

## Research Article

# Dynamic Brittle Instability Characteristics of 2000 m Deep Sandstone Influenced by Mineral Composition

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The study of dynamic brittleness and failure characteristics is of guiding significance for promoting the full exploitation and utilization of deep sandstone reservoirs. At present, there have been more comprehensive studies on the mechanical properties of deep sandstone reservoirs, but the study of mineral composition on the dynamic brittleness and failure characteristics of deep sandstone reservoirs is relatively weak. In this paper, XRD mineral composition analysis, uniaxial compression experiment, and Brazilian splitting are used to study the influence of mineral composition on mechanical properties and failure characteristics of deep sandstone reservoirs. It was concluded that (1) the mineral compositions of deep sandstone reservoirs are mainly three kinds of oxides: SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO. The failure modes of deep sandstone reservoir samples under uniaxial compression are more complicated, with tension failure and shear failure each accounting for half. In the Brazilian split test, the failure modes of sandstone samples are mainly shear failure. (2) The compressive strength decreases obviously with the increase of CaO content. The contents of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO all have a great influence on the residual strength of deep sandstone reservoirs. The deformation modulus decreases gradually with the increase of Al<sub>2</sub>O<sub>3</sub> content. (3) The brittleness increases slightly when the content of SiO<sub>2</sub> increases, while the brittleness decreases slightly when the content of Al<sub>2</sub>O<sub>3</sub> increases. Considering factors such as strength, modulus, brittleness, and failure characteristics, SiO<sub>2</sub> content has the greatest influence on the mechanical properties of deep sandstone reservoirs, followed by Al<sub>2</sub>O<sub>3</sub> content, and CaO content has the least influence. The research results have a guiding role in the utilization and development of oil and gas resources in deep sandstone reservoirs and promote oil and gas development from the middle to deeper layers.

## 1. Introduction

The deep reservoirs on the land are extremely rich in oil and gas reserves, and most of the oil and gas exploration work on the land has gradually developed from the initial shallow and middle layers to the deep and even ultradeep layers. However, the current oil and gas resource exploitation is mainly concentrated at depths of 1000 m, and deeper resource mining is still in the development stage [1–3]. Therefore, strengthening the research on the mechanical

properties, failure characteristics, and fracturing brittleness of deep reservoirs is of guiding significance for promoting the full exploitation and utilization of deep reservoir resources.

At present, some progress has been made in the exploration and development of sandstone reservoirs, and sandstone reservoirs are rich in oil and gas resources and have good development potential. Many scholars have conducted further studies on the characteristics and properties of sandstone reservoirs. Xu et al. (2020) have

established a reservoir pore evolution model based on reservoir diagenesis and quantitative evaluation of reservoir pores. And the reservoirs are divided into two categories: low porosity with low permeability and ultralow porosity with ultralow permeability [4]; Li et al. (2020) have studied the multiple fracture interaction behavior of water-bearing and oil-bearing unsaturated reservoirs, which confirmed the importance of applying the two-phase flow process to multifracture interaction analysis and fracture trajectory function in the process of sandstone oil and gas development [5–7]; Yin et al. (2020) have conducted further research on the pore structure and physical properties of sandstone, and the research showed that sandstone has the characteristics of strong dissolution, low cementation rate, weak cementation, high porosity, and high permeability [8, 9]; Li et al. (2020) have used nuclear magnetic resonance technology to determine the changes in the size and quantity of sandstone pores after high temperature treatment. And the development of cracks and changes in rock mechanical properties after high temperature treatment have been studied [10, 11]; Wang et al. (2020) have observed and analyzed the dynamic failure and failure process of sandstone under cyclic impact load from a microscopic scale. And the dynamic mechanical properties of sandstone have been explored [12]; Rong et al. (2020) have explained the mechanism of the weakening of the mechanical properties of single-hole yellow sandstone from a microscopic point of view [13]; Sun et al. (2020) have studied the influence of temperature cycles on the mechanical properties of sandstone through a rigid rock mechanics experimental system. Experiments show that, at the same temperature, as the number of cycles increases, the peak strength and tensile strength of sandstone decrease. The higher the temperature, the more obvious the decrease in peak strength and tensile strength [14, 15].

