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Retraction

Retracted: Study on Rheological Properties of Coal Rock Containing Gas under Disturbance Conditions

Shock and Vibration

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] G. Zhang, Z. Huang, T. Zhu et al., "Study on Rheological Properties of Coal Rock Containing Gas under Disturbance Conditions," *Shock and Vibration*, vol. 2022, Article ID 2370301, 10 pages, 2022.

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Research Article

Study on Rheological Properties of Coal Rock Containing Gas under Disturbance Conditions

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In view of the dynamic phenomenon that coal and rock are susceptible to external impact disturbance in the mining process, combined with the rheological hypothesis mechanism of coal and gas outburst, the RLSS-II-type triaxial loading creep test system of gas-containing coal and rock developed by ourselves is used to carry out the conventional triaxial rheological test of gas-containing coal and rock and the rheological disturbance effect test of gas-containing coal and rock under impact disturbance. The strength limit neighborhood of gas-containing coal and rock is determined, and the gas-containing coal and rock entering the strength limit neighborhood are subjected to different impact disturbances. The experimental results show that, (1) under the confining pressure of 0 MPa, 2.5 MPa, and 5 MPa, the longitudinal deformations of gas-bearing coal and rock are 32 mm, 27 mm, and 22 mm, respectively, indicating that the deformation of coal and rock will be affected by confining pressure, and with the increase of confining pressure, the deformation will decrease. (2) In the test, the deformation of coal and rock in the late stage of uniform creep stage can be regarded as a strain threshold. Before this threshold, the strain of coal and rock is not obvious, and the deformation is only 1.1 mm. After exceeding a threshold, the deformation of coal and rock is 9 mm, and the deformation increases significantly. Then, it enters the accelerated creep stage quickly and finally damages. The vicinity of this threshold is called the strength limit neighborhood of coal and rock containing gas. (3) The gas-bearing coal and rock without entering the strength limit neighborhood and entering the strength limit neighborhood are changed by confining pressure and different impact disturbance, respectively. It is found that, whether in the strength limit neighborhood or outside the strength limit neighborhood, the confining pressure has an effect on the strain, but the influence is not large. Under different impact disturbance, the deformation of coal and rock within and outside the strength limit neighborhood is 8 mm and 0.4 mm, respectively, and the deformation changes obviously, indicating that the impact disturbance has a great influence on the deformation of coal and rock within the strength limit neighborhood, and the coal and rock with large impact disturbance are destroyed before the coal and rock with small impact disturbance, indicating that the greater the impact disturbance, the shorter the time required for destruction.

1. Introduction

With the increase of mining depth of coal resources, the risk of coal and gas outburst increases, which poses a serious threat to the personal safety of underground staff. Relevant studies suggest that coal and gas outburst is a rheological process of coupling ground stress and pore gas after the coal containing gas is affected by mining [1, 2]. Moreover, the closer the load value is to the yield limit of coal containing gas, the greater the influence of external impact disturbance load on the rheological process is. Therefore, the study on the dynamic response of external impact load to the creep state of coal containing gas when the external load value is close to the yield limit of coal containing gas can enrich the rheological hypothesis of coal containing gas and further supplement the rheological mechanism of coal and gas outburst.

For a long time, many scholars have conducted extensive and in-depth studies on rheological test, mechanical properties of coal and rock, mechanical model construction, and rheological properties of coal and rock under various conditions. Professor Gao et al. [3–7] firstly proposed the concepts of "rock rheological disturbance effect" and "rock strength limit neighborhood" and then carried out a large number of studies on rheological disturbance effect. Wu and Wang [8] explored the influence of coal rock internal damage on coal rock strength through coal rock rheological test and determined the rheological coefficient of coal. Wang et al. [9] found that the influence of gas on the mechanical properties of coal samples decreased with the increase of confining pressure. Li et al. [10] studied the creep law of coal rock under triaxial loading under low gas pressure and put forward the viewpoint of creep inflection point. Jiang et al. [11] carried out the gas seepage test of coal rock containing gas under unloading confining pressure and found that the deformation of coal rock is closely related to permeability and confining pressure. Lu and Li [12] found that the peak strength of coal samples will decrease with the increase of gas pressure. Wan et al. [13] explored the failure characteristics of coal and rock containing gas under different stress paths. Li et al. [14] through the coal permeability test found that temperature and coal permeability are not in a single linear relationship, but there is a turning point. Jiang et al. [15] studied the loading and unloading variation of gas-bearing raw coal under different water-cut conditions. Zhang et al. [16] studied the influence of moisture on isothermal adsorption characteristics and swelling deformation characteristics of coal and concluded that the existence of moisture can inhibit the adsorption swelling deformation of coal. Changang et al. [17] studied the damage characteristics of various gases in briquette adsorption instantaneous pressure relief and quantitatively characterized the coal adsorption swelling deformation and instantaneous pressure relief deformation. Zhao et al. [18] obtained the creep curves of coal rock under different stress levels by graded loading triaxial creep test and established the creep constitutive equation of coal rock under different stress levels. Xian et al. [19, 20] obtained the creep state equation of coal rock under the condition of containing gas considering the effect of coal seam gas and constructed the mathematical analysis model of gas-containing coal solid-gas coupling. He et al. [21] established the criterion of coal rock creep rupture through theoretical analysis and applied it to numerical simulation. Zhang et al. [22] established the multiple linear regression equation of the coupling effect of saturation and confining pressure on the duration of stress platform in coal containing gas hydrate and tested the equation and obtained high fitting degree. Xu et al. [23] established a fluid-solid coupling model of coalbed methane by using elastic mechanics, fluid mechanics of porous media, and effective stress principle based on the theory of coalbed methane migration under multiple physical fields coupling. Liu [24] studied triaxial compression mechanical properties of gas-bearing raw coal under high stress. From the above, it can be seen that there are few studies on the rheological properties of gas-bearing coal and rock under impact disturbance, especially those close to the yield limit.

