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Significance of Rock Mineral Composition on Rock Mechanical Properties and Brittleness Evaluation of Roof and Floor of Broken Soft Coal Seam

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Abstract Fracture of coal structure and low permeability were the main reasons for the “difficult to released gas” in broken soft coal seam. Exploration of horizontal well coalbed gas technology of roof and floor of broken soft coal seam provided a new technical way for coalbed gas development in broken soft coal seam. In this paper, taking Xinxie -1 drilling as an example, the evaluation method of fractured reservoirs in roof and floor of broken soft coal seam was improved. By systematic studied on mineralogy, petrology and engineering mechanics characteristics of top and bottom plates in broken soft coal seam, the influence of rock mineral composition on the rock mechanics properties of the roof and floor of coal seam was explored. In

addition, By used correlation analysis and grey relational analysis, a brittle evaluation method of coal seam top and bottom plates based on mineral composition was established. The research results showed that: ①The main components of rock minerals in the top and bottom plates of broken soft coal seam were quartz and clay minerals, followed by plagioclase, siderite and pyrite. The main types of rock cementation were quartz enlargement and siderite cementation, and the pore damage caused by cementation was much greater than that of compaction; ②With the increased of rock particle size, compressive strength (CS) and elastic modulus (E) showed a gradual increase trend, Poisson's ratio (μ) showed a gradual decrease trend, other rock mechanical parameters had no obvious changes. The difference of mineral composition and cementation type was the key factor cause abnormal mechanical properties of rocks; ③Compared with clay minerals, the change of brittle mineral content such as quartz, plagioclase and siderite in rocks were sensitive to the mechanical properties of rocks. The sensitive minerals of compressive strength, shear strength, elastic modulus and softening coefficient were quartz, the sensitive minerals of compressive strength were plagioclase and siderite, and the sensitive minerals of Poisson's ratio are quartz and clay; ④The calculation results of the established mineral weight analysis method were more realistic. It could be concluded that the roof of 13-1 coal, 11-2 coal, 9-2 coal and 4-2 coal seams were more inclined to form fracture network during fracturing, which had guiding significance for the optimization of fracturing horizon.

Key words minerals; broken soft coal seam; roof and floor of coal seam; rock mechanics; brittleness evaluation

1. Introduction

At present, the exploration and development of clean energy such as unconventional natural gas (shale gas, coalbed gas and tight sandstone gas) became a hot topic in energy science in the world today (Dai et al., 2014; Christopher et al., 2008; Zhu et al., 2016). Lianghuai coalfield in Anhui Province is the most important coal production base in eastern China. The potential of coalbed methane resources is huge and the geological resources of coalbed methane can reach 90 million cubic meters. However, the broken soft coal seams are extremely developed in Lianghuai coalfield. The so-called "broken soft coal seam" refers to the coal seam where the original natural fracture network system was destroyed or even disappeared under the action of structural compression and shear stress and the coal structure was characterized by broken block, fragmented, powder, scale and so on. Compared with hard coal seam, the development of coalbed gas in broken soft coal seam was more difficult. Broken soft coal seam was characterized by broken, soft and low permeability, it was "difficult to released gas" and rapid productivity attenuation in coalbed gas development. Conventional fracturing along structural coal reservoir is not effective (Yuan et al., 2013), but the fracturing along the roof and floor of coal seam have achieved initial results. For example, the LG drilling group of Luling coal mine, Huaibei coalfield, Anhui province (Fig. 1) had a daily gas production of 10000 m³ and a stable production of 3000 m³/d in 100 days (Zhang et al., 2018; Wu et al., 2018). Therefore, for the traditional coalbed gas development, the parameters such as coal quality, gas content and reservoir physical properties (porosity, permeability) of coal reservoirs became the key parameters of coalbed gas reservoir evaluation. For the development of coalbed gas in broken soft coal seam, it was pay special attention to the evaluation and research of key parameters of reservoir fracturing such as mineralogy, petrology and engineering mechanics of roof and floor of coal seam(Wang et al., 2012;Wu et al., 2012; Rahimzadeh et al., 2018; Raef et al., 2018).

