Coals

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Abstract: Understanding the principle underlying the coupling between coal seam stress and gas pressure will help prevent the occurrence of dynamic coal and gas disasters. However, previous studies have mainly focused on the macroscopic qualitative analyses of the coupling between coal seam stress and gas pressure. In fact, laboratory quantitative tests, which investigate gas pressure in sealed sample tanks, fail to represent the essential relationship between stress and gas pressure in real time. In this study, a model of the stress–porosity–gas pressure relationship was established based on the pore characteristics of gassy coals and gas adsorption theory to quantify the coupling between coal seam stress and gas pressure. In addition, a method for determining the law governing stress and gas pressure coupling was proposed based on stress–strain curves obtained through triaxial loading tests. Results show that the porosity and gas pressure of gassy coals first decrease and then increase as loading stress increases. Under various confining pressures and initial gas pressures, porosity declines at a lower rate with the increase in the initial gas pressure. Specifically, gas pressure increases with stress before the value of stress reaches that of the compressive strength of the coal. This behaviour demonstrates that gas pressure and stress are positively correlated. High initial gas pressures are associated with small increments (i.e., from 136% to 30%) in pore gas pressure under stress. When stress exceeds the compressive strength of the coal, gas pressure begins to decrease with stress. Thus, stress and gas pressure are negatively correlated. Finally, the validity of the research method was verified through afield experiment. The proposed method provides new concepts for the study of the mechanism, prevention, and control technology of dynamic coal and gas disasters.

Keywords: coupling effect; experimental study; gassy coals; pore gas pressure; stress

1 INTRODUCTION

The frequency and intensity of coal and gas disasters have drastically increased with the occurrence of deep coal mining [1] because coal seam stress and gas pressure increase with the increment in mining depth. The extremely complex coupling between these two factors, in turn, promotes dynamic coal and gas disasters [2]. Therefore, the effect of the coupling between coal seam stress and gas pressure should be analysed to reveal the nature of dynamic coal and gas disasters, improve disaster prevention, and control technology.

Currently, domestic and international studies on the interaction between coal seam stress and gas pressure have mainly involved macro statistical analyses, laboratory experiments, and numerical simulation. The macro statistical analysis method measures the stress and gas pressure in original coal seams and seams in working faces. It then statistically analyses the trend of the qualitative change relationship between stress and gas pressure based on measurement results. Under the same geological conditions, stress and gas pressure are positively correlated with mining depth in original seam faces [3] and are typically coupled in working faces. Given that, gas pressure first increases and then decreases under increasing mining stress, the macro statistical analysis method cannot comprehensively reveal the coupling relationship between gas pressure and mining stress. Laboratory tests and numerical simulations have shown that coal seam gas pressure is controlled by mining stress, which easily induces dynamic coal and gas disasters [4]. Domestic and foreign laboratory studies that detect the gas pressure of coal samples in sealed tanks by using precision sensors consider gas pressure in coal sample tanks as equivalent to that in gassy coals. The coal seam gas desorption and adsorption theory states that in a gassy coal seam, gas pressure, which macroscopically represents the impact force of the free thermal motion of gas molecules in coal pores, is closely related to variations in porosity and free gas contents. During loading and compression, the cavity volume of the coal sample tank constantly decreases. The decrease in gas pressure caused by the reduction in the cavity volume of the coal sample tank is considerably larger than that caused by the variation in porosity. Thus, replacing the gas pressure of gassy coals with that of the sample tank may inevitably cause the failure of real-time synchronization between stress and gas pressure. Domestic and international works on the numerical simulation of the effects of stress and gas pressure on coal and gas outbursts [5-7] have failed to consider the effect of coupling between coal seam stress and gas pressure. In short, previous studies on the effect of the coupling between stress and gas pressure remain limited.

Existing experimental means and methods for investigating the law of the coupling of stress and gas pressure should be comprehensively improved given their existing problems and limitations.

2 STATE OF THE ART

Coalmines in major mining countries are gradually entering the stage of deep coal mining because of the depletion of shallow coal resources. Crustal stress and gas pressure, as well as the frequency and intensity of coal and gas outburst dynamic disasters, dramatically increase with mining depth [8, 9]. Coal and gas disasters are complex dynamic phenomena. Domestic and foreign scholars have hypothesized that outburst disasters result from the combined effects of different factors, such as crustal stress, gas, and coal physical and mechanical properties, which depend on and also restrict each other in the same system [10].

