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Application of Field Emission Scanning Electron Microscopy in Liquid CO_2 Gas Fracturing Technology

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Abstract

In the process of coal mining, gas disaster is an important problem that restricts the safe and efficient production of coal mine. Gas extraction is an effective way to control gas disaster, but the efficiency of gas extraction can not reach the expected effect due to the complicated geological conditions and low permeability of coal seam in China. Gas fracturing with Liquid CO_2 is a new and efficient gas treatment technology, but there are few theoretical and laboratory studies on the physical process of gas fracturing, lack of understanding on the micro-characteristics of coal sample destruction and the mechanism of increasing permeability and preventing outburst. This weak theory limits the further development and safe application of CO_2 gas phase fracturing technology. Faced with this research situation, the team designed and developed a coal-rock fracturing device using liquid CO_2 gas phase fracturing, and applied the coal samples from Pingmei No. 8 mine in Pingdingshan, Henan province, fourteen coal samples were tested under three high pressure conditions of 120 MPa, 150 MPa and 185 MPa. With the aid of field emission Scanning electron microscope experiment, the corresponding micro-morphology, fracture observation and analysis were completed, in this paper, the microscopic characteristics of coal and rock failure caused by CO_2 gas phase fracturing are systematically studied, and the main research results are as follows. A large number of “Erosion damage pits” and radial “Three wings” branching fissures were found on the surface of coal matrix by field emission scanning electron microscopy, this is the result of alternating stress wave produced by multiphase CO_2 jet impinging on coal and rock.

Keywords

CO_2 Gas-phase fracturing; Crack mechanism; Field-emission SEM.

1. OVERVIEW

1.1. Research Background and Significance

Coal is the long-term main energy source for national development, and the energy structure dominated by coal is difficult to change in the short term[1]. In the process of coal mining, gas disasters are an important issue that restricts the safe and efficient production of mines, and with the increase of mining intensity and depth, the harmfulness of gas becomes increasingly severe [2]. Gas extraction is an effective way to control gas disasters [3], but given the complex geological conditions and low permeability of coal seams in China, the efficiency of gas extraction has not yet reached the expected results. In China, over 40% of mines are high gas mines or coal and gas outburst mines, and over 95% of high gas and outburst coal seams belong to low-permeability coal seams. The deeper the mining depth, the higher the coal seam gas

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content, gas pressure, and geostress, and the greater the threat of gas dynamic disasters. More gas mines are transforming into high gas mines, and high gas mines are transforming into outburst mines, making gas control more difficult.

Improving coal seam permeability includes intensive drilling, hydraulic fracturing, hydraulic slotting, hydraulic punching, hydraulic drilling, mechanical drilling, controlled pre fracturing blasting, CO_2 gas phase fracturing, etc. These methods form cracks or holes in the coal body through physical means to relieve pressure in local areas, or damage the coal body through blasting to form large-scale cracks for pressure relief, improving the permeability of the coal seam and achieving efficient gas extraction. These methods have been applied in coal mines across the country and have achieved good results, but they also have certain limitations. Liquid CO_2 gas phase fracturing has the technical characteristics of low frequency, low speed, and long duration, which can form a fracture pressure relief ring in coal seams, causing a certain range of coal body pressure relief, balancing the regional stress field and gas pressure field, improving coal seam permeability, achieving efficient gas extraction, and effectively reducing the risk of coal and gas outbursts.

Henan University of Technology has carried out a large number of on-site industrial applications of CO_2 gas phase fracturing gas treatment in high gas outburst mines. The main application areas include CO_2 gas phase fracturing enhanced permeability extraction tests in the mining face, CO_2 fracturing pressure relief and anti outburst rapid excavation experiments in the outburst coal seam excavation work, and pressure relief and anti outburst experiments in the through layer drilling, which have achieved good application results.

Study the characteristics and evolution laws of coal rock fractures through CO_2 gas-phase fracturing experiments on the micro **damage** characteristics of coal rock.

1.2. Current Research Status at Home and Abroad

1.2.1 Research Status of Field Emission Scanning Electron Microscopy Technology

Field emission scanning electron microscopy (FESEM) is a high-resolution, high magnification microscope based on scanning electron microscopy technology. The basic principle is to use the electron beam generated by the electron gun to scan the surface of the sample, excite various signals (such as secondary electrons, backscattered electrons, etc.), which are then received by the detector and converted into electrical signals, further amplified and displayed, forming an image of the sample. The sample preparation requirements for field emission scanning electron microscopy are high, as it is necessary to ensure that the electron beam can pass through the sample smoothly while generating effective signals on the sample. Samples usually undergo steps such as fixation, dehydration, drying, and coating to ensure sufficient conductivity and stability.