In view of different diagenetic facies had different petrology, diagenesis and physical properties (Railsback, 1984; Zou et al., 2008), and these characteristics directly determine the size of rock mechanical parameters (including compressive strength, Poisson's ratio and elastic

modulus) and the reasonable evaluation of rock brittleness (Li et al., 2017). It is of great significance to the effective prediction of formation fracture pressure and the evaluation of wellbore stability during coalbed methane development (Xie et al., 2004; Wang 2013). According to Liu et al. (2020), there were many factors affecting the brittleness of rock, and it was generally believed that the brittleness of rock was related to mineral composition and rock mechanical properties. However, there was no consistent definition of brittleness index in the literature, resulting in different quantitative methods (Josh et al., 2012; Rahimzadeh et al., 2018). According to literature research, the current evaluation methods of brittleness index include dozens of methods based on rock strength or firmness coefficient, rock mechanical properties, mineral composition and content, stress-strain relationship and so on (Hucka et al., 1974; George, 1995; Jarvie et al., 2007; Rickman et al., 2008; Josh et al., 2012; Tarasov et al., 2013; Rahimzadeh et al., 2018). However, the traditional brittleness evaluation method based on elastic parameters and mineral composition analysis was limited by the anisotropic petrophysical behavior of reservoirs, and lacks universal applicability and feasibility (Zhang et al., 2016). In addition, the definition of brittle minerals was vague, and it was still controversial whether feldspar minerals and carbonate minerals are identified as brittle minerals (Singh et al., 2013; Hofmann et al., 2013). So, it was necessary to comprehensively judge the response law of rocks and minerals in combination with the mechanical properties of rocks. Therefore, this study intended to take Xinxie -1 drilling (CBM parameter drilling) (Fig.1) in Huainan Coalfield as an example, and revealed the geological occurrence law of rock mineral components in coal measures strata through experimental research on the roof and floor system of broken soft coal seams in the study area. The response of mineral composition to mechanical properties of coal seam roof and floor rocks was expounded and the brittleness evaluation method of coal seam roof and floor based on rock mineral composition was established. It provided guidance for the development practice of coalbed methane in broken soft coal seam development area.

Fig.1 Location map of study area

2. Sample collection and testing

2.1 Geological background

Huainan Coalfield was located in the southeast margin of North China 's Claratong on the large tectonic site, and the whole interior showed a complex syncline structural belt complicated by a series of secondary folds. The main coal-bearing strata in Huainan coalfield include Permian Shanxi Formation, Upper Shihezi Formation and lower Shihezi Formation. Xinxie -1 drilling was located in the monoclinical structure of the south wing of Huainan Hedging Fault Basin and the drilled strata were Quaternary, Neogene, Paleogene, Triassic, Permian and Carboniferous. The final hole depth of Xinxie -1 drilling was 1541.61m, and the final hole horizon was Carboniferous-Permian Taiyuan Formation 7th limestone. A total of 30 layers of coal had been discovered by drilling, including 16 minable coal seams, among which 4 stable minable coal

seams were 13-1#, 11-2#, 8# and 7#. The main lithology of the roof and floor of the drilled coal seam were mudstone, sandy mudstone, argillaceous siltstone, siltstone, fine sandstone and medium sandstone.

2.2 Sample collection

This study focused on sampling and field description of the core samples of roof and floor of the main minable seam exposed in Xinxie -1 drilling (Fig.2). There are 15 samples, and the length of samples should be greater than 300mm (core diameter 60mm). There were 15 core samples collected this time and the length of samples were more than 300mm (core diameter 60mm). The structure of core samples were complete and representative. After the dirt on the surface of the samples were cleaned on site, the samples were sealed preservation and sent to the laboratory for later use.

2.3 X-ray diffraction analysis

The mineral composition identification and quantitative analysis of the samples were carried out by YST-1 X-ray diffractometer. The weight of the sample to be measured is about 15mg. By extracting the characteristic peaks of rock minerals, the mineral composition characteristics of rock can be obtained quantitatively. The experimental test process was carried out with reference to the oil and gas industry standard of the People's Republic of China (SY-T6210-1999).

2.4 Casting thin-section

ZT-3 rock casting instrument was used to prepare rock casting sheet. Firstly, the project team selected representative parts of rock samples to be measured and cut them into squares of 24×24×6mm, put the samples in a drying oven for 4 hours, control the temperature between

105-110°C, dry the moisture, and put them into a dryer for later use after natural cooling. Secondly, the prepared dyeing resin was injected into the sample tube, and the sample was submerged for more than 10 mm. Finally, the cast thin sections after pressure perfusion and heating solidification were observed under microscope, the types of minerals, cements and contact types in the rock were identified and analyzed.