In view of the shortcomings of the above research, this paper carries out the rheological disturbance effect test of gas-bearing coal rock under impact disturbance and obtains the dynamic response of external impact load to gas-bearing coal rock in creep state when the external load value is close to the yield limit of gas-bearing coal rock. The research results can enrich the rheological dynamics theory of gas-bearing coal rock and provide theoretical basis for preventing coal and gas outburst.

Figure 1: Coal rock specimens installed.

2. Test Equipment and Test Scheme

2.1. Preparation and Selection of Specimens. The coal sample was selected as a standard cylinder specimen with a diameter of about 50 mm and a height of about 100 mm. Before the test, the size, density, and acoustic wave of the coal sample were measured, and the specimens with similar measurement results were selected for the test. The installed coal sample is shown in Figure 1.

2.2. Test Instruments. This test instrument mainly adopts RRTS-IV rock rheological disturbance effect test system and RLSS-2 coal rock rheological disturbance effect seepage test device.

2.2.1. RRTS-IV Rock Rheological Disturbance Effect Test System. It mainly includes the test host, loading device, pressure sensor, impact weight, data acquisition system, etc., as shown in Figure 2. The sensitivity of the data acquisition system is set to 1.8 mV/mm.

(a) (b) (c)

Figure 2: RRTS-IV rock rheological disturbance effect test system. (a) Testing host machine. (b) Data acquisition system. (c) Impact weights.

2.2.2. RLSS-2 Coal Rock Rheological Disturbance Effect Seepage Test Device. It mainly includes coal sample holder, confining pressure loading system, stress-strain measurement extensometer, intake system, data acquisition and control system, etc., as shown in Figure 3. Among them, the coal sample holder can withstand the maximum confining pressure loading which is 20 MPa and the maximum axial loading pressure which is 35 MPa (see Figure 4). The confining pressure loading system adopts imported servomotor with programmable controller and intelligent display screen, which can accurately control the inlet, outlet, constant pressure, and constant speed of the loading pump and can automatically compensate the confining pressure. The compensation error is ±0.01 MPa. The confining pressure loading system is shown in Figure 5. The axial displacement range of stress-strain extensometer is 0~150 mm.

2.3. Test Scheme. Before the rheological disturbance effect test of gas-bearing coal sample under impact disturbance, the conventional rheological test of gas-bearing coal rock was carried out to determine the strength limit and rheological state of gas-bearing coal rock under confining pressure of 0 MPa, 2.5 MPa, and 5 MPa. Then, the impact disturbance of gas-bearing coal rock entering the rheological state was carried out to analyze the rheological disturbance law of gas-bearing coal rock under rheological state. The specific test steps are as follows:

(1) The coal sample specimen A-1-1 is installed in the pressure chamber. After the specimen was installed, the vacuum pump was used for vacuuming for 3 h to eliminate the interference of other gases. After the vacuum is completed, the gas is injected into the specimen, and the gas and the coal sample specimens

Figure 3: RLSS-2 seepage test device for coal rock rheological disturbance effect.

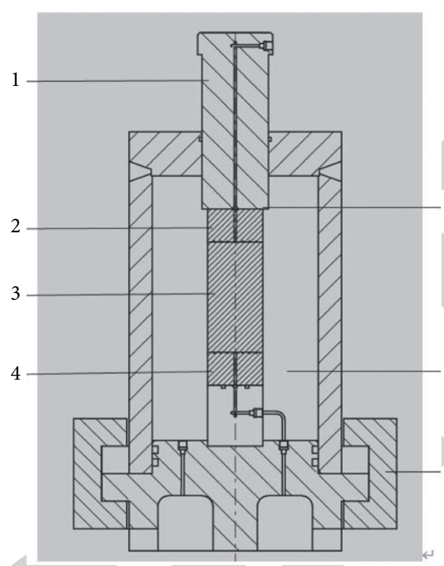

Figure 4: Coal sample holder. (1) Pressure loading piston rod. (2) Upper sample seat. (3) Coal specimen. (4) Lower sample seat. (5) Axial pressure chamber. (6) Confining pressure chamber. (7) Rapid installation of clamp.

are placed for a period of time to achieve adsorption equilibrium. The specimens were subjected to axial compression of 3 MPa, 6 MPa, 9 MPa, etc. until the specimen is completely destroyed. The above test steps are repeated for specimens A-1-2 and A-1-3.

(2) Specimens A-2-1~A-3-3 are also vacuumed, and after the vacuum is completed, the same content of gas is injected into the specimen, and the gas and coal samples are placed for a period of time to achieve adsorption equilibrium. Then, the confining pressure loading system was used to apply the confining pressure of 2.5 MPa to specimens A-2-1~A-2-3 and the confining pressure of 5 MPa to specimens A-3-1~A-3-3, and the test steps in (1) were repeated. The strength limit and rheological state of gas-bearing coal and rock under different confining pressures were determined by the above three groups of specimens, and this was used as the classification standard of impact disturbance load.

Figure 5: Confining pressure loading system.