The image resolution of field emission scanning electron microscopy is generally between a few nanometers and several tens of nanometers, which mainly depends on the focusing effect of the electron beam and the performance of the detector. In 1931, German Luska and Noel invented the world's first electron microscope based on the principle that magnetic fields can converge electron beams, with a magnification of 1200 times [5]. In 1939, Siemens in Germany produced the first commercial transmission electron microscope with a resolution of 10nm. From the early 1950s to the late 1960s, the resolution of electron microscopy reached 1nm. In the 1960s and 1980s, the performance of electron microscopy had reached a perfect level, with rapid development in resolution and ultra-high voltage, with resolution increased to 0.1nm. At present, the resolution of the latest product has reached 0.07nm.

The detector is an important component of field emission scanning electron microscopy, and its performance directly affects the quality of the image. The commonly used detectors currently include secondary electron detectors, backscattered electron detectors, etc. Field

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emission electron source is one of the core components of field emission scanning electron microscopy, and its performance directly affects the quality and stability of the electron beam. The commonly used field emission electron sources currently include cold field emission and hot field emission, each with its own advantages and disadvantages. Signal processing and image presentation are important steps in field emission scanning electron microscopy, which aims to convert the signals received by the detector into high-quality images. The commonly used signal processing and image presentation techniques currently include digital signal processing, digital filtering, digital image processing, etc. Field emission scanning electron microscopy has a wide range of applications in various fields, such as materials science, biology, medicine, environmental science, etc. In the field of biology, field emission scanning electron microscopy can be used to observe the structure of cell surfaces, which helps to gain a deeper understanding of cell functions and behaviors; In the field of medicine, field emission scanning electron microscopy can be used to observe the structure and morphology of human tissues, which is helpful for the diagnosis and treatment of diseases; In the field of environmental science, field emission scanning electron microscopy can be used to observe the structure and morphology of environmental pollutants, which is helpful for pollution control and treatment.

1.2.2 Research Status of Liquid CO_2 Gas Phase Fracturing Technology

Liquid CO_2 gas phase fracturing is an efficient new technology and process for gas treatment. Liquid CO_2 gas phase fracturing technology is a technique that utilizes the expansion energy generated by the rapid gasification of liquid CO_2 under high pressure to fracture formations. The impact and mechanism of liquid CO_2 gas phase fracturing technology on the formation are manifested in several aspects. Changing the stress state of the formation: The expansion energy generated by the rapid gasification of liquid CO_2 under high pressure can alter the stress state of the formation, forming a wider network of fractures. The impact on the physical properties of rocks: After injecting liquid CO_2 into the formation, it can affect the physical properties of rocks, such as changing their hardness and brittleness. The impact on formation fluids: Injecting liquid CO_2 into the formation can reduce the viscosity of the formation fluid and improve its fluidity.

The liquid CO_2 phase change fracturing technology was developed by American engineer D. Ferrell in 1914. In 1919, this technology was applied to coal mining and became a safe mining technique for high gas coal mines in the 1930s and 1950s. It was widely used in the United States, United Kingdom, and Canada. In 1990, CO_2 blasting technology was introduced into China's coal industry. In 2010, CO_2 blasting began to be applied in coal mine gas control, named CO_2 phase change fracturing technology; Since 2015, it has been applied in non coal mines in China and has achieved good results. Academician Wang Xuguang has shown great concern and support for the development of this technology.

Cao Yunxing (Academician of the Canadian Academy of Engineering) and his team from Henan University of Technology conducted CO_2 gas phase fracturing and gas extraction technology experiments on excavation and mining faces. They believe that this technology can form a complex fracture network in coal seams, improve gas extraction efficiency, homogenize gas pressure, and ultimately achieve the technical goal of rapid excavation/mining in coal mines [7-10].

Zhou Jianbin et al. found through the analysis of extraction parameters before and after CO_2 gas phase fracturing in Xinyuan Coal Mine that the permeability coefficient of the coal seam was 0.014 $m^2/(MPa^2\cdot d)$ before fracturing, which was difficult to extract. However, after the gas phase fracturing test, the permeability coefficient of the coal body became 0.763 $m^2/(MPa^2\cdot d)$, which increased by 54 times and became a extractable coal seam [11].

Chen Haidong et al. analyzed the mechanism of CO_2 gas phase fracturing, established a model for numerical simulation, and conducted CO_2 gas phase fracturing gas extraction experiments

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in the 15th coal seam of Tian'an Coal Mine. After implementation, the maximum impact range was 32.08 m, which was consistent with the numerical simulation results. The pure flow rate of gas extraction around the borehole is increased by 1.64 times, and the optimal hole layout scheme is a spacing of 4.5 m between adjacent fracturing holes [12].