2.5 Testing of rock mechanical properties

RMT-150C rock and concrete mechanics test system was used for rock mechanics property test. Uniaxial compression test (natural water-bearing condition) was carried out on the samples to be tested according to the rock physical and mechanical properties test regulations (DZ/T 0276.18-2015). The test process was as follows: The processed test piece (coated with a thin layer of vaseline lubricant on the upper and lower bottom surfaces) was placed in the center of the base. A rigid cushion block was placed between the upper end of the sample and the pressure bearing plate of the experimental machine. The pressure bearing head was adjusted so that the sample was uniformly stressed and loaded at a rate of 0.1~0.5 MPa per second until the sample was damaged. Among them, soft rock and softer rock took lower loading rate. According to the axial deformation and radial deformation of rock specimen in uniaxial compression test, the stress-strain curve of rock was drawn and the corresponding rock mechanical parameters were calculated.

Fig.2 Schematic diagram of roof and floor of coal seam sampling

3. Experimental test results

In this study, experimental methods such as casting thin-section and X-ray whole rock

analysis, mineral petrology analysis were carried out on sandstone of roof and floor of the main coal seam in Xinxie -1drilling (Fig.3 and Table 1), which mainly revealed mineralogical composition, cementation type and dissolving attack situation of rocks. The mineral composition of roof and floor of coal seam sandstone in the research region was mainly quartz (average of 56.9%, with a range of 28 - 75.4%) and clay mineral(average of 30.4%, with a range of 11.2 - 64.3%), followed by anorthose (average of 6.0%, with a range of 0 - 23.6%), siderite (average of 5.1%, with a range of 0.4 - 43.3 %) and pyrite (average of 0.4%, with a range of 0 - 3%), other minerals are scattered. Compressive strength (CS) of roof and floor of the main coal seam was between 17.3Mpa and 92.3Mpa, with an average of 52.01Mpa. Tensile strength (TS) was between 1.33-12.07Mpa, with an average of 4.73Mpa. Shear strength (SS) was between 5.3-18.5Mpa, with an average of 11.49Mpa. Softening coefficient (K) was between 0.15-0.83, with an average of 0.49. Elastic modulus (E) ranged from 5.36 to 28Gpa, with an average of 16.69Gpa. Poisson's ratio (μ) is between 0.18 and 0.26, with an average of 0.22. The results of casting thin-section analysis were consistent with Table 1. It could be seen from Figure 3 that quartz, feldspar and siderite were widely distributed in casting thin-section. The cementation types of roof and floor of coal seam were mainly quartz enlargement and siderite cementation (MS, FS-1, FS-2, MS-2, FS-5, FS-6 samples), besides that argillaceous cementation and calcareous cementation were found in roof of local coal seam(MS-1,MS-3,FS-3 samples). Except for a few feldspar and rock debris dissolved pores (Fig.3A), a few calcite metasomatic feldspar (Fig.3F) and organic matter strips (Fig.3C, H) were found. Quartz enlargement edge and siderite were common in roof and floor of other coal seams, and no obvious dissolution was observed. In

addition to the development of organic matter and fractures in the argillaceous zone, the whole rock was relatively dense, with extremely poor porosity and permeability, and the pore damage caused by cementation was far greater than that caused by compaction.

Fig.3 Cementation mode of minerals in roof with different lithology

A: lithic quartz sandstone, $\times 10$, mainly the cementation of silicious quartz enlargement, with a small amount of feldspar and cuttings dissolution pores can be seen, MS sample; B1: Siderite lithic quartz sandstone, $\times 10$, mainly the cementation of Siderite, undeveloped quartz enlargement, undeveloped dissolution, FS-1 sample; B2: Siderite lithic quartz sandstone, $\times 10$, mainly the cementation of Siderite, Siderite is extremely developed, feldspar minerals can be seen without dissolution, FS-2 sample; C: muddy siltstone, $\times 10$, argillaceous cementation, with argillaceous strip, organic matter and fracture development, MS-1 sample; D: Feldspathic lithic sandstone, $\times 10$, calcite cementation, with feldspar-quartz enlargement edge, FS-3 sample; E: feldspar lithic fine sandstone, $\times 10$, siderite cementation, with small amount of quartz increase, MS-2 sample; F: lithic quartz sandstone, $\times 10$, quartz enlargement and calcite cementation, with minor calcite metasomatic feldspar, MS-3 sample; G: Feldspathic lithic sandstone, $\times 10$, siderite and quartz enlargement cementation, with small amount of quartz increase, FS-5 sample; H: Feldspathic lithic sandstone, $\times 10$, organic matter bands are mainly cemented with siderite, with small amount of calcite lithic and quartz increase, FS-6 sample.