(3) The test steps of (2) were repeated for specimen B-1. After the axial compression is applied to the preset value until reaching the rheological stability, the impact disturbance is carried out. The impact weight is 1 kg, the impact height is 10 cm, and the impact is once every 3 minutes, a total of 10 times. After the impact is completed, wait for 10 minutes for the impact disturbance of the next load, and then load to the final load level until the specimen is completely destroyed.

(4) Repeat the test steps of (3) for specimens B-2 and B-3, and adjust the weight of impact weight to 2 kg and 3 kg and impact height to 20 cm and 30 cm, until the specimen is completely destroyed. The stress-strain data of each specimen were recorded throughout the test. Figure 6 is part of the coal rock specimen that is damaged.

The preset confining pressure and gas pressure of the above coal sample specimens can be monitored for a long time by the seepage experimental device of rheological disturbance effect of gas-bearing coal rock, and the pressure can be automatically compensated and unloaded. The compensation error is ±0.1 MPa, so it can ensure that the confining pressure and gas pressure remain stable for a long time in the experimental process.

3. Test Equipment and Test Scheme

3.1. Rheological Test Results and Analysis of Coal Rock Containing Gas under Different Confining Pressures. The rheological tests of coal and rock containing gas under different

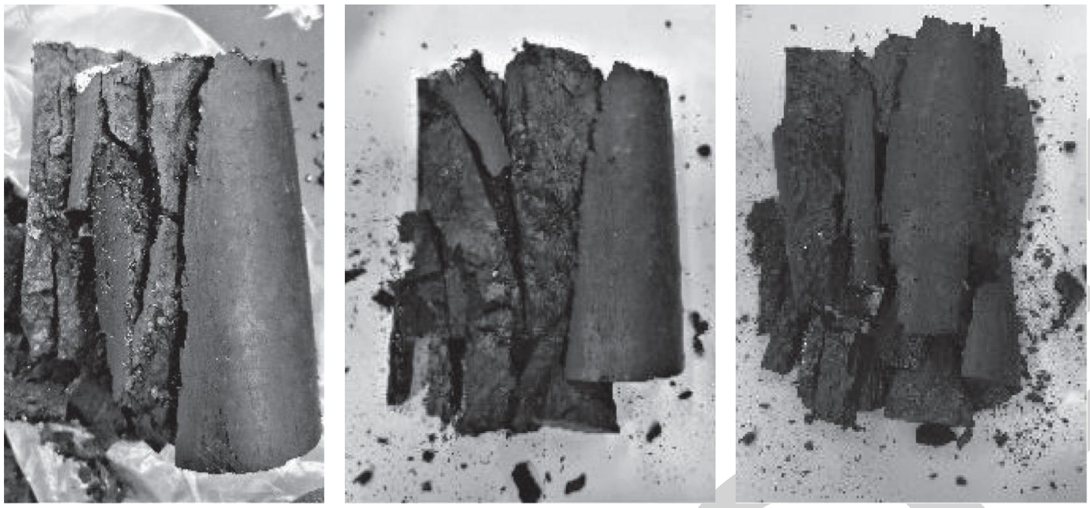

Figure 6: Partial coal rock specimens damaged occurs.

Table 1: Rheological test results and analysis of coal rock containing gas under different confining pressures.

Specimen number	Diameter (mm)	Height (mm)	Confining pressure (MPa)	Failure load (kN)	Strength limit (MPa)
A-1-1	50.02	100.03	0	30.14	15.06
A-1-2	50.06	99.97	0	29.72	15.1
A-1-3	49.99	100.1	0	30.01	15.29
A-2-1	50.08	100.1	2.5	40.81	20.72
A-2-2	50.02	100.2	2.5	41.05	20.89
A-2-3	50.05	99.98	2.5	40.61	20.64
A-3-1	49.96	100.5	5	49.24	25.12
A-3-2	50.04	100.06	5	49.60	25.22
A-3-3	50.03	100.12	5	49.26	25.06

confining pressures were carried out on three groups of specimens A-1~A-3, and the failure load and strength limit of specimens under different confining pressures were obtained. The relevant data are shown in Table 1.

It can be seen from Table 1 that when the confining pressure is fixed, the test results of each group of coal and rock specimens are basically the same. Therefore, the test data of specimens A-1-2, A-2-1, and A-3-2 are selected as the reference data for subsequent tests. The full-range graded loading rheological curves of these three coal and rock specimens are shown in Figures 7–9.

It can be seen from the analysis in Figure 7 that, in the whole loading process, the longitudinal deformation of the coal rock specimen is about 32 mm, and the transverse deformation is about 22 mm. The longitudinal deformation of the coal rock specimen is significantly different from the transverse deformation. From the point of view of strain under all levels of load, in the early rheological stage, when the first stage load (about 3 MPa) is applied, there is a small deformation stage similar to the straight line. With the increase of time, the deformation of the specimen is also increasing and finally tends to be stable. The longitudinal deformation of coal and rock under the first stage load is about 4.3 mm, and the transverse deformation is about 2.6 mm. When the second load (about 6 MPa) is applied, it is obvious that the curve will show the characteristics of leap change when the load is just applied,