Over the past few years, a large number of related studies have applied macro statistical analysis, laboratory tests, and numerical simulations to investigate the effect of crustal stress on gas occurrence and provided highly informative results. Through macro statistical analysis, Mamunya et al. [11-15] demonstrated that gas pressure in the original coal seam increases with mining depth, and the gas pressure gradient in the methane zone varies with geological conditions. In geological blocks under similar geological conditions, coal seams at the same depth have the same gas pressure, and the gas pressure of most coal seams increases linearly with burial depth. Based on the statistical analysis of measured data for Chongqing, Beipiao, Hunan, and other mining areas in China, the Liaoning Coal Research Institute determined that gas pressure is distributed near the static water-pressure line with the change in buried depth. Moreover, in the deep mining stage, gas pressure in the coal seam has a limit value and new variation characteristics that result from high crustal stress, ground temperature, and pore water pressure [16]. Cheng found that crustal stress participates in the control of coal structure and gas pressure. In outburst disasters, crustal stress acts as the main motive force in coal destruction and is the precondition for the existence of high-pressure gas [17]. The macro statistical analysis method is based on the in-situ measurement of crustal stress and gas pressure. In this method, the observed data are statistically analysed to determine the trend of qualitative change between two factors. This method mainly deduces an empirical rule based on the measured coal-seam gas pressure data and the specific geological conditions of the mining area through one-dimensional linear or polynomial regression methods. Given that gas pressure is affected by various factors, the measured values deviate from the actual values. Consequently, the macro statistical analysis method fails to provide the basic conditions for the regression method and cannot truly reveal the coupling effect between two factors.

The numerical simulation of the effects of stress and gas pressure coupling on coal and gas outburst has provided various results. Valliappan et al. proposed a solid–gas coupling model of coal and gas outbursts and numerically analysed coal-bed gas flow on the basis of the theories of coal layer mechanics and seepage mechanics [18, 19]. Sobczyk, who also numerically analysed solid–gas instability in coal and gas outbursts, concluded that stresses or gas pressures have crucial roles in outburst disasters. These studies have inspired scholars to investigate the underlying mechanism of coal and gas outbursts induced by crosscut coals [20]. Tian discussed the variation characteristics of stress, displacement, and gas pressure fields of overlying strata under long-distance coal seam group mining and established a multi physical field model of stress distribution and gas migration coupling in surrounding rocks; he also used the finite element method to solve the mathematical model with the aid of FLAC software [21]. Nevertheless, numerical simulation studies have mainly focused on the effects of stress and gas pressure on coal and gas outbursts while ignoring the coupling between stress and gas pressure. The interaction between coal seam stress and gas pressure must be investigated first to analyse the mechanism of dynamic coal and gas disasters induced by stress and gas pressure.

Scholars all over the world have extensively studied the effects of crustal stress and gas pressure on coal and gas outbursts. Bodziny et al. revealed the influence of porosity on outburst velocity by modelling outburst phenomenon similar to that observed in the field with the aid of a cylindrical outburst device, which can increase gas pressure [22, 23]. Tang conducted deep coal and gas outburst tests under the action of crustal stress and gas pressure and stated that outburst distance and strength increase exponentially with mining depth, axial pressure, confining pressure, and gas pressure, whereas the influence of crustal stress and gas pressure on outburst gradually diminishes with the increase in depth [24]. Nevertheless, few studies on the relationship between stress and the gas pressure of gassy coals have been reported. Xie et al. constructed a mechanical model for the coupling of mining stress and gas pressure in gassy coals and found that the gas pressure of coal seams in the working face is exponentially and positively correlated with mining stress; this correlation revealed that gas pressure in the coal seam is controlled by mining stress [25, 26]. In previous laboratory studies, pore gas pressure in the coal sample is replaced by sealed tank pressure. In fact, pore gas pressure is closely related to porosity and the free gas content of pores. As a result, although the gas pressure in the sealed tank is numerically equivalent to that in coal over time, the time difference required for the two kinds of gas pressure to become equivalent is related to the adsorption performance of the coal. Thus, the interaction between stress and gas pressure should be presented in real time. However, laboratory studies fail to reveal the real-time, synchronous relationship between stress and gas pressure.

Therefore, considering the limitations of existing studies, this work proposes a mature laboratory testing technology for investigating the law-governing coupling between pore gas pressure and stress in gassy coals. The proposed method is based on laboratory test data and effectively resolves the problems of macroscopic measurement errors and reveals the intrinsic coupling effects between factors. Moreover, it avoids the inaccuracy of laboratorial gas pressure measurement results. The stress-volumetric strain curve and stress–porosity-gas pressure-coupling model are used to characterize the stress–gas pressure coupling law of gassy coals by taking porosity as an intermediate variable. This approach has practical significance for exploring the mechanism and prevention and control technologies of dynamic coal and gas disasters.