Table 1 List of mineral petrology and rock mechanics parameters of roof and floor of main coal seam

Numbering	Lithology	Position	Sampling depth / m	Rock composition /%							Rock mechanics parameters					
				Quartz	Plagioclase	Calcite	Ankerite	Siderite	Pyrite	Clay	CS /MPa	TS /MPa	SS /Mpa	K	E /GPa	μ
SM-1	sandy mudstone	roof of 13-1#	1149	47.00	0.80	0.00	0.00	2.30	0.00	49.90	26.00	1.33	5.50	0.330	7.00	0.25
SM-2	sandy mudstone	floor of 4-2#	1396	35.30	0.00	0.00	0.00	0.40	0.00	64.30	17.30	3.46	6.30	0.400	5.36	0.26
MS-1	muddy siltstone	floor of 12#	1162	58.40	0.70	0.00	0.00	4.60	0.00	36.30	41.1	3.29	9.0	0.640	11.00	0.22
MS-2	muddy siltstone	roof of 11-2#	1225	62.70	0.30	0.00	0.00	2.50	0.00	34.50	41.10	1.42	11.40	0.390	11.00	0.23
MS-3	muddy siltstone	floor of 8#	1304	60.00	5.10	0.00	0.00	3.20	0.00	31.70	27.00	3.63	5.30	0.190	7.00	0.24
MS-4	muddy siltstone	Roof of 7#	1345	57.50	0.00	0.00	0.00	2.20	0.00	40.30	31.60	3.20	7.40	0.150	8.00	0.24
MS-5	muddy siltstone	roof of 4-2#	1390	57.80	10.80	0.00	0.00	0.80	1.20	29.40	29.50	5.18	14.30	0.710	10.00	0.23
SS	siltstone	roof of 9-3#	1289	67.30	6.70	0.00	0.00	2.50	0.00	23.50	78.00	4.54	8.80	0.760	22.00	0.20
FS-1	fine sandstone	roof of 13-1#	1146	28.00	1.40	9.50	6.60	43.30	0.00	11.20	86.40	12.07	18.20	0.750	28.00	0.18
FS-2	fine sandstone	roof of 10#	1266	58.30	23.60	0.00	0.00	4.70	0.30	13.00	58.5	3.70	16.2	0.830	19.00	0.21
FS-3	fine sandstone	roof of 9-3#	1283	68.00	2.60	1.50	0.00	3.30	0.80	23.80	51.8	11.10	7.3	0.490	16.00	0.22
FS-4	fine sandstone	floor of 9-3#	1296	57.80	10.80	0.00	0.00	0.80	1.20	29.40	69.8	4.80	18.5	0.510	23.00	0.18
FS-5	fine sandstone	roof of 9-2#	1299	58.60	12.70	0.00	0.00	3.30	3.00	22.30	75.50	6.09	16.30	0.360	24.00	0.19
FS-6	fine sandstone	roof of 8#	1338	61.40	7.00	0.00	0.00	1.70	0.00	29.90	54.20	4.00	17.50	0.450	18.00	0.22
MS	medium sandstone	roof of 13-1#	1137	75.40	7.00	0.70	0.00	0.40	0.00	16.50	92.30	2.43	10.40	0.440	26.00	0.19

Annotation: CS: compressive strength; TS: tensile strength; SS: shear strength; K: softening coefficient; E: modulus of elasticity; μ: Poisson's ratio

4. Discussion

4.1 Geological occurrence law of mineral components

4.1.1 Mineral distribution law under different sedimentary ages and buried depths

With the increase of buried depth, the mineral content in the roof and floor of different coal seams showed different change rules. Through polynomial fitting and linear fitting analysis of measured data (some abnormal data points have been eliminated), it could be concluded that with the increase of buried depth, the content of quartz in roof and floor of coal seam first decreased and then increased (Fig.4A), while the content of siderite first increased and then decreased (Fig.4B). Among them, the content of quartz were higher ($> 65\%$) in roof of No.13-1 and No.4 coal seams, and lower ($< 60\%$) in roof and floor of No.9 and No.10 coal seams. The siderite content was opposite, but the inflection point was the same, which was located at the bottom of the Upper Shihezi Formation and the top of the Lower Shihezi Formation. The analysis might be related to the development of interbedded sandstone and mudstone in the transitional zone of delta plain (Wei, 2012). In addition, with the increase of buried depth, the content of plagioclase and clay minerals in the roof and floor of coal seam changed linearly. Among them, plagioclase content was positively correlated with buried depth (Fig.4C), while clay mineral content was negatively correlated with buried depth (Fig.4D). The above inference might be related to the gradual evolution of the sedimentary environment in the study area from the lower delta plain sedimentary environment to the delta plain transitional zone and the upper delta plain sedimentary environment (Jiang et al., 2007).