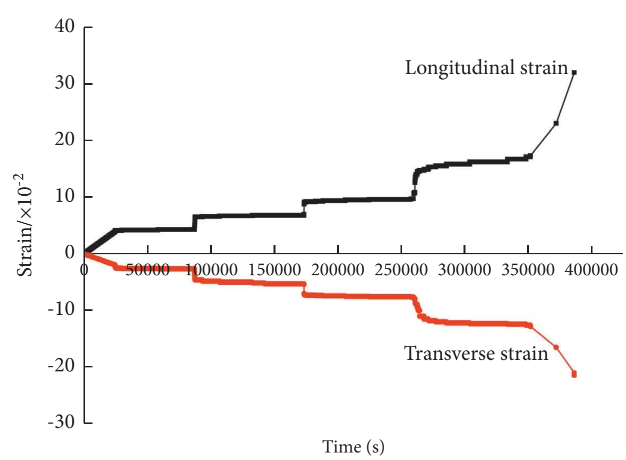

Figure 7: Rheological curves of specimen A-1-2 under full loading (confining pressure 0 MPa).

and then the strain will tend to be stable with the increase of time. The longitudinal deformation of coal and rock under this first load is about 2.5 mm, and the transverse deformation is about 2.7 mm. The deformation of coal and rock under the third stage load (about 9 MPa) is similar to that under the second stage load. The longitudinal deformation of coal and rock under this stage load is about 2.8 mm, and the transverse deformation is about 2.3 mm.

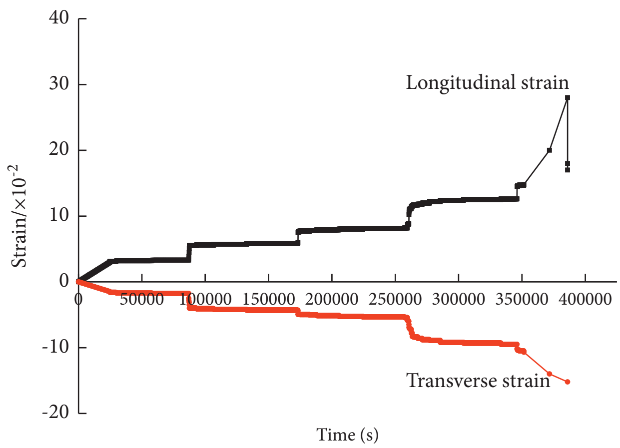

Figure 8: Rheological curve of specimen A-2-1 under full grade loading (confining pressure 2.5 MPa).

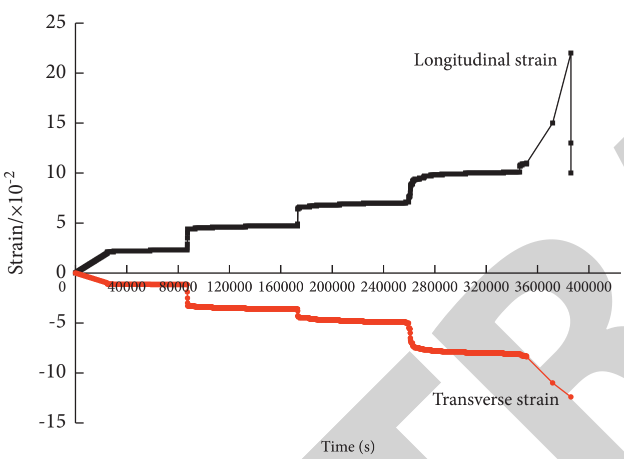

Figure 9: Rheological curve of specimen A-3-2 under full grade loading (confining pressure 5 MPa).

When applied to the fourth load (about 12 MPa), the rheological curve has a trend of elevation, the longitudinal deformation of the specimen under the first load is about 7 mm, the transverse deformation is about 5 mm, and the deformation is significantly higher than that under the second and third load levels. When applied to the fifth load, the deformation of coal rock specimen increases sharply until the specimen is destroyed. For the above changes, the author makes the following explanation: in the initial creep stage, the coal rock specimen is in the range of elastic deformation, and the deformation increases linearly. Then, with the increase of time, the coal rock specimen gradually enters the uniform creep stage from the initial creep stage, and the coal rock specimen is mainly plastic deformation in this stage. Therefore, with the increase of time, the deformation tends to be flat. Due to the sudden increase of external load on the coal rock specimen in the uniform creep stage, the deformation will suddenly increase, showing a sudden leap in the curve. However, since it does not exceed the plastic limit of the coal rock specimen itself, the deformation will become stable over time. When the fourth stage load is applied, the applied load is more and more close to the plastic limit of the coal rock specimen itself, so the deformation will have a significant upward trend, but there is still no big change in the curve. When the fifth-order load is applied, the load has exceeded the plastic limit of the coal rock itself. The deformation of the coal rock specimen increases rapidly in a short period of time until it is destroyed. The curve shows an obvious acceleration increase. This stage is the accelerated creep stage.

Comparing Figures 7–9, it can be found that coal and rock under different confining pressures have the above variation characteristics, but the final deformation of each specimen under different confining pressures is obviously different: the final longitudinal deformation of coal and rock specimen under confining pressure of 0 MPa is about 32 mm, and the transverse deformation is about 21 mm. The final longitudinal deformation of coal rock specimen under confining pressure of 2.5 MPa is about 27 mm, and the lateral deformation is about 15 mm. The final longitudinal deformation of coal rock specimen under confining pressure of 5 Mpa is about 22 mm, and the lateral deformation is about 12 mm. From the above changes, it can be concluded that, with the increase of confining pressure, the total deformation of coal rock specimens will be reduced. For this change, the author believes that when the axial compression is applied to the specimen, due to the existence of confining pressure, the internal pores of coal rock specimens will be gradually compressed, the gas between pores will be gradually reduced, and the pore pressure will be reduced. According to the principle of effective stress,

$$\sigma' = \sigma - \mu, \tag{1}$$

where σ' is the effective stress, σ is the total stress, and μ is the pore pressure.