3 METHODOLOGY

3.1 Model for the Response of Pore Gas Pressure under Gassy Coals Loading

Crustal stress and gas pressure are positively correlated with mining depth. In this study, the law governing pore gas pressure and stress coupling during loading was analysed in accordance with the pore characteristics of gassy coals with volumetric strain as the intermediate variable.

In accordance with the pore characteristics of gassy coals, porosity can be expressed as：

$$\eta=\frac{V_{\mathrm{p}}}{V_{\mathrm{b}}}=\frac{(V_{\mathrm{p0}}-\Delta V_{\mathrm{p}})/V_{\mathrm{b0}}}{(V_{\mathrm{b0}}-\Delta V_{\mathrm{b}})/V_{\mathrm{b0}}}=\frac{\eta_0-\Delta V_{\mathrm{p}}/V_{\mathrm{b0}}}{1-\varepsilon_{\mathrm{v}}}, \tag{1}$$

where: η (%) is the porosity of gassy coals; η_0 (%) is the original porosity of gassy coals; V_{p} (m^3/t) is the pore volume of the gassy coals sample; V_{b} (m^3/t) is the volume of the gassy coals sample; V_{p0} (m^3/t) is the original pore volume of the gassy coals sample; V_{b0} (m^3/t) is the original volume of the gassy coals sample; ΔV_p (m^3/t) is the pore volume variation of the gassy coals sample; ΔV_b (m^3/t) is the volume variation of the gassy coals sample; and ε_v is the volumetric strain of the gassy coals sample.

The pore volume variation of a gassy coals sample comprehensively results from the volume variations of gassy coals and coal skeleton.

$$\frac{\Delta V_{\mathrm{p}}}{V_{\mathrm{b0}}}=\frac{\Delta V_{\mathrm{b}}-\Delta V_{\mathrm{g}}}{V_{\mathrm{b0}}}=\varepsilon_{\mathrm{v}}-\varepsilon_{\mathrm{vg}}. \quad (2)$$

The skeleton volume variation, which is related to hydrostatic pressure, can be expressed as:

$$\varepsilon_{\mathrm{vg}}=\frac{\sigma_0}{K}, \quad (3)$$

where: ε_{vg} is the skeleton volumetric strain; and σ_0 (MPa) is the hydrostatic pressure. In $\sigma_0 = (\sigma_1 + \sigma_2 + \sigma_3)/3$ - σ_1, σ_2, and σ_3 (MPa) are the principal stresses in three directions; and K is the bulk modulus.

By combining Eqs. (1), (2), and (3), Eq. (4) can be obtained as:

$$\eta=\frac{\eta_0-\varepsilon_{\mathrm{v}}+\sigma_0/K}{1-\varepsilon_{\mathrm{v}}}, \quad (4)$$

In accordance with the definition of porosity and pore volume, Eq. (5) is written as:

$$\eta=\rho V, \quad (5)$$

where: ρ (t/m^3) is the density of gassy coals; and V (m^3/t) is the pore volume of gassy coals.

Through the calculation of free gas content, Eq. (6) can be obtained as:

$$X_y=VPT_0/(TP_0\xi), \quad (6)$$

where: X_y (m^3/t) is the free gas content in gassy coals; P (MPa) is the gas pressure of gassy coals; P_0 (MPa) is the standard atmospheric pressure; T_0 (273 K)is the absolute temperature under standard conditions; T (°C) is the absolute temperature of gas; and ξ is the gas compression coefficient.

By combining Eqs. (4), (5), and (6), Eq. (7) is obtained as:

$$P=\frac{(1-\varepsilon_{\mathrm{v}})\rho X_y P_0 \xi T}{\left[\eta_0-\varepsilon_{\mathrm{v}}+3\sigma_0(1-2\nu)/E\right]T_0}, \quad (7)$$

where: v is the Poisson's ratio of gassy coals; and E (MPa) is the elastic modulus of gassy coals.

Assuming $T_0 = T$, and $\xi = 1$, then Eq. (7) can be rewritten as:

$$P=\frac{(1-\varepsilon_{\mathrm{v}})\rho X_y P_0}{\eta_0-\varepsilon_{\mathrm{v}}+3\sigma_0(1-2\nu)/E}. \quad (8)$$

For a specific working face, the free gas content, visual density, original porosity, and Poisson's ratio of the coal seam can be regarded as fixed values. Analysing Eqs. (8) and (4) suggests that the gas pressure of the coal seam is affected by pore volume, volumetric strain, and stress, among which the former two are affected by stress. As a result, coal would undergo complicated microcosmic changes under stress. However, from a macroscopic perspective, porosity does not change linearly with stress in different stages of deformation. This behaviour results in the nonlinear variation in gas pressure with stress.