In addition, rock brittleness is an inherent property of rock when it is damaged by force. Rock brittleness is closely related to its mechanical properties. According to different research purposes, domestic and foreign scholars have proposed many indicators of rock brittleness according to the definition of brittleness and failure phenomena. Zhang et al. (2020) have established a new brittleness evaluation index and revealed the evolution process of the overall fracture induced by the internal rock fracture, which is based on the energy mutation process of the quasistatic equilibrium equation of the two-body system [16]; Zhao and Guo (2020) have analyzed the failure characteristics of rocks from the energy point of view and established a brittleness evaluation method based on the relationship between fracture energy, mechanical parameters, and mineral composition [17]; Liu et al. (2020) have conducted experiments on two materials with different length-diameter ratios and found that the use of postpeak data is of great significance [18]; Zhou et al. (2020) have analyzed the influence of unloading rate on rock mechanical parameters, failure characteristics, and brittleness, through axial loading and confining unloading experiments, and then proposed a brittleness evaluation method considering the unloading effect [19].

In summary, it can be seen that the mechanical properties of sandstone reservoirs have been further studied in

terms of microstructure, fabric characteristics, impact load, high temperature cycling, etc. There is also a comprehensive method system for evaluating the brittleness of sandstone reservoirs. However, the research on the influence of the content of specific mineral components in deep sandstone reservoirs on the mechanical properties of sandstone failure is still relatively weak. This paper selects coal-measure formation sandstone of Shanxi Formation in Ordos Basin to study the influence of mineral composition of deep sandstone reservoir on its failure mechanical properties. This paper will start with the XRD mineral composition analysis, uniaxial compression test, and Brazilian split test, and other test methods. With the help of experimental data analysis and fitting related curves, the influence law of mineral composition on the failure mechanical properties of sandstone will be studied. New coal brittleness index is based on energy unsteady state release theory to analyze the relationship between mineral composition and brittleness of deep sandstone reservoirs. The influence of the specific mineral components of deep sandstone reservoirs on its failure mechanical properties can be well shown by the research results. The research results have a guiding role in the utilization and development of oil and gas resources in deep sandstone reservoirs and promote oil and gas development from the middle to deeper layers.

## 2. Experimental Program

*2.1. Sampling Locations.* In this experiment, the coal-measure strata core of the Shanxi Formation in the Ordos Basin is selected as the test object. The rock layer is buried from the depth of 1960 m to 2000 m and belongs to the Lower Permian of Paleozoic. The lithology of this coal measure is gray-gray-black lithic sandstone, lithic quartz sandstone, and silt-bearing sandstone with black mudstone. The sampling location is shown in Figure 1.

*2.2. Sample Preparation.* Because the sample cracks are relatively developed, the sample with the size of  $\varnothing 25 \times 50$  mm is selected for uniaxial compression test, and the sample with the size of  $\varnothing 50 \times 50$  mm is for Brazilian splitting test.

The cylindrical rock sample retrieved from the site is fixed on the drilling rig to ensure that the rock sample does not deviate during operation. After cutting the initial specimen with a diameter of 25 mm, replace the drill with a diameter of 50 mm to obtain a specimen with a diameter of 50 mm. Then use a cutting machine to cut all the specimens into 50 mm high cylinders, and place the cut specimens on a stone grinder for polishing to make the surface smooth, and the specimen specifications meet the requirements of the international rock mechanics experiment specifications. Finally, the specimens are numbered according to different specifications and different experiments, such as S1-1, which means that the first specimen taken from the first sandstone reservoir sample is subjected to uniaxial compression test; Sm-1 represents the first sandstone sample for Brazilian split test. The process of drilling samples in this experiment is shown in Figure 2. A total of 8 samples are tested in uniaxial

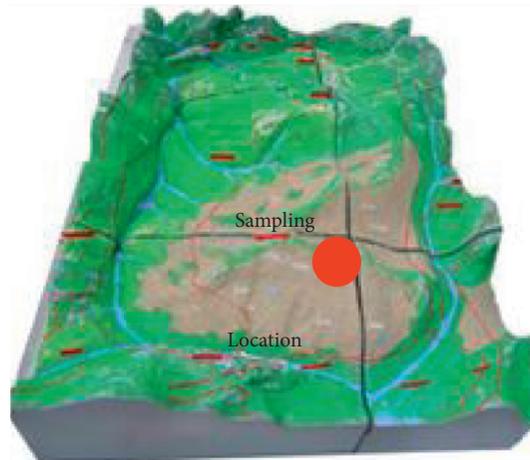


FIGURE 1: Sampling site of deep sandstone reservoir.