It can be seen that when the total stress (σ) is constant, with the increase of confining pressure, the internal pores of the coal rock specimen are gradually compacted, and the gas in the internal free state is gradually reduced. Since the pore pressure is mainly generated by the free gas, the pore pressure (μ) is gradually reduced, and the effective stress (σ') in the specimen is gradually increased. The bearing capacity of the coal rock specimen will gradually increase, and the deformation ability to resist the external load will naturally increase, showing that the deformation of the coal rock decreases with the increase of confining pressure.

3.2. Test Results and Analysis of Gas-Bearing Coal Rock under Step Loading. The above analysis shows that the longitudinal deformation is more obvious than the transverse deformation, so the following analysis adopts longitudinal deformation. Table 2 is the loading deformation of specimen A-3-2 under confining pressure of 5 MPa. Figure 10 is the longitudinal deformation of coal rock under confining pressure of 5 MPa.

Combined with Figure 10 and Table 2, it is obvious that, under the confining pressure of 5 MPa, the coal rock under the axial compression of 5 MPa, 10 MPa, 15 MPa, and 20 MPa is in the uniform creep stage for most of the time.

Table 2: The deformation of specimen A-3-2 under different levels of confining pressure of 5 MPa.

Load grade (MPa)	Longitudinal initial strain	Longitudinal end strain	Amount of deformation (mm)
5	0	0.023	2.3
10	0.044	0.048	0.4
15	0.064	0.071	0.7
20	0.08	0.11	3
25	0.13	0.22	9

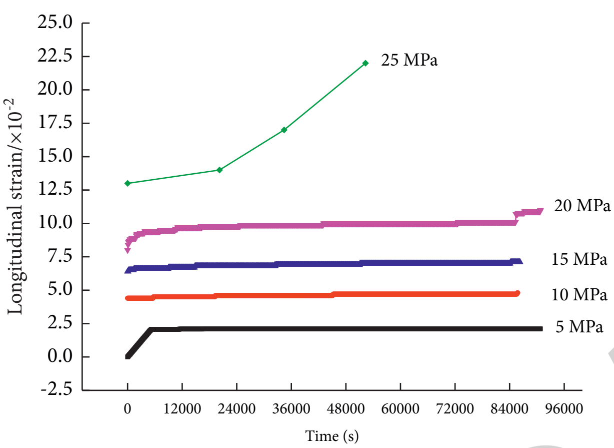

Figure 10: Rheological curves of coal and rock specimens under different loading levels under confining pressure of 5 MPa (specimen A-3-2).

Under the axial compression of 5 MPa, the coal rock has entered the uniform creep stage from the initial creep stage. Under the axial compression of 10 MPa and 15 MPa, the coal rock is in the early and middle stage of uniform creep stage, the deformation of the specimen is not obvious, and the total deformation is only 1.1 mm. When the axial pressure is loaded to 20 MPa, it is temporarily called that the coal rock is in the late stage of uniform creep. The deformation of coal rock during this period is more obvious than that of the early and middle stages of uniform creep. The deformation is 3 mm. The rheological curve has a tendency to rise with time, but the deformation rate is still relatively flat. When the axial pressure was loaded to 25 MPa, the coal rock entered the accelerated creep stage. During this period, the deformation rate of the specimen increased, and the specimen was quickly destroyed. The rheological curve was significantly increased, and the deformation reached 9 mm during this period, which was significantly greater than that in the later stage of uniform creep.

From the above analysis, it can be concluded that the deformation of coal rock specimens in the late stage of uniform creep has a significant upward trend, and the strain is significantly higher than that in the early and middle stages of uniform creep, but the total deformation remains unchanged. The deformation of coal rock in the accelerated creep stage is significantly higher than that in the later stage of uniform creep, and the deformation is significantly increased. In this regard, we can regard the deformation of coal and rock in the late stage of uniform creep as a strain threshold. When it is lower than this threshold, coal and rock will not undergo large deformation, and once it is higher than this threshold, coal and rock will undergo obvious deformation and damage quickly. The vicinity of this threshold is called the strength limit neighborhood of gas-bearing coal rock.

3.3. Experimental Results and Analysis of Rheological Disturbance Effect of Gas-Bearing Coal Rock under Impact Disturbance. Figure 11 shows the stress-strain curves of coal and rock containing gas under different confining pressures and the same impact disturbance (impact weight $M = 1$ kg, impact height $h = 10$ cm). It can be seen that, with the increase of stress, the strain growth gradually bends downward and then tends to be stable, and the three lines gradually change from dense to sparse, but the three curves do not have a large span in the whole process, which indicates that although the rheological state of coal and rock containing gas under the impact disturbance is affected by the confining pressure, the change of confining pressure does not have a great influence on the deformation of coal and rock. Figure 12 shows the rheological curve of gas-bearing coal rock at the late stage of uniform creep stage. It is obvious that the strain increases with time from the trend of the curve. The author believes that the coal rock specimen enters the strength limit neighborhood described in 2.2 in this period. Once the coal rock enters the strength limit neighborhood, it will soon enter the accelerated creep stage and change greatly until the specimen is destroyed. The deformation difference of the three curves is about 1 mm, indicating that confining pressure has an impact on the rheology of gas-bearing coal rock, but the impact is not large.