3.2 Experimental Research on Gassy Coals

3.2.1 Sample Preparation

The coal samples used in this study were obtained from the 13-1 coal mine of Zhangji Coal Mine in Huainan Mining Area, China. The average density of the coal was 1.412 kilogram per cubic meter with an approximate porosity of 25-30%.The adsorption constant of this coal sample was 26.15 m^3/t at room temperature (26 °C). For the mechanical test, the raw coal was processed into cylindrical specimens with heights of 100 mm and diameters of 50 mm. To reduce the influence of bedding on the strength of sample, the raw coal was drilled vertically along the axial direction of the coring machine.

3.2.2 Experimental Device and Process

The ZTR-203 triaxial test system of electro hydraulic servo rock was adopted as the mechanical test system for gassy coals, as shown in Fig. 1. Axial loading was conducted at the rate of 0.1 mm/min through displacement control. The deformation of the specimen was monitored with the aid of a strain gauge.

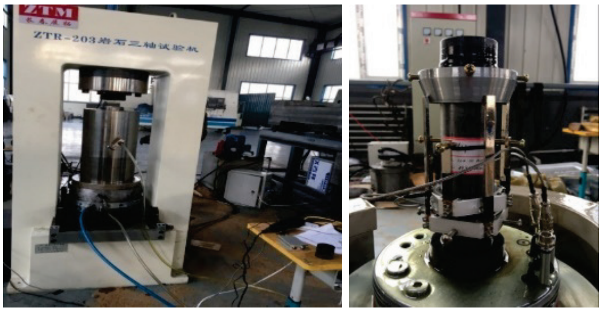

Figure 1 ZTR-203 electro-hydraulic servo rock three-axis test system

Gassy coals was subjected to triaxial loading tests under different confining pressures and initial gas pressures.

1) For experiments under different initial gas pressures, coal samples were placed in a sealed device for gas and affixed with strain gauges. Then, air in the sealed device was released by an air pump. After a certain vacuum (<0.01 MPa) was reached, the vacuum pump was closed, and the sealed device was filled with gas. Gas pressure was maintained at the preset experimental value for 24 h to ensure the complete adsorption of gas on coal samples.

Initial experimental gas pressures were set to 0.5, 1, and 1.5 MPa.

2) For experiments under different confining pressures, coal samples were placed in a triaxial pressure chamber and affixed with strain gauges. The pressure source and the triaxial pressure chamber were connected by a pipeline. Next, the gas source was connected, and gas pressure was slowly adjusted such that the oil in the oil chamber was pressed into the triaxial chamber to the preset test confining pressure. The test confining pressures were set to 2, 4, and 6 MPa.

3.2.3 Data Acquisition

A static strain device was used to monitor sample deformation and to acquire experimental data. Static strain was monitored withYE2539 high-speed static strain gauges and BX120-2AA strain gauges. To measure the axial and longitudinal strains during the loading, two strain gauges were perpendicularly fixed along the axial and longitudinal directions of the specimen. Strain data for the calculation of the volumetric strain of the specimen were acquired twice per *s*.

4 RESULT ANALYSIS AND DISCUSSION

4.1 Analysis of the mechanical characteristics of gassy coals

The mechanical deformation characteristics of gassy coals were obtained through the above experimental system and scheme as presented in Figs. 2 and 3. The specific mechanical characteristic parameters of the specimens are listed in Tab. 1.

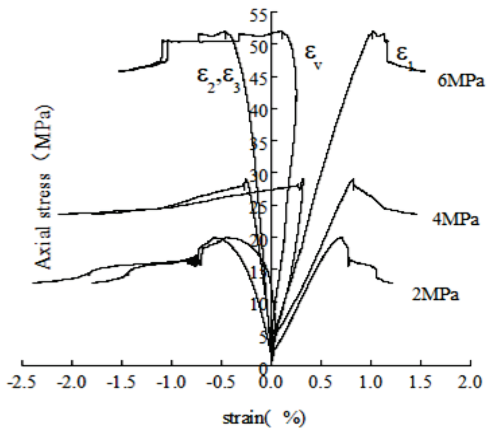

Figure 2 Stress–strain curve of gassy coals

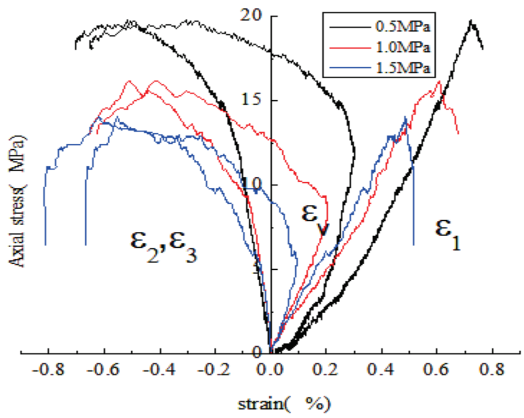

Figure 3 Stress–strain curve of gassy coals under different confining pressures

Table 1 Uniaxial compressive strengths, elastic modulus, and corresponding strain values of specimens