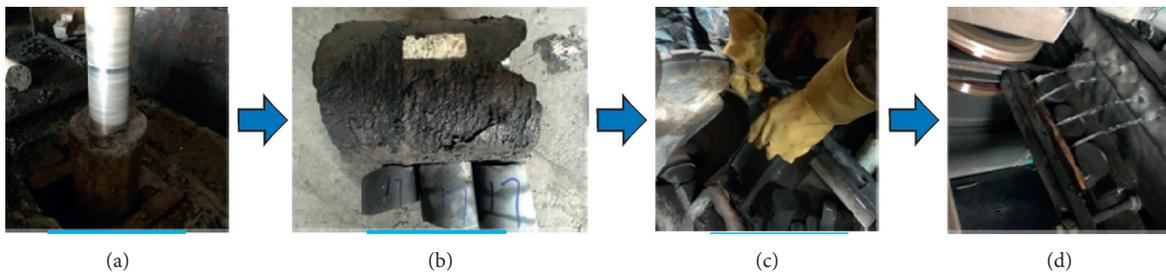


FIGURE 2: Deep sandstone sample preparation process. (a) Drill samples. (b) prototype samples. (c) cutting. (d) polishing.

compression test, numbered SM-1~SM-8. And a total of 3 samples are tested in the Brazilian split test, with the serial numbers of SM-1, SM-4, and SM-5, respectively. The specific sample number and size are shown in Table 1.

**2.3. Experimental Program and Apparatus.** In this test, all samples are analyzed by XRD mineral composition, S1-1~S1-8 samples are tested for uniaxial compressive strength, and Sm-1, Sm-4, and Sm-5 samples are tested for Brazilian split tensile strength.

(1) XRD mineral composition analysis

In this test, Malvern Panalytical XRD experimental analysis equipment is used for mineral composition analysis. As shown in Figure 3(a), this equipment is equipped with superenergy array detectors. The ideal combination of speed and strength can meet the application requirements of various powders and has strong scalability. When conducting XRD mineral composition analysis test, sandstone needs to be ground into powder. This process requires the sample to pass a 200-mesh sieve. Generally, the crystal grain size of the sample used for the diffractometer is required to be appropriate, and the best value is about  $1\ \mu\text{m}$ – $5\ \mu\text{m}$ . The particle size of the powder should also be within this range, and it is generally required to pass through a 325-mesh sieve.

The powdered sample is put into the groove of the sample holder, the surface of the powder is scraped and consistent with the plane of the frame, and the sample is made and numbered, respectively, Sm-1, Sm-4, and Sm-5.

(2) Uniaxial compression test

The loading system required for this test adopts the RTR-1000 high temperature and high pressure rock triaxial mechanical test system, which can complete uniaxial full stress strain test, triaxial full stress strain test, creep, relaxation test, etc. As shown in Figures 3(b) and 3(c). Before the test, the size of each rock sample is measured and recorded. During the test, the rock sample is installed on the press, the various parameters of the loading system are set, the loading system is started, and the stress and strain information in the whole process of the test is collected in real time until the test is completed, then the rock sample is taken out, and the data is recorded.

(3) Brazilian split test

The WAD-100E microcomputer controlled electronic universal testing machine is used in this test. The system is composed of a press host and a control system, which uses Japanese AC servo drives and AC servo motors. The performance is stable and reliable and has protection functions such as overload, overcurrent, overvoltage, upper and lower

TABLE 1: Deep sandstone sample number and size.

Experiment	Number	Length (mm)	Diameter (mm)
Uniaxial pressure experiment	S1—1	50.36	25.18
	S1—2	50.34	25.16
	S1—3	50.18	24.85
	S1—4	49.88	25.12
	S1—5	50.26	24.58
	S1—6	49.76	25.16
	S1—7	50.26	25.18
	S1—8	50.16	24.88
Brazil split test	Sm—1	50.20	50.16
	Sm—4	50.18	49.86
	Sm—5	50.12	50.18

displacement limits, and emergency stop. Maximum test force: 100 kN; measurement range: 0.4%–100% FN; relative error of indication: better than  $\pm 1\%$ .

Before the start of the test, measure the size of each rock sample and record it according to its serial number. During the test, the rock sample is installed on the press with a loading speed of 0.2 MP/s. Photographs are taken throughout the test, and the failure process of sample is recorded.