Figure 4. Relationship between rock mineral composition and depth

4.1.2 Mineral distribution law under different lithologic conditions

The mechanical behavior of rock at macro-scale depended largely on its granular meso-scale structure and the properties of each mineral component (Yu et al., 2021). It could be seen from Fig.5 that the mineral content changed regularly under different roof and floor of coal seam lithology conditions. The concrete manifestations were as follows: 1) The change trend of quartz and clay minerals in roof and floor of coal seam was the most obvious, followed by plagioclase and siderite (Fig.5); 2) With the increase of rock particle size (i.e., sandy mudstone < argillaceous siltstone < siltstone < fine sandstone < medium sandstone), the content of quartz and plagioclase minerals gradually increased (Fig.5A and B). The content of siderite changed relatively little,

showing a gradual increase trend (Fig.5C), while the content of clay decreases gradually (Fig.5D). It could be seen that the larger the particle size of rock (such as medium sandstone and fine sandstone), the higher the content of quartz and plagioclase in rock and the lower the content of clay. On the contrary, the smaller the particle size of rock (such as sandy mudstone and argillaceous siltstone), the lower the content of quartz and plagioclase and the higher the content of clay. Under different lithologic conditions, the content of siderite did not change obviously, but local aggregation easily occurred in fine sandstone and medium sandstone formations. The analysis might be related to the later metasomatic origin of siderite in sandstone fractures, while the siderite in sandy mudstone and argillaceous siltstone with small particle size of rock particles might be the product of early diagenesis. (Zhuang, 1988).

Fig.5 Relationship between lithology and mineral content

4.2 The relationship between mineral composition and rock mechanical properties of roof and floor of coal seams

In conventional reservoir fracturing design, mechanical parameters such as elastic modulus (E), Poisson's ratio (μ) and compressive strength of rocks were often used to predict the fracturability and fracture pressure of reservoir rocks, and petrological characteristics were the most important factors affecting the mechanical properties of rocks (Wang et al., 2012; Wu et al., 2012). When the content of mineral components in rocks was different, the mechanical properties of rocks must be different. With the change of lithologic composition, the rock mechanical properties of roof and floor of coal seams showed different laws (Fig.6A and B). It showed as follows: 1) With the increase of rock particle size, compressive strength (CS) and elastic modulus (E) showed an increasing trend. It was characterized by sandy mudstone < argillaceous siltstone < siltstone < fine sandstone < medium sandstone. Poisson's ratio (μ) showed a decreasing trend and other rock mechanics parameters did not change obviously. The above conclusions were consistent with (Liu et al., 2020); 2) Generally speaking, quartz, feldspar and clay mainly affected the elastic

modulus of shale. The increase of quartz and feldspar content led to the increase of elastic modulus, while clay minerals had the opposite. On the contrary, carbonate and organic matter had little effect on the elastic modulus of rock ([Liu et al., 2020](#)), which was slightly different from this research conclusion. Compared with SS, K and μ , the increase of siderite content in the study area was an important factor causing abnormal increase of CS, TS and E values of rocks. For example, the content of siderite in FS-2 sample was 43%, which corresponded to the CS, TS and E values of this sample being 86.4Mpa, 12.07Mpa and 28GPa, respectively. Therefore, the influence of the change of carbonate content on rock mechanical properties in the study area needed to be paid attention to; 3) Under the same rock composition condition, the different rock particle cementation methods would lead to significant differences in rock mechanical parameters ([Cheng et al., 2016](#)). For example, the whole rock analysis results of MS-2 and MS-3 samples were relatively similar. The content of quartz was between 60-63%, and the content of siderite was between 2-3%. According to the previous analysis, the siderite cementation of MS-2 sample was relatively developed, while the cementing method of MS-3 sample was mainly siliceous cement. The difference in the type of cementation might be an important reason for the obvious difference in the CS, SS and E values of the MS-2 samples ([Handin et al., 1967](#); [Cheng et al., 2016](#)); 4) According to the physical meaning of brittleness in elastic mechanics: Generally, the larger E was, the smaller μ was, which was consistent with the change law of E and μ in [Fig.6B](#). It could be preliminarily speculated that fine sandstone and medium sandstone with large particle size of rock

particles had good compressive strength, tensile strength, shear strength, elastic modulus and brittleness characteristics. However, in view of the difference in mineral composition and cementation type would have different degrees of impact on the mechanical properties and brittleness characteristics of rocks. Therefore, the effective and reasonable determination of the weight coefficients of different rock minerals was the key to quantitatively evaluate the mechanical characteristics and brittleness characteristics of rocks.