Sample number	Confining pressure / MPa	Initial gas pressure / MPa	Uniaxial compressive Strength σ_1 / MPa	Average value / MPa	Peak volume strain ε_V / MPa	Average value / MPa	Elastic modulus E / MPa	Average value / MPa
1	2	-	19.56	20.83	−0.102	−0.137	3505	4120
2			24.38		−0.179		5918	
3			18.56		−0.130		2884	
1	4	-	28.33	28.43	0.315	−0.021	3817	4588
2			31.58		−0.209		5419	
3			`25.39		−0.179		4528	
1	6	-	51.28	45.82	0.155	0.166	5698	7390
2			36.66		0.127		6026	
3			49.53		0.218		10445	
1	-	0.5	19.73	19.70	−0.306	−0.278	2671	2669
2			23.20		−0.284		2919	
3			20.68		−0.241		2753	
4			18.90		−0.312		2618	
5			15.96		−0.247		2388	
1	-	1.0	16.12	15.71	−0.423	−0.424	2616	2570
2			12.61		−0.489		2418	
3			13.40		−0.514		2593	
4			18.81		−0.371		2696	
5			17.64		−0.323		2528	
1	-	1.5	14.04	13.75	−0.623	−0.616	2386	2375
2			17.80		−0.491		2437	
3			12.26		−0.722		2412	
4			9.03		−0.577		2209	
5			15.62		−0.666		2433	

Under different confining pressures, gassy coals exhibit different mechanical deformation patterns. First, the peak strengths and elastic modulus of gassy coals increase with confining pressure. As the confining pressure increases from 2 to 6 MPa, the uniaxial compressive strength of gassy coals increases from 20.83 to 45.82 MPa, the elastic modulus of gassy coals increases from 4.10 to 7.39 GPa, and the peak volumetric strain of gassy coals increases from −0.10 to 0.166%. These results suggest that under high confining pressure, coal tends to accumulate elastic deformation energy with increasing mining depth. The peak strength and elastic modulus of gassy coals decrease as initial gas pressure increases. As the initial gas pressure increases from 0.5 to 1.5 MPa, the uniaxial compressive strength of gassy coals decreases from 19.7 to 13.75 MPa, the elastic modulus gassy coals decreases from 2.67 to 2.38 GPa, and the peak volumetric strain of gassy coals decreases from −0.27 to −0.616%. This observation indicates that as gas pressure increases, the ability of gassy coals to resist deformation and destruction is reduced and gas expansion energy increases. This condition facilitates the induction of dynamic coal and gas disasters.

4.2 Analysis of the Response of the Stress and Porosity of Gassy Coals

The coupling curves between porosity and stress (Figs. 4 and 5) can be inferred from the stress–volumetric strain curve of gassy coals and the physical mechanical model of porosity-volumetric strain–loading stress with volumetric strain as the intermediate variable. The parameters involved in the model of Eqn. (4) are given in Tab. 2.

Table 2 Porosity and bulk modulus of coal samples

Initial gas pressure / MPa	Confining pressure / MPa	Original porosity η_0 / %	Bulk modulus k / MPa
-	2	25	6156
-	4	25	3823
-	6	25	4250
0.5		30	2118
1.0		30	1259
1.5		30	1884

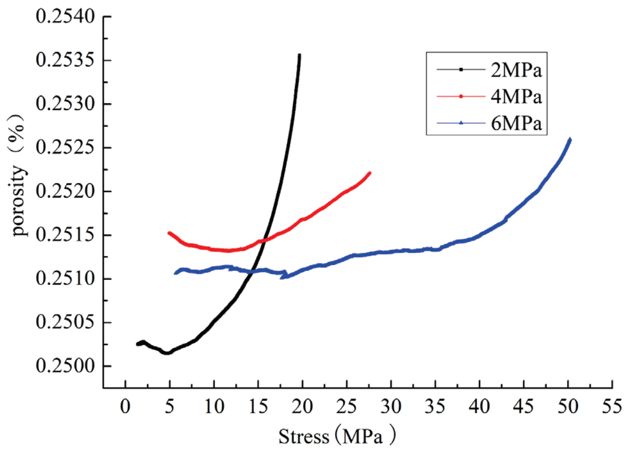

Figure 4 Stress–porosity curves of gassy coals under different confining pressures

As shown in Fig. 4, under different confining pressures, the porosity of gassy coals first decreases and then increases with stress. As stress increases, coal pores are compacted and gradually decrease in number. Then, new fractures are generated, thus increasing porosity until the coal samples are destroyed. The reduction rate of porosity first increases and then decreases as the confining pressure increases from 2 to 6MPa. This behaviour indicates that axial stress drastically affects the degree of pore compaction. The effect of confining pressure on the porosity and compaction of coal is strengthened under increasing confining pressure. At this time, axial stress negligibly influences porosity. Under increasing axial stress, the coal is subjected to high stress, which increases porosity by expanding coal fractures.