Figure 13 is the stress-strain curves of gas-bearing coal and rock obtained by different impact disturbance under confining pressure of 5 MPa. It can be seen that the three curves also gradually move from dense to sparse, but compared with the rheological curves of gas-bearing coal and rock under the same confining pressure, the span of the three curves is larger. When the same deformation occurs, the greater the impact disturbance, the smaller the required stress. At the same stress level, the greater the impact disturbance, the greater the deformation. This shows that the impact disturbance has a great influence on the rheology of coal and rock containing gas, and the greater the disturbance amplitude is, the greater the influence on the rheology of coal and rock containing gas is. The rheological curves of gas-bearing coal and rock in the early and late stage of uniform creep stage are given in Figures 14 and 15, respectively. It can be found that, under axial compression of 10 MPa, the deformation trend of the three curves in the early stage of uniform creep stage is basically synchronous. Under the action of impact disturbance, the strain of the three curves increases, but the strain rate decreases gradually. At this time, the coal rock has not entered the neighborhood of strength limit, and the impact disturbance has little effect on the deformation of coal and rock. However, when the axial pressure is 25 MPa, the coal rock enters the

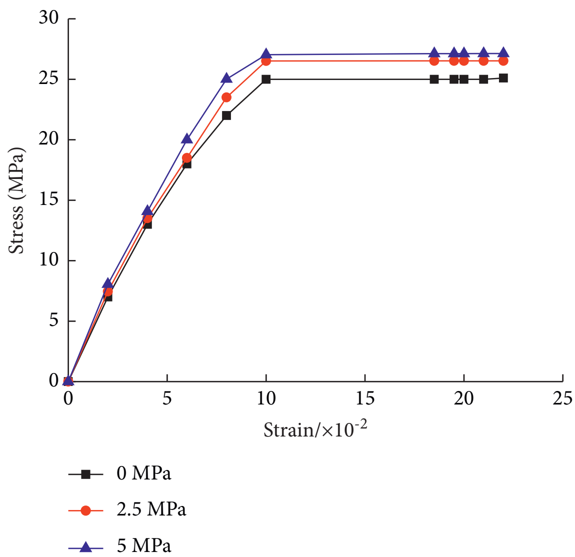

Figure 11: Stress-strain curve of coal rock containing gas under different confining pressure and the same impact disturbance.

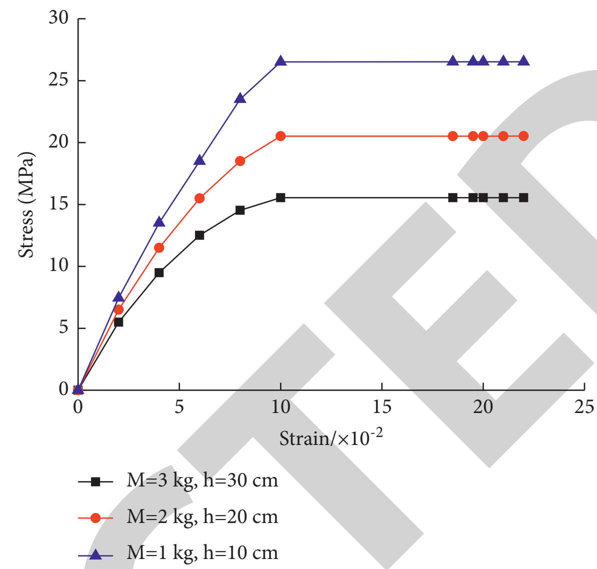

Figure 13: Stress-strain curve of coal rock containing gas under the same confining pressure (5 MPa) and different impact disturbance.

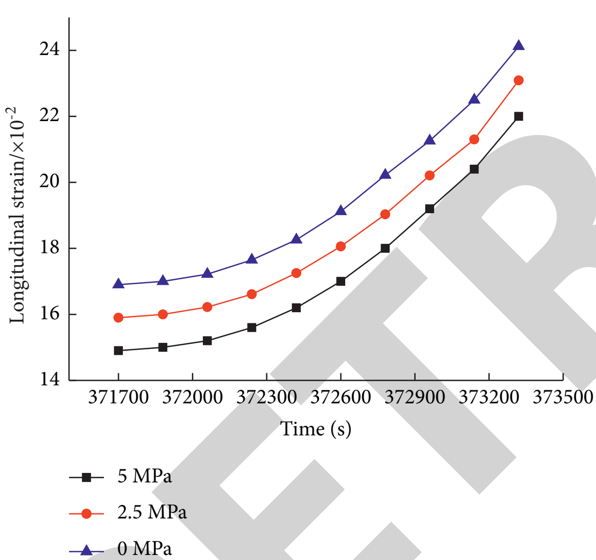

Figure 12: Rheological curves of gas-bearing coal rock under different confining pressures and the same impact disturbance under axial pressure of 25 MPa (after entering the neighborhood of strength limit).

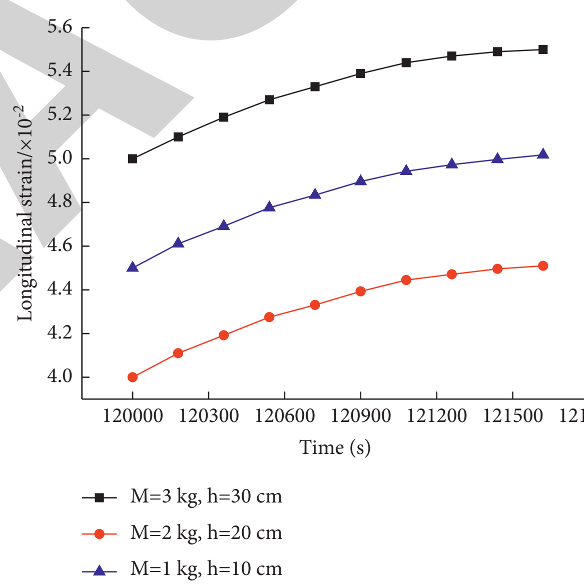

Figure 14: Rheological curves of gas-bearing coal and rock under the same confining pressure and different impact disturbance under axial compression of 10 MPa (without entering the neighborhood of strength limit).