On the basis of analyzing the phase changes in the supercritical CO_2 fracturing process, Yan Hao et al. established a numerical model for CO_2 gas phase fracturing, conducted numerical simulations, and analyzed the mechanism of supercritical CO_2 fracturing in stages. They obtained the roles of the supercritical stage and the induced fracturing stage in the entire supercritical CO_2 fracturing process. The energy of CO_2 gas phase fracturing was calculated to be 4250 kJ/kg, and the amount of CO_2 used has a positive effect on the fracturing effect. The larger the amount used, the longer and wider the crack propagation [13,14].

Bai Junjie [15] conducted experiments on CO_2 phase transition induced fracturing of coal and rock in the laboratory. Step sequence: Fix the collected raw coal sample on the jet valve with fiber tape, then place the fracturing device in a protective steel pipe, and finally perform blasting impact. Conduct isothermal adsorption and mercury injection experiments on the impacted coal sample. The methane isothermal adsorption experiment found that under the same pressure conditions, the adsorption capacity of the fractured coal sample was greater than that of the original coal sample, indicating that the pore surface area, micropore surface area, and micropore volume of the fractured coal sample were greater than those of the original coal sample, indicating that CO_2 phase change induced cracking has an impact on the micropore structure of coal. The mercury intrusion test showed that after fracturing, the total pore volume and total specific surface area of coal showed a decreasing trend, while the average pore size showed an increasing trend. This indicates that new pores are generated in the coal structure after fracturing, and small pores are transformed into large pores, resulting in improved connectivity compared to the original coal. The desorption index K_1 of drill cuttings is positively correlated with gas pressure, and the K_1 value after fracturing shows no significant change compared to the original coal body; The initial velocity$\triangle P$ of gas release decreases with the increase of coal sample particle size. When the coal sample particle size is less than 0.25mm, there is no significant change before and after fracturing; When the particle size of the coal sample is greater than 1mm, the$\triangle P$ of the fractured coal sample is greater than that of the original coal sample.

2. FIELD EMISSION SCANNING ELECTRON MICROSCOPY COAL SAMPLE OBSERVATION EXPERIMENT

2.1. Experimental Equipment

2.1.1 Experimental setup

CO_2 phase change fracturing coal rock experimental device and testing instruments: CO_2 gas phase fracturing device, safety experimental chamber, simulated coal seam drilling coal rock fracturing device, coal sample cutting equipment, industrial CT, field emission scanning electron microscope (FESEM) and other experimental instruments.

2.1.2 Field emission scanning electron microscope (FESEM) experimental instrument

The experiment used the Merlin Compact high-performance field emission scanning electron microscope from Carl Zeiss in Germany, as shown in Figure 2-1.

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Figure 2-1. Merlin Compact High Performance Field Emission Scanning Electron Microscope

2.1.3 CO_2 gas phase fracturing device

The CO2 gas phase fracturing device consists of core components such as jet valve, shear plate, liquid storage pipe, liquid CO2, heater, and inflation valve, as shown in Figure 2-2. Using a booster pump to inject liquid CO_2 into the storage pipe, the heater is powered on and quickly burns to release a large amount of heat. The liquid CO_2 in the storage pipe absorbs heat and undergoes a supercritical phase change, causing the pressure to rise sharply to the limit pressure. The shear plate ruptures to form a high-pressure jet, which acts on the medium through the spray valve.

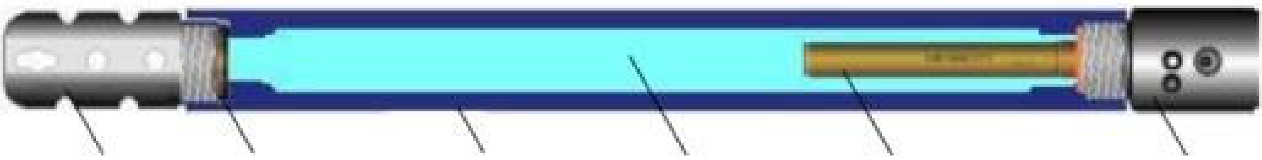

Figure 2-2. Structural diagram of liquid CO_2 gas phase fracturing device

2.1.4 Safety laboratory

The safety laboratory is 3.6m long, 1.8m wide, and 1.8m high, equipped with two explosion-proof doors, adjustable fixed brackets, sensor mounting seats, pressure testing systems, lighting fixtures, etc. Laying anti-static belts on the inner wall of the warehouse to prevent the impact of vibration caused by blasting on the test results; Adjustable fixed bracket is used to fix CO_2 fracturing device and simulate coal seam drilling coal rock fracturing device.