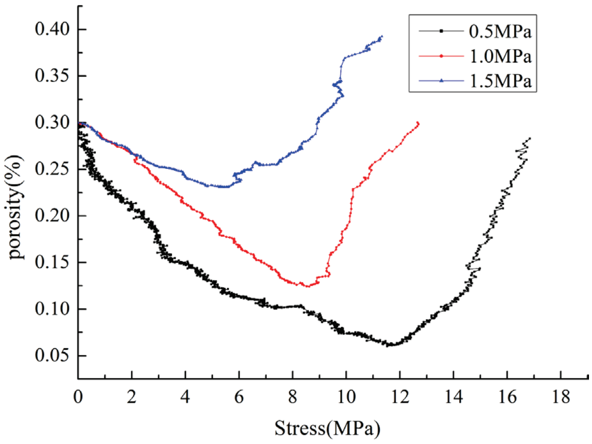

Figure 5 Stress–porosity curves of gassy coals under different initial gas pressures

As shown in Fig. 5, under different initial gas pressures and confining pressure conditions, the stress and porosity of gassy coals follow the same macroscopic change rule. Specifically, coal pores are first compacted and gradually decrease in number as stress increases. Subsequently, new fractures are generated and increase porosity until the gassy coals fails. The porosity of gassy coals decreases by 0.24% from 0.3 to 0.06% under the initial gas pressure of 0.5 MPa and by 0.18%, from 0.3 to 0.12% under the initial gas pressure of 1.0 MPa. It further decreases by 0.07% from 0.3 to 0.23% under the initial gas pressure of 1.5 MPa. The porosity of gassy coals gradually decreases with the increase in initial gas pressure. This behaviour suggests that gassy coals are easily deformed and that gas erosion reduces porosity at a gradually lower rate. In summary, the porosity of gassy coals first decreases and then increases as loading stress increases, irrespective of gas and confining pressures. The reduction in porosity decreases as confining pressure increases. High initial gas pressure results in the low porosity of gassy coals.

4.3 Response of Gassy Coals Stress and Pore Gas Pressure

4.3.1 Analysis of the Characteristics of the Coupling between Stress and Pore Gas Pressure

Using porosity as the intermediate variable, the model for the response of stress and gas pressure coupling was transformed based on the stress–porosity curve of gassy coals to obtain the response curve for stress–gas pressure coupling, as exhibited in Fig. 6.

Analysing Fig. 6 reveals that under different confining pressure conditions, the gas pressure of gassy coals first increases and then decreases as stress increases.

The pores of gassy coals are first compacted, and the gas pressure in free pores gradually increases. Porosity continues to increase because of the generation of new fractures until the gassy coals are destroyed. Thus, pressure in free pores decreases.

As shown in Fig. 7, under different initial gas pressure conditions, the gas pressure of gassy coals first increases and then decreases as stress increases. Stress gradually decreases when the gas pressure of gassy coals peaks. This behaviour indicates that compressive strength decreases as gas pressure increases. When the value of stress is equivalent to that of compressive strength, gassy coals undergo fracture failure, which macroscopically represents the reduction in gas pressure. Gas pressure increases by 136% from 0.5 to 1.18 MPa when the initial gas pressure is 0.5 MPa and by 58% from 1.0 to 1.58 MPa when the initial gas pressure is 1.0 MPa. It increases by 30% from 1.5 to 1.95 MPa when the initial gas pressure is 1.5 MPa. The increase in gas pressure in gassy coals gradually declines as initial gas pressure increases. This result indicates that coal is vulnerable to damage due to gas erosion, which accounts for the narrowed range of the increment in gas pressure.