late stage of uniform creep stage and enters the neighborhood of the strength limit. The two coal rock specimens subjected to large impact disturbance have entered the neighborhood of the strength limit in advance and have been damaged, and the strain reaches the maximum and remains near the deformation of the damage. Therefore, there are two flat linear characteristics on the curve. The coal rock specimens subjected to small impact disturbance are in the neighborhood of the strength limit, and the strain has been accelerating, showing a concave feature on the curve. In addition, the deformation gap of the three coal rock specimens is about 0.4 mm under the axial compression of 10 MPa, and the deformation gap of the coal rock specimens is about 8 mm under the axial compression of 25 MPa. It can be seen that the impact disturbance on the coal rock containing gas in the strength limit neighborhood is far greater than the influence outside the strength limit neighborhood.

For the above experimental results, the author believes that, at the initial stage of loading, under the combined action of external load and gas, the internal gas and coal rock are in a stable solid-gas equilibrium state. Due to the adsorption and free state of gas in coal rock, the gas in the free state generates pore pressure on the surface of coal rock fracture. At this time, the effective stress in coal rock is small. When the external impact disturbance is applied, the coal

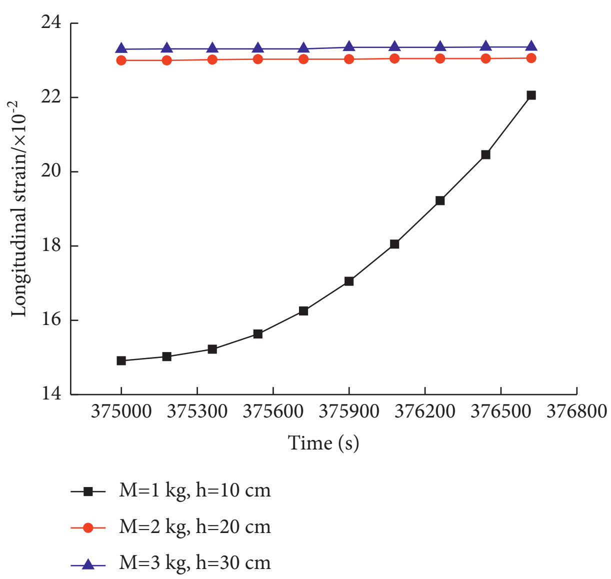

Figure 15: Rheological curves of gas-bearing coal rock under different confining pressures and the same impact disturbance under axial pressure of 25 MPa (after entering the neighborhood of strength limit).

rock skeleton, gas adsorption force, and pore pressure jointly resist the external impact load, and the resistance is strong. Therefore, the deformation of coal rock does not change greatly. At this time, the coal rock has not entered the strength limit neighborhood described in 2.2. When loading to 25 MPa, the effective stress inside the coal rock increases, and the pore pressure no longer resists deformation but accelerates the crack propagation inside the coal rock. At the same time, due to the increase of external load, the pores inside the coal rock are gradually compressed, and the adsorbed gas is gradually reduced. At this time, only the coal rock skeleton and a small part of the adsorbed gas resist deformation, and the coal rock skeleton, the adsorbed gas, and the free gas are in a very unstable fragile equilibrium state. When the impact disturbance is applied to it, the impact disturbance will accelerate the expansion of the internal cracks in the coal rock and produce a large number of new cracks in a short time. At the same time, the unstable fragile equilibrium state is broken instantly. The coal rock specimen reaches the yield limit in a short time and is destroyed. At this time, the coal rock specimen has entered the strength limit neighborhood described in 2.2. At the same time, it can be seen from the experimental results obtained in Figure 15 that the larger the external impact disturbance is, the faster the propagation speed of internal cracks in coal rock will be, and the time required for failure time will be reduced.

4. Conclusion

Under three different confining pressures of 0 MPa, 2.5 MPa, and 5 MPa, the longitudinal deformation of gas-bearing coal rock is 32 mm, 27 mm, and 22 mm, respectively, which indicates that the deformation of gas-bearing coal rock decreases with the increase of confining pressure under the same other conditions.

The step-by-step loading tests of gas-bearing coal and rock under different load levels are carried out. It is found that the deformation of gas-bearing coal and rock in the late stage of uniform creep is significantly larger than that in the early and middle stages of uniform creep, but it is also significantly smaller than that in the accelerated creep stage. The deformation of coal rock in the later stage of uniform creep is regarded as a strain threshold, which is called the strength limit neighborhood of coal rock containing gas.

The impact disturbance is carried out on the gas-containing coal rock in and out of the neighborhood of the intensity limit, and it is found that there is a large difference in the deformation of the gas-containing coal rock in and out of the intensity limit, indicating that when the gas-containing coal rock enters the neighborhood of the intensity limit, the external impact disturbance accelerates the rheological process of the gas-containing coal rock. And for the coal rock in the neighborhood of the strength limit, the greater the amplitude of the impact disturbance, the shorter the time required to destroy.

Data Availability

The data used to support the findings of the study are available within the article.