The main functions are as follows:

(1) Fixed CO_2 fracturing device, simulated coal seam drilling temperature and pressure testing device, simulated coal seam drilling coal rock fracturing device, to prevent vibration during fracturing, which may affect test results or even damage the testing device;

(2) The CO_2 cracking device is greatly affected by external temperature, especially in high temperature weather in summer. The indoor experimental chamber is not limited by external temperature conditions, which is conducive to the consistency of experimental results;

(3) Easy to install temperature and pressure sensors, as well as explosive impact testers, to prevent damage to the testing instruments during the testing process;

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(4) The maximum explosion pressure of the CO_2 fracturing device is 185MPa, and the sound and vibration generated by the explosion are large, while also having a large reaction force. The entire experiment is conducted inside a safety chamber to ensure the safety of the experiment.

2.2. Experimental Plan for Coal Rock Failure Characteristics

2.2.1 Experimental method for microscopic characteristics of coal rock failure

The experiment prepared the original coal sample and the coal sample after impact according to the experimental standards, and studied the micro pore and fracture failure characteristics of coal rock using scanning electron microscopy as the main characterization method.

2.2.2 Main parameters of coal rock fracturing experimental device

The main parameters are as follows: (1) Simulated drilling parameters: outer diameter 140mm, wall thickness 20mm, inner diameter 100mm, length 2000mm; (2) Coal sample box: inner diameter 50mm, inner height 70-100mm; (3) Coal pillar size: diameter 50mm, height 70mm; (4) CO_2 fracturing device: C74.

2.2.3 Experimental Plan

Based on the on-site application parameters of CO_2 phase change induced fracturing gas treatment, a CO_2 phase change induced fracturing coal rock experimental plan was developed, as shown in Table 2-1. Process the original coal sample into coal pillars with a diameter of 50mm and a height of 70mm using wire cutting for CO_2 phase change induced cracking impact experiments. At the same time, prepare the remaining cut coal samples according to experimental standards to study the pore and fracture structure characteristics and evolution laws of coal.

Table 2-1. Experimental Plan for Liquid CO2 Gas Phase Fracturing of Coal and Rock

experiment Numbe	Model	Length(m)	Heater Model	filling quantity (Kg)	Experimental temperature (℃)	Pressure (MPa)	Coal sample quantity (pieces)	Impact position
01	C74	1.8	D220	2.2	＜31	120	4	Bottom hole
02	C74	1.8	D220	2.2	＜31	150	4	Bottom hole
03	C74	1.8	D220	2.2	＜31	185	4	Bottom hole

Raw coal sample experimental parameter testing: (1) Industrial analysis: 2 groups x 1 time; (2) Elemental analysis: 2 sets x 1 time; (3) Reflectivity: 2 sets x 1 time; (4) Scanning electron microscopy: 3 sets x 8 times; (5) Industrial CT: 2 sets x 1 time.

Place a 50mm × 70mm coal pillar in a simulated coal seam drilling and fracturing device for impact testing. Prepare the impacted coal sample according to the experimental standards and conduct the following experiments:

1) Scanning electron microscopy: 3 sets x 8 times; 2) Industrial CT: 2 sets x 1 time.

By comparing and analyzing the micro pore and fracture characteristics of the original coal sample and the coal sample after impact, the micro characteristics of CO_2 phase change induced coal rock failure are studied. The main experimental steps are as follows: (1) Assembly: Assemble the inflation valve, heater, liquid storage pipe, jet valve, sealing gasket, and shear plate according to the operating specifications; (2) Fill with liquid CO_2; (3) Install simulated coal seam drilling and fix the simulated drilling on the support in the experimental chamber; (4) Installation of CO_2 fracturing device: Push the CO_2 fracturing device into the simulated borehole, adjust the angle of the jet valve, align with the four coal sample impact holes on the hole wall, fix the CO_2 fracturing device to prevent displacement during the experimental process; (5)

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Installation of coal sample box: First, put the cut coal samples into the coal sample box in order, tighten the cover of the coal sample box, and then install the coal sample box on the simulated coal seam drilling hole wall; (6) Closed simulated drilling: Install flanges at both ends of the simulated drilling and seal the simulated drilling; (7) Power on the heater: Close the cabin door, connect the wires, power on the heater, and wait for 30 minutes;(8) Take coal samples: turn on the fan, exhaust the safety compartment, open the cabin door, dismantle the coal sample box, and take out the coal sample; (9) Dismantling experimental setup: Open the flange and remove the CO_2 fracturing device.