(A)

Figure 6. Relationship between rock mechanical properties and mineral composition

4.3 Contribution of mineral components to rock mechanical properties of coal top and bottom plates

Different ineral components contributed differently to the mechanical properties of rocks (Mavko et al., 1988; Katahara,1996; Vanorio et al., 2003). In order to quantitatively evaluate the contribution of mineral groups to the mechanical properties of coal seam roof rock and simplify the model parameters, the influences of minerals such as ankerite, pyrite and calcite were not considered for the time being (Li et al., 2019). In this paper, the grey relational analysis method is proposed (Deng, 1982). Rock mineral composition (quartz, plagioclase, siderite and clay) and mechanical parameters (CS, TS, SS, K, E and μ) were selected as sub-indicators and parent indicators respectively. Matlab language was used to program by computer according to the basic principle of grey relational model. Finally, according to the output results, the contribution of each mineral composition content to rock mechanical properties

was calculated quantitatively.

The grey relational model and the determination method of the parent index were as follows:

Let $\xi_i(K)$ ($i=1, 2, \dots, m$) be the correlation coefficient of x_i to x_0 at the sampling position of K , then:

$$\xi_i(K) = \frac{\Delta_{\min} + k\Delta_{\max}}{\Delta_i(K) + k\Delta_{\max}}$$

In the formula, K was the resolution coefficient, the value was between $[0.1, 1]$, generally 0.5;

$\Delta_{\min}$ ——Minimum absolute value difference,

$$\Delta_{\min} = \min_i \min_K |x_0(K) - x_i(K)| \text{ (generally, 0 is acceptable);}$$

$\Delta_{\max}$ ——Maximum absolute value difference, $\Delta_{\max} = \max_i \max_K |x_0(K) - x_i(K)|$;

$\Delta_i(K)$ ——The absolute difference between the factors at the sampling point K ,

$$\Delta_i(K) = |x_0(K) - x_i(K)|.$$

In order to facilitate the comparison, the correlation degree of x_i to x_0 was adopted to centralize them, $\gamma_i = \frac{1}{N} \sum_{i=1}^n \xi_i(K)$. After calculating the correlation degree of each evaluation index, the weight coefficient of each evaluation index could be obtained by normalization. The normalized expression was:

$$a_i = \frac{\gamma_i}{\sum_{i=1}^m \gamma_i}, \text{ See Table 2}$$

for normalization results, and Table 3 and Fig.7 for calculation results of weight coefficients.

In the above formula, a_i ——weight coefficient; γ_i ——the correlation degree of the sub-index relative to the parent index; m —— number of evaluation indexes.

Table 2 Normalized results of each evaluation index and brittleness index

Numbering	Subindex				Parent index					
	quartz	plagioclase	siderite	clay	CS	TS	SS	K	E	μ
SM-1	0.62	0.03	0.05	0.78	0.28	0.11	0.30	0.40	0.25	0.96
SM-2	0.47	0.00	0.01	1.00	0.19	0.29	0.34	0.48	0.19	1.00
MS-1	0.77	0.03	0.11	0.56	0.45	0.27	0.49	0.77	0.39	0.85
MS-2	0.83	0.01	0.06	0.54	0.45	0.12	0.62	0.47	0.39	0.88
MS-3	0.80	0.22	0.07	0.49	0.29	0.30	0.29	0.23	0.25	0.92
MS-4	0.76	0.00	0.05	0.63	0.34	0.27	0.40	0.18	0.29	0.92
MS-5	0.77	0.46	0.02	0.46	0.32	0.43	0.77	0.86	0.36	0.88
SS	0.89	0.28	0.06	0.37	0.85	0.38	0.48	0.92	0.79	0.77
FS-1	0.77	0.46	0.02	0.46	0.94	1.00	0.98	0.90	1.00	0.69
FS-2	0.37	0.06	1.00	0.17	0.63	0.31	0.88	1.00	0.68	0.81
FS-3	0.77	1.00	0.11	0.20	0.56	0.92	0.39	0.59	0.57	0.85
FS-4	0.90	0.11	0.08	0.37	0.76	0.40	1.00	0.61	0.82	0.69
FS-5	0.78	0.54	0.08	0.35	0.82	0.50	0.88	0.43	0.86	0.73
FS-6	0.81	0.30	0.04	0.47	0.59	0.33	0.95	0.54	0.64	0.85
MS	1.00	0.30	0.01	0.26	1.00	0.20	0.56	0.53	0.93	0.73

Table 3 Weight coefficient of each evaluation index

Parent index	weight coefficient			
	quartz	plagioclase	siderite	clay mineral
compressive strength(CS)	0.2799	0.2431	0.2281	0.2489
tensile strength(TS)	0.2058	0.2785	0.2578	0.2579
shear strength(SS)	0.2743	0.2461	0.222	0.2576
softening coefficient(K)	0.2768	0.2557	0.2141	0.2533
modulus of elasticity(E)	0.2722	0.2557	0.2142	0.2533
Poisson's ratio(μ)	0.3471	0.2116	0.1777	0.2637