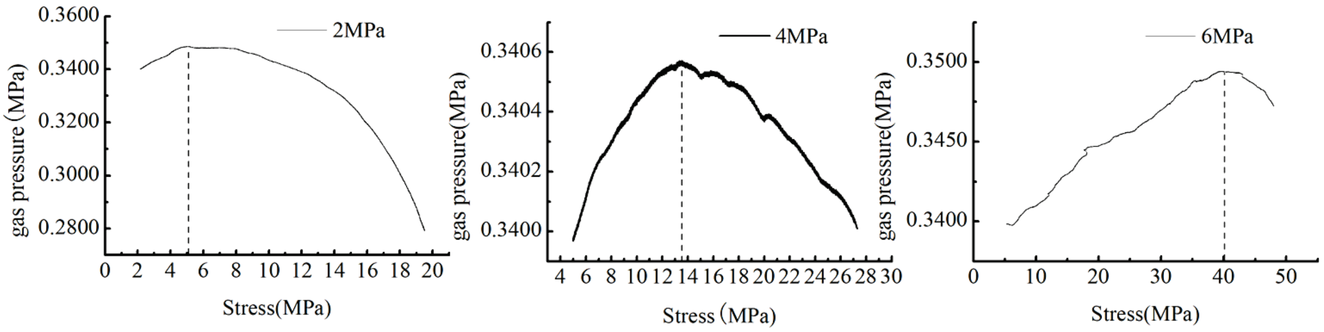

Figure 6 Stress–porosity gas pressure curve of gassy coals under different confining pressures

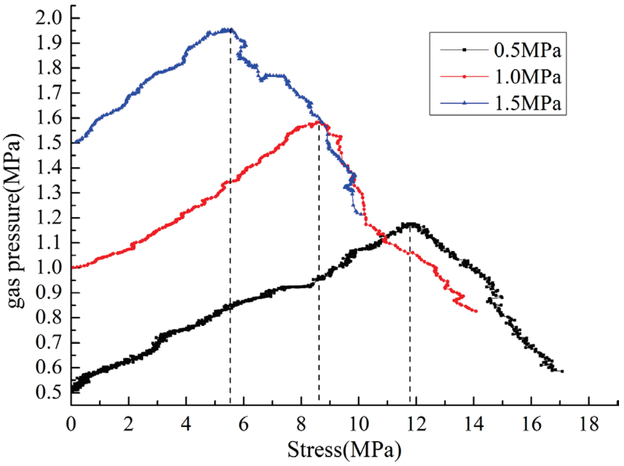

Figure 7 Stress–pore gas pressure curves under different initial gas pressures

Analysing Figs. 6 and 7 reveals that under different confining pressures and initial gas pressures, gas pressure in gassy coals first increases and then decreases as stress increases. The value of the gas pressure of gassy coals increases with the stress before it reaches that of compressive strength, and a positive correlation is observed between the two factors. Gas pressure decreases with stress when stress exceeds compressive strength, and a negative correlation is observed between the two factors.

4.3.2 Response Characteristics of Coal Seam Gas Pressure and Mining Stress

An experimental study was conducted to validate the conclusions on the coupling relationship between stress and gas pressure and to eliminate the disadvantages of the independent observation of stress and gas pressure. In the experiment, mining stress and gas pressure in the 714 working face of the Qinan Coal Mine of Huaibei Mining Group were measured using an integrated method (patent number ZL201310675975.X). Monitoring results were compared with laboratory test results.

The upper part of the 714 working face is adjacent to the 712 working face. The average depth of the working face is 550 m. In this working face, a combined mining method is adopted to recover the 71 and 72 coal layers. The coal seam (including 71, 72, and gangue) has a total thickness of 0.3–6.0 m and an average thickness of 4.8 m. The space between the two coal seams is 0–2.0 m with an average of 0.8 m. Given that the two coal seams have dip angles of 5°–16° with an average of 8°, they are classified as coal seams with a stable and simple structure. The main roof of the coal seam is composed of medium sandstone with a thickness of 4–14.8 m; the immediate roof is composed of mudstone with a thickness of 0.8–2 m; and the immediate bottom roof is composed of mudstone with a thickness of 0.8–3.8 m. The 714 working face is an outburst coal seam. Pre drainage was implemented prior to recovery, and the gas index meets safety regulation requirements.

Two test stations are arranged in the return airway of the 714 working face in accordance with geological conditions. The layout of integrated test boreholes is presented in Fig. 8. Two sets of observation stations are arranged in the lower side seam of the return airway, which is 200 m in front of the 714 working face. The distance between the stations is 30 m. Stress and gas pressure measuring devices are arranged at each station to enable the integrated monitoring of stress and gas pressure. The depths of the stress observation hole and the gas pressure test hole are 30 and 25 m, respectively.