3. EXPERIMENTAL SAMPLES

3.1. Collection and preparation of raw coal samples

The experimental coal samples were collected from the Wu Formation coal seam of the Eighth Mine in Pingdingshan mining area, with sampling points located in the ventilation roadway of the Wu 9.10-12160 working face. The coal structure is primary structural coal. The thickness of the coal seam is 3.12-5.20m, with an average of 4.05m. The coal quality parameters of the coal seam are shown in Table 3-1. The volatile matter of coal ranges from 7.32% to 9.29%, with an average of 8.18%; Ash content ranges from 11.02% to 17.44%, with an average of 14.03%; Moisture content ranges from 0.80% to 4.19%, with an average of 2.56%; The vitrinite reflectance of coal ranges from 2.94% to 3.69%, with an average of 3.83%; The strength coefficient f of coal varies between 0.3 and 0.7.

Table 3-1. Coal Quality Parameters of the Wu Formation Coal Seam in Pingmei No.8 Mine

project	Reflectance Ro, max/(%)	moisture content, Mad/(%)	ash content Ad/(%)	volatile matter Vdaf/(%)	apparent density VDad(t·m-3)
Parameters	2.94～3.69	0.80～4.19	11.02～17.44	7.32～9.29	1.39～1.57
	3.83	2.56	14.03	8.18	1.49

Take the original coal sample as shown in Figure 3-1 and use a wire cutting instrument to make 14 cylindrical samples with a diameter of 50 mm × 70 mm. Two samples were used for CT scanning, and 12 samples were used for CO_2 phase transition impact experiments. Some coal pillar samples are shown in Figure 3-2. After wrapping the cylindrical sample with a thermoplastic tube, two samples were grouped together for a total of six groups, as shown in Figure 3-2. The impact pressures were 120MPa, 150MPa, and 185MPa, and two parallel tests were conducted for each impact pressure, using two coal samples for each test.

Figure 3-1. Original Coal Sample

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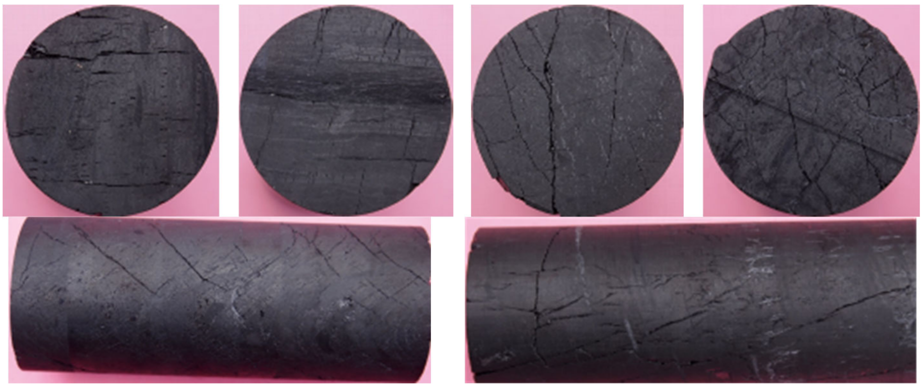
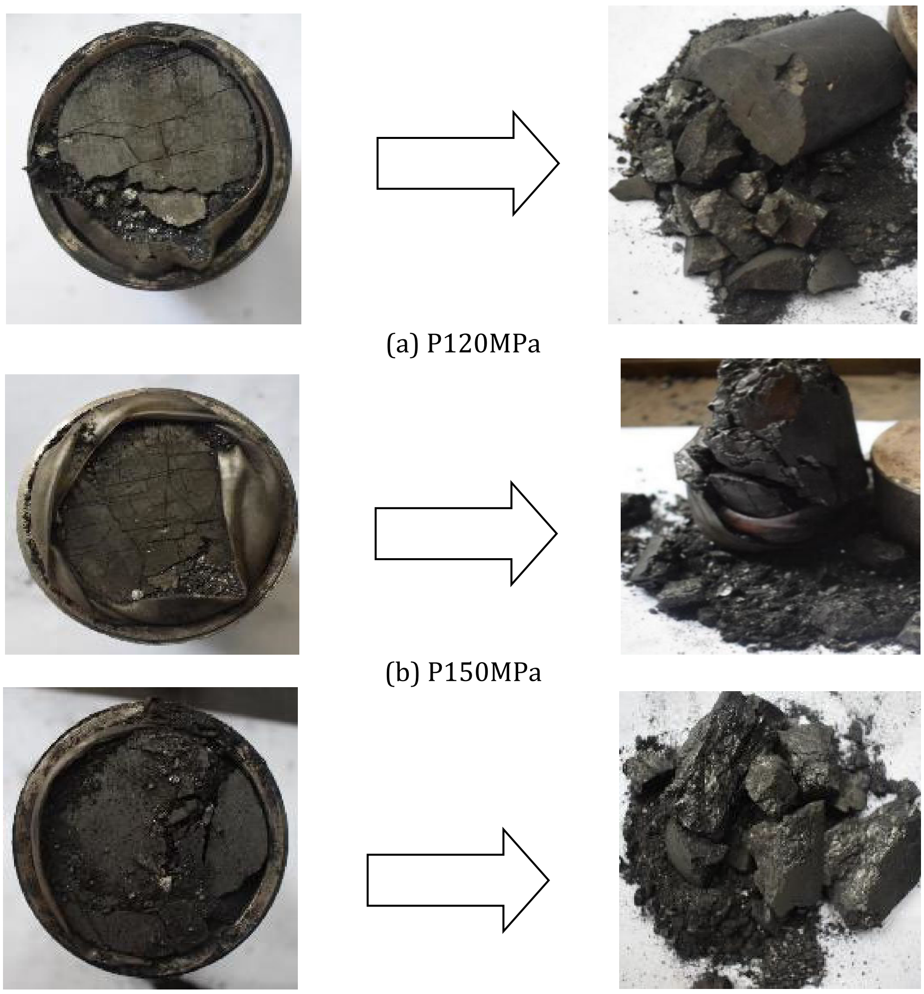