Fig.7 Weight coefficients of different mineral components corresponding to rock mechanical parameters

It could be seen from [Fig.7](#) that the weight coefficients of different mineral components corresponding to rock mechanical parameters were also different, which was shown as follows: 1) quartz minerals had the largest contribution to Poisson's ratio (0.3471), the smallest contribution to tensile strength (0.2058), and the contribution to other rock mechanical parameters was about 0.28; 2) Oblique feldspar and siderite had the same contribution to the above six rock mechanical parameters, which generally showed that they had a greater contribution to tensile strength, a smaller contribution to Poisson's ratio and a general contribution to other rock mechanical parameters; 3) The influence of clay minerals on rock mechanical parameters was consistent, and each weight coefficient was about 0.25. Therefore, compared with clay minerals, the content changes of brittle minerals such as quartz,

plagioclase and siderite in rocks were sensitive to the mechanical properties of rocks. Among them, the sensitive minerals of compressive strength, shear strength, elastic modulus and softening coefficient were quartz. The sensitive minerals of compressive strength were plagioclase and siderite. The sensitive minerals of Poisson's ratio were quartz and clay. The above results were basically consistent with the conclusion of [Liu et al.\(2020\)](#). It should be pointed out that clay content had a direct impact on Poisson's ratio, which was positively correlated with Poisson's ratio, while quartz content was inversely related to Poisson's ratio.

4.4 Evaluation method of brittleness of coal seam top and bottom plates based on mineral composition

Brittleness index of fractured reservoir in coal seam top was an important evaluation index that determined the fracturing effect and gassed production effect of coalbed gas ([Kim et al. 2017](#); [Rahimzadeh et al. 2018](#); [Raef et al., 2018](#)). There were more than 20 methods to measure brittleness. At present, there were two commonly used methods to calculate rock brittleness continuously. One was the elastic parameter method, which held that the higher the elastic modulus, the lower the Poisson's ratio. However, this method had its shortcomings. First, the maximum and minimum values of elastic modulus were difficult to determine ([Rickman et al., 2008](#)). Second, the weight of elastic modulus and Poisson's ratio in brittleness evaluation was uncertain, which made brittleness evaluation uncertain. Another method was rock mineralogy ([Jarvie et al., 2007](#); [Wang et al. 2009](#); [Jin et al., 2014](#)), but this method did not fully consider the influence of other brittle minerals on rock mechanical parameters. The

brittleness of rock was not only related to the basic mineral composition, but also to its mechanical properties. At present, [Qin et al. \(2016\)](#) and [Li et al. \(2019\)](#) had tried to establish a brittleness evaluation method based on rock mineral composition and mechanical parameters, but the model lacked universal applicability due to the influence of evaluation index selection. Therefore, in the brittleness evaluation, the mineral composition (quartz, plagioclase, siderite and clay) and mechanical parameters (E and μ) of the rock in the study area were comprehensively considered as the key indicators for the evaluation of rock brittleness, and a new method for evaluating rock brittleness-mineral weight analysis method was proposed. This time, the rock brittleness (BI_{avg}) determined by elastic parameter method was taken as the parent index, and the specific calculation method of the parent index was as follows:

$$E_{BI} = (E_C - E_{min}) / (E_{max} - E_{min})$$

$$\mu_{BI} = (\mu_C - \mu_{max}) / (\mu_{min} - \mu_{max})$$

$$BI_{avg} = (E_{BI} + \mu_{BI}) / 2$$

E_C , μ_C : The calculated elastic modulus and Poisson's ratio; E_{max} , E_{min} : The maximum and minimum of elastic modulus; μ_{max} , μ_{min} : Maximum and minimum Poisson's ratio; E_{BI} , μ_{BI} : The brittleness of rock calculated for elastic modulus and Poisson's ratio respectively; BI_{avg} : Brittleness of rock. Since the measured sample datas were few, the values of maximum and minimum values of elastic modulus and Poisson's ratio refer to [Rickman et al. \(2008\)](#). According to [Rickman et al. \(2008\)](#), under the condition of large sample data, $E_{max}=85\text{Mpa}$, $E_{min}=5\text{MPa}$; $\mu_{max}=0.37$, $\mu_{min}=0.16$. Taking the main mineral components