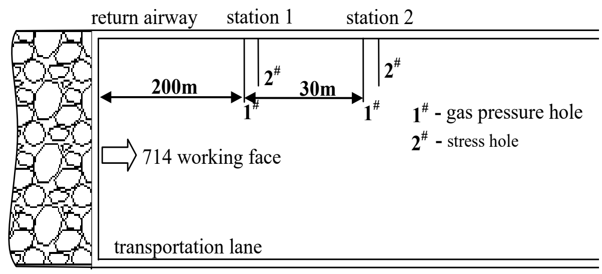

Figure 8 Field observation of mining stress and gas pressure in a working face

The results of mining stress and gas pressure are measured as the 714 working face advanced and are as illustrated in Fig. 9.

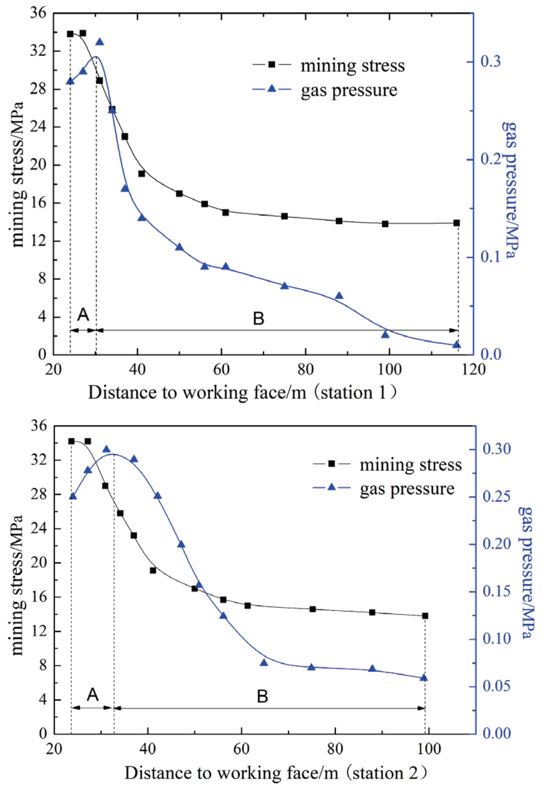

Figure 9 Curves of mining stress and gas pressure in each station at the 714 working face

As shown in Fig. 9, stress in the coal seam at 100 m, in front of the working face to the position of working face, first increases and then decreases. Atypical coupling effect between the gas pressure and the mining stress exists, and gas pressure is controlled by mining stress. Gas pressure increases before peaking as mining stress increases and then decreases as mining stress decreases because the coal near the working face undergoes pressure relief and loses its bearing capacity, thus producing plastic deformation. As a result, fractures increase, expand, and connect rapidly inside the coal, and gas flows through the fracture network into the coal or into the overlying fractured field. Gas pressure sharply declines because gas is discharged from the coal seam.

In summary, integrated on-site observations revealed that, the coupling of mining stress and gas pressure follow typical laws. This result is in good agreement with the results of the proposed method. Thus, the rationality of the proposed method for investigating the coupling between loading stress and gas pressure is verified. The proposed method provides new concepts and has practical significance for studies on the mechanisms, prevention, and control technologies of dynamic coal and gas disasters.

5 CONCLUSION

This study investigated the law governing the coupling of pore gas pressure and stress in gassy coals through mature laboratory test technology and by integrating coal-seam gas occurrence theory, laboratory tests, and on-site integration testing methods. The main conclusions are as follows:

(1) A physical mechanical model of porosity–volumetric strain–loading stress was constructed in accordance with the pore characteristics of gassy coals. The porosity–loading stress curve and relationship were obtained with volumetric strain an intermediate variable. Porosity first decreases and then increases as stress increases.

(2) A stress–porosity–gas pressure relationship model was established based on the coal-seam gas desorption adsorption theory and the change in gassy coals porosity. Finally, the coupling relationship between stress and gas pressure was obtained.

(3) Under different experimental conditions, pore gas pressure first increases and then decreases as stress increases. The value of the gas pressure of gassy coals increases with stress before it reaches that of compressive strength. This behaviour indicates that gas pressure and compressive strength are positively correlated. When the value of stress exceeds that of compressive strength, gas pressure decreases with stress. The validity of the laboratory research method proposed in this study was verified through an on-site empirical test.

The proposed method for investigating the coupling law of stress and gas pressure is scientific, reasonable, and simple. It can conveniently determine mechanical parameters and scientifically reveal the nature of the coupling interaction between gassy coals stress and gas pressure. However, dynamic gas desorption and adsorption occur when gassy coals are subjected to force. These phenomena can change the gas content and the physical and mechanical properties of coal. These effects, in turn, delay the responses of stress and gas pressure. Therefore, the laws governing gas desorption and adsorption should be investigated in the future. Moreover, the effect of gas desorption and adsorption on free gas content should be considered to improve the effectiveness of the coupling model and to provide a new theoretical basis for understanding the mechanism of dynamic coal and gas disasters.

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