Figure 3-2. A cylindrical specimen with a diameter of 50 × 70mm from the Ba Mine coal mine

3.2. Sample collection after impact experiment of CO2 fracturing experimental device

The simulated coal seam drilling CO_2 phase change fracturing experimental device was used to conduct impact experiments on the original coal sample under three pressures of 120 MPa, 150 MPa, and 185 MPa. The failure mode of the coal sample after impact is shown in Figure 3-3. Prepare the coal sample after impact according to experimental standards, and quantitatively characterize the morphology distribution and development rules of pores and fractures through industrial CT, field emission scanning electron microscopy (FESEM).



(c) P185MPa

Figure 3-3. Coal samples under different CO_2 phase impact pressures

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4. FIELD EMISSION SCANNING ELECTRON MICROSCOPY (FESEM) EXPERIMENTS

The experiment was completed in the State Key Laboratory of Henan University of Technology, using Merlin Compact high-performance field emission scanning electron microscope produced by Carl Zeiss of Germany. Acceleration voltage: 0.02-30 KV, magnification: 120000-400000 times, focusing working distance: 0.1-50 mm, resolution: 0.8 nm @ 15 KV, 1.6 nm @ 1 KV.

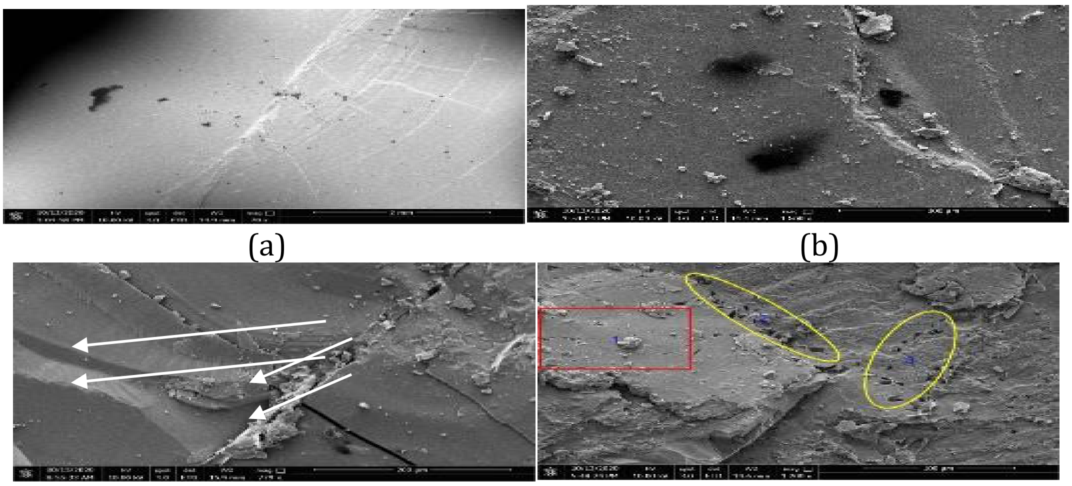
4.1. Sample preparation and experimental plan

Prepare the original coal sample and the impacted coal sample into 1cm × 1cm samples with a thickness of 2-4mm, and observe them using FESEM. In order to ensure the reliability and accuracy of experimental data, the morphological characteristics of pores and microcracks before and after CO2 phase change induced fracturing of coal and rock were comprehensively observed. Original coal samples, 9 sets of coal samples after impact pressures of 120MPa, 150MPa, and 185MPa were selected, totaling 36 sets of samples. Different magnifications were selected to observe the coal samples in sequence.