Disclosure

A preprint has previously been published [25].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] S. Zhou and X. He, “Rheological hypothesis of coal and gas outburst mechanism,” *Journal of China University of Mining & Technology*, vol. 19, no. 02, pp. 4–11, 1990.

[2] X. He, *Rheological Dynamics of Coal and Rock Containing Gas*, China University of mining and Technology Press, Xuzhou, China, 1995.

[3] Y. Gao, Q. Fan, X. Cui, and Z. Fu, *Experimental Study on Rock the Perturbation Effect of Rock Rheology*, Beijing Science Press, Beijing, China, 2007.

[4] Y. Gao, X. Huaqiang, B. Wang, and Y. Zhang, “Rheological test of sandstone with perturbation effect and its constitutive relationship study,” *Chinese Journal of Rock Mechanics and Engineering*, vol. 27, no. 1, pp. 3180–3185, 2008.

[5] C. Xihai and F. Zhiliang, “Experimental study on rheology properties and long-term strength of rocks,” *Chinese Journal of rock Me-chanics and Engineering*, vol. 25, no. 5, pp. 1021–1024, 2006.

[6] F. Qingzhong and G. Yanfa, “Experimental study on creep properties of rocks under stepwise loading,” *Chinese Journal of Geotechnical Engineering*, vol. 27, no. 11, pp. 1273–1276, 2005.

[7] B. Wang, Y. Gao, and J. Wang, “Evolution law analysis on surrounding rock stress field by rheology disturbed effects,” *Journal of China Coal Society*, vol. 35, no. 9, pp. 1446–1450, 2010.

[8] L. Wu and J. Wang, “Preliminary study on rheological properties and microscopic influence of coal and rock,” *Journal of rock mechanics and engineering*, vol. 15, no. 04, pp. 25–29, 1996.

[9] J. Wang, T. Shao, and H. Zhao, “Experimental study on influence of gas on mechanical properties of coal outburst,” *Journal of mining and safety engineering*, vol. 28, no. 03, pp. 391–394+400, 2011.

[10] X. Li, L. Zhang, Z. Li, and Y. Jiang, “Creep law and model of coal and rock under triaxial loading under different gas pressure,” *Journal of Coal Studies*, vol. 43, no. 02, pp. 473–482, 2018.

[11] C. Jiang, G. Yin, and Q. Huang, “Unloading confining pressure deformation characteristics of gas-bearing coal and gas seepage test,” *Journal of Coal Industry*, vol. 36, no. 05, pp. 802–807, 2011.

[12] Z. Lu and S. Li, “Experimental study on permeability strain characteristics of gas bearing coal,” *Coal mine safety*, vol. 51, no. 06, pp. 1–4, 2020.

[13] K. Wan, Q. Hu, and G. Huang, “Experimental study on seepage and acoustic emission characteristics of gas-bearing coal under different stress paths,” *Journal of rock mechanics and engineering*, vol. 32, no. 07, pp. 1315–1320, 2013.

[14] Z. Li, X. Xian, and Q. long, “Experimental study on coal permeability under different temperature stress conditions,” *Journal of China University of Mining & Technology*, vol. 38, no. 04, pp. 523–527, 2009.

[15] C. Jiang, M. Duan, and G. Yin, “Experimental study on loading and unloading of gassy raw coal under different water-cut conditions,” *Journal of Coal Studies*, vol. 41, no. 09, pp. 2230–2237, 2016.

[16] Z. Zhang, D. Zhao, and C. Yi, “Isothermal adsorption characteristics and swelling deformation characteristics of soft coal under different moisture content conditions [J/OL],” *Acta coal Sinica*, vol. 45, pp. 1–8, 2020.

[17] D. Changang, S. Lulu, and G. Yangyang, “Experimental study on the coal damage characteristics of adsorption, instantaneous pressure relief in coal containing gases with different adsorption characteristics,” *Applied Sciences*, vol. 9, no. 23, 2019.

[18] B. Zhao, Z. Wang, and J. Wu, “Creep and failure characteristics of coal and rock under different stress levels,” *Proceedings of the China University of Petroleum: Natural Science*, vol. 37, no. 4, pp. 140–144, 2013.

[19] X. Xian, X. Li, and D. Jiang, “Study on time prediction of creep instability of exposed surface of gas seam,” *Geomechanics*, vol. 26, no. 06, pp. 841–844, 2005.

[20] S. Cao and X. Xian, “Rheological mechanical analysis of solid-gas coupling in coal,” *Journal of China University of Mining & Technology*, vol. 30, no. 04, pp. 42–45, 2001.

[21] F. He, L. Wang, and N. Zhao, “Criteria and application of creep fracture of coal,” *Journal of coal*, vol. 36, no. 1, pp. 39–42, 2011.

[22] B. Zhang, Y. Yang, X. Gao, Q. Wu, and Q. Zhang, “Experimental study on stress-strain characteristics of coal containing gas hydrate under unloading confining pressure [J/OL],” *Acta coal Sinica*, vol. 1, pp. 11–14, 2020.

[23] G. Xu, H. Meng, and H. Jin, “Study on fluid-solid coupling mathematical models and numerical simulation of coal containing gas,” vol. 113, no. 1, 2018.

[24] K. Liu, “Study on mechanical properties of gas-bearing raw coal under high-stress triaxial compression,” *Journal of rock mechanics and engineering*, vol. 36, no. 02, pp. 380–393, 2017.

[25] B. Wang, Z. Huang, S. Hu et al., “Experimental Study on Rheological Disturbance Effect of Gas-Bearing Coal Rock,” *PREPRINT (Version 1) available at Research Square*, 2021.