(quartz, plagioclase, siderite and clay minerals) in the roof and floor of coal seam as sub-indicators, the weight of each mineral component to brittleness index was determined by the grey relational analysis method mentioned above. After calculation, the weight coefficients of quartz, plagioclase, siderite and clay minerals were 0.3271, 0.2244, 0.1919 and 0.2566 respectively. In order to highlight more brittle rocks, the author put forward a new formula for calculating the brittleness (*BI*) of rocks in this area:

$$BI = \frac{V_{Quartz} * 0.3271 + V_{Carbonatite} * 0.1919}{V_{Quartz} * 0.3271 + V_{Plagioclase} * 0.2244 + V_{Carbonatite} * 0.1919 + V_{Clay} * 0.2566}$$

In order to verify the rationality of the above formula, the calculation results were compared with rock mechanics parameter method and rock mineralogy method (Fig.8), in which the calculation formula of rock mineralogy method was as follows:

It could be seen from Fig.8 that the calculation result of rock mechanics parameter method was low, which was related to the lack of consideration of rock mineral composition in this method (Zhang et al. 2016). Although the rock mineralogy method was close to the results calculated by the mineral weight analysis method, the comprehensive influence of brittle minerals in carbonate rocks on brittleness index was not considered. When the content of calcite, siderite and other carbonate minerals in rocks was abnormal, the calculated results would be abnormal (FS-2 sample in Fig.8). The new formula proposed by the author considered the influence of carbonate minerals widely existing in the study area, and the calculated results were more realistic and could avoid the occurrence of abnormal data results.

Fig.9 showed the evaluation results of the brittleness of the roof and floor of different

coal seams obtained by using the new calculation formula. With the increase of buried depth of coal seam, the brittleness coefficient of roof and floor of coal seam in Xinxie -1 drilling generally showed a decreasing trend. The roof and floor of coal seams with brittleness coefficient greater than 70 were mainly roof of 13-1, 11-2, 9-2, 4-2 coal seams. The above-mentioned coal seam roof tends to form fracture network, which had guiding significance for the optimization of fracturing horizon.

Fig.8 Comparison of different calculation methods of brittleness index

Fig.9 Brittleness evaluation of roof and floor of different coal seams in the study area

5. Conclusion

Through systematic sampling, testing and analysis of the roof and floor of coal seams in Xinxie -1 drilling, the occurrence law of mineral components in coal seam strata was deeply analyzed from the perspectives of mineralogy, petrology and engineering mechanics. The response of mineral components to the rock mechanical properties of coal seam bottom and top was clarified. The brittleness evaluation method of roof and floor of coal seam based on rock mineral components was established, which provided guidance for the development practice of coalbed gas in broken soft coal seam development areas. The main findings of this study were as follows:

(1) The casting thin section and X-ray analysis experiments showed that the rock mineral composition of the roof and floor of broken soft coal seam was mainly quartz

and clay minerals, followed by plagioclase, siderite and pyrite. The main types of rock cementation were quartz enlargement and siderite cementation. Excepted for a small amount of feldspar and cuttings dissolution pores on the roof and floor of some coal seams, the whole rock was relatively dense with extremely poor porosity and permeability, and the pore damage caused by cementation was far greater than that caused by compaction.

(2)The variation law of rock mineral composition content with depth and lithology was obvious. With the increase of depth, the content of quartz first decreases and then increases, while the content of siderite first increased and then decreased, which might be related to the development of sandstone and mudstone interbedding in the transitional zone of delta plain during this period.

(3)With the increase of rock particle size, compressive strength (CS) and elastic modulus (E) showed a trend of increasing gradually, Poisson's ratio (μ) showed a trend of decreasing gradually, and other rock mechanical parameters had no obvious changes. The difference of mineral composition and cementation type was the key factor causing abnormal mechanical properties of rocks.

(4)Compared with clay minerals, the content changes of brittle minerals such as quartz, plagioclase and siderite in rocks were sensitive to the mechanical properties of rocks, among which the sensitive minerals of compressive strength, shear strength, elastic modulus and softening coefficient were quartz, the sensitive minerals of compressive strength were plagioclase and siderite, and the sensitive minerals of Poisson's ratio were quartz and clay.

(5)The mineral weight analysis method considered the influence of carbonate minerals widely existing in the study area, and the calculation results were more in line with the reality. The practical application showed that the fracture network tends to form in the fracturing process of roof of 13-1,11-2, 9-2 and 4-2 coal seams in the study area, which had guiding significance for the optimization of fracturing horizon.

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Ethical Statements

Guangqing Hu, Wenxu Liang, Qingting Shan, Meng Zhao, Xianzeng Shi and Dun Wu declare that the publication of this paper is original, and there are no conflicts of interest and multiple submissions.

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