4.2. Fracture morphology characteristics of coal samples before and after impact

Based on the observation results of FESEM raw coal samples, qualitative and semi quantitative descriptions were made on the surface development, types of pores and microcracks, and connectivity of the coal matrix. Figure 4-1 shows typical features observed by FESEM at different magnifications. The surface of the coal matrix exhibits a flat, uniform, and smooth characteristic from the millimeter scale to the micrometer scale (Figure 4-2 (a), 4-2 (b)). Some arc-shaped lines intersecting with radial lines were also found near the left smooth surface of Figure 4-2 (a). After high magnification, it was found that the arc-shaped image showed a stepped structure composed of several uniformly smooth planar steps (Figure 4-2b).

As shown in Figure 4-2 (c), there is often a cleavage formed by two intersecting cracks, which exhibit a straight characteristic and belong to the shear type of crack. Different pores are often visible, with some individual pores dispersed on a uniform plane or as combinations of many different sizes and shapes, most of which are open and not filled with clay. As shown in Figure 4-2 (d), the pores in the yellow oval box area are densely clustered and develop in isolation from each other. Their shapes often exhibit circular, elliptical, and irregular features, and common pores and microcracks develop in isolation.



(c) (d)

Figure 4-1. Microcracks and Pores of Original Coal

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Compared with the original coal sample, the number and complexity of newly formed micro scale cracks inside the coal sample increased after CO_2 impact. Based on the observation of FESEM scanning results of coal samples after different pressure impacts in Figure 4-2, five new phenomena of newly formed pores and microcracks were discovered.

(1) Three wing "(TRW) crack mode. This fracture pattern is commonly observed in the observation results of coal samples after different pressure impacts, as shown in Figure 4-2. Most of the fractures in the damaged areas exhibit scattered development along the midpoint, as indicated by yellow circles in Figure 4-2 (A, B, E, F, G, H). In some areas, there are also four branching fractures. Ultimately, multiple sets of "three wing shaped" fractures communicate and interweave to form a micro fracture network (Figure 4-3E, F, G), providing a fast channel for gas seepage and significantly increasing the permeability of the coal seam.

(2) Damage Pit "(DM). The midpoint of the crack branch origin is an obvious damage and failure zone, which is an erosion pit, and there are some broken coal particles around the erosion pit (Figure 4-2 E, F, G, H). The size of erosion pits varies from tens of square micrometers (Figure 4-2 A, B) to hundreds of square micrometers (Figure 4-2 E), and is closely related to the opening of branch cracks. The larger the crack opening, the larger the erosion pit area.

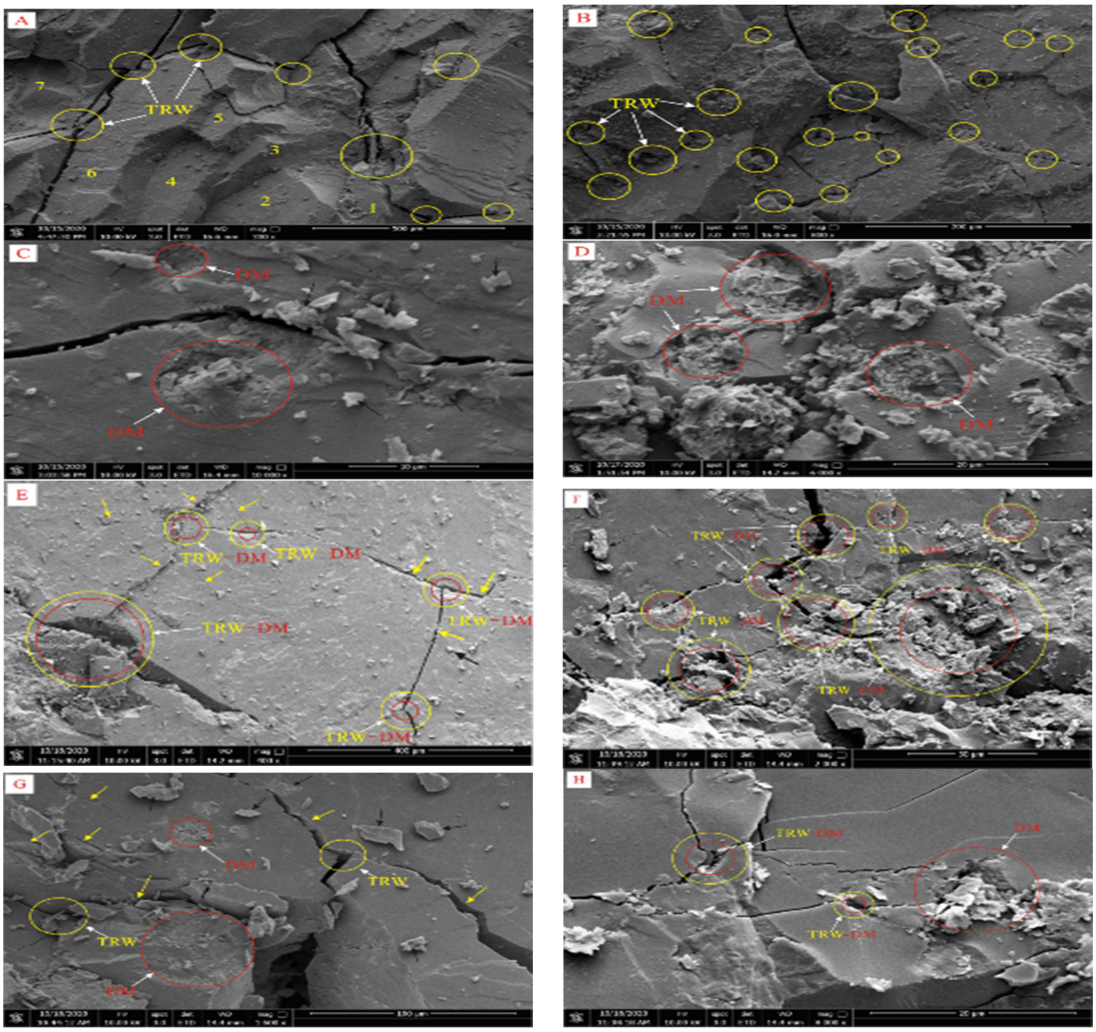

Figure 4-2. Micro cracks in Coal Samples Damaged by Impact

(3) Step fracture ": When CO_2 fluid collides with coal, it is a multiphase, high-pressure, high-speed jet beam. After impact, the surface of the coal sample was damaged and destroyed, forming multiple stepped fractures (Figure 4-2A).

(4) Coal matrix particles are broken. After CO_2 shock, no cleavage system commonly found in the original coal sample was observed (Figure 4-2A), indicating that the CO_2 jet has completely destroyed the original cleavage system, and both the "three wing" failure mode and erosion pit failure occurred on the coal matrix particles. The existence of newly formed network state fractures in coal matrix is a very important discovery, indicating that the CO_2 effect has achieved a high degree of coal destruction, providing a foundation for pressure relief and infiltration enhancement.

(5) Serrated fissures. As shown in Figure 4-2, on the one hand, the newly formed cracks are open without any filling. The distribution range of crack opening ranges from micrometer scale to millimeter scale, but most cracks have narrow openings and are distributed on the micrometer scale. On the other hand, the plane of newly generated cracks develops in a zigzag pattern, only showing a straight line within a short distance from the crack development end.

5. CONCLUSION

By simulating the CO_2 phase change induced fracturing of coal rock in coal seam drilling, pressure impact experiments were conducted on the original coal pillar at 120MPa, 150MPa, and 185MPa. Through FESEM and CT experiments, the evolution patterns of fractures at different scales in the original coal sample and the coal sample after impact were studied, and the following conclusions were drawn:

(1) The original coal sample has few cracks, small opening, poor connectivity, discontinuous development, isolated crack development, and almost no communication between cracks and pores. The CT fracture fractal dimension is between 1.0 and 1.2, and the overall fracture volume fraction is less than 0.10%.

(2) After impact, new cracks within the coal sample were generated, including small-scale μm cracks and large-scale cracks. The proportion of small-scale cracks between 75μm and 3000μm was greater than 35%, while the proportion of large-scale cracks was greater than 98%. The large-scale fracture distribution diameter of the coal sample after 185MPa impact ranges from 28000μm to 29000μm, and the fracture diameter after 120MPa impact ranges from 17600μm to 18100μm. At the same time, the proportion of large-scale coal samples after 185MPa impact is 99.2%, which is greater than 99.05% of 120MPa.

(3) FESEM experiments have shown that the impact of CO_2 causes the original cleavage and fracture system of coal samples to be destroyed, and the coal matrix is broken into a μm level multi branched "three wing" fracture network. The "three wing" fractures all develop radially in a scattered manner around the "damage pit", that is, the damage and failure zone, and the micro fracture development shows an open sawtooth shaped tortuous development characteristic.

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