### 3. Test Results

*3.1. Mineral Composition Test Results.* After the test result spectrum is obtained, the corresponding element content data can be obtained by analyzing with the supporting analysis software. Figure 4 is a bar graph of the element content of the S1-1 sample.

It can be seen from Figure 4 that the deep sandstone reservoir sample S1-1 contains quite a lot of quartz  $\text{SiO}_2$ , which is highly brittle and prone to cracks under the action of external force. At the same time, it also contains a large amount of  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{CO}_2$ ,  $\text{K}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ , and other oxides. This test mainly analyzes the influence of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{CaO}$  on the compressive strength and tensile strength of sandstone. Table 2 shows the content of main mineral components of all deep sandstone reservoir samples.

*3.2. Compressive and Tensile Test Results.* Uniaxial compression equipment is used to test the compressive strength of the samples, and the Brazilian split test is used to test the tensile strength. The axial and lateral stress-strain curves of each sample are shown in Figure 5. According to the stress-strain curve, the compressive strength, tensile strength, residual strength, secant modulus, and elastic modulus of each sample can be obtained. Table 3 shows the comparison of compressive strength, tensile strength, residual strength, secant modulus, and elastic modulus of each sample. Details are as follows:

It can be seen from Figure 5 that the variation law of the stress-strain curve of the deep sandstone reservoir sample under uniaxial compression is approximate as follows: during the compaction stage, the internal microcracks in the deep sandstone reservoir gradually get closer under the load.

Then the curve enters the elastic stage. As the stress gradually increases and exceeds the yield stress of the sandstone, the curve enters the plastic stage, and the curve is down concave. This stage is very short, and there is almost no such stage in some samples. At the same time, the internal cracks of the sandstone propagate rapidly, and the bearing capacity of the sandstone sample reaches its peak. The stress continues to increase, the bearing capacity of the sandstone sample decreases, showing the characteristics of strain softening, and the curve begins to decline. At this time, the internal cracks of the deep sandstone reservoir are gradually penetrated. Finally, the curve enters the residual strength stage, and the strength no longer decreases, but the strain continues to increase. The tensile stress-strain curve of deep sandstone reservoir samples can be divided into three stages: the compaction stage, the elastic stage, and the plastic stage. The elastic stage is shorter, while the plastic stage is longer, and the curve oscillates irregularly at this stage until the stress reaches its peak tensile strength.

It can be seen from Table 3 that the compressive strength of the deep sandstone reservoir samples is between 62.612 MPa and 80.103 MPa. The residual strength is between 3.884 MPa and 6.800 MPa. The secant modulus is between 4.671 GPa and 8.711 GPa. The deformation modulus is between 6.530 GPa and 10.480 GPa. The compressive strength dispersion of deep sandstone reservoir samples with different mineral composition is larger, while the residual strength dispersion is smaller. In the tensile test, there are some differences in the characteristics of the strain-stress curve of deep sandstone reservoirs. It can be seen from Table 3 that the tensile strength of samples with different mineral compositions is between 3.960 MPa and 4.626 MPa.

The failure modes of each sample are shown in Figure 6:

### 4. Analysis

*4.1. Effect of Mineral Composition on Compressive Strength.* The fitting curve of  $\text{CaO}$  content and compressive strength is shown in Figure 7; it can be seen that the compressive strength of deep sandstone reservoir shows an overall downward trend with the increase of  $\text{CaO}$  content. The compressive strength is between 62.612 MPa and 80.103 MPa. This indicates that, with the increase of  $\text{CaO}$  content, the compressive strength of deep sandstone reservoirs gradually decreases.

*4.2. Effect of Mineral Composition on Residual Strength.* The fitting curve of  $\text{SiO}_2$  content and residual strength is shown in Figure 8(a), the fitting curve of  $\text{Al}_2\text{O}_3$  content and residual strength is shown in Figure 8(b), and the fitting curve of  $\text{CaO}$  content and residual strength is shown in Figure 8(c). It can be seen from Figure 8(a) that the residual strength range of deep sandstone reservoir is from 3.884 to 6.8, with a large degree of dispersion. And the residual strength of deep sandstone reservoirs shows a downward trend with the increase of  $\text{SiO}_2$  content; that is, the  $\text{SiO}_2$  content is negatively correlated with the residual strength. It can be seen from Figure 8(b) that the residual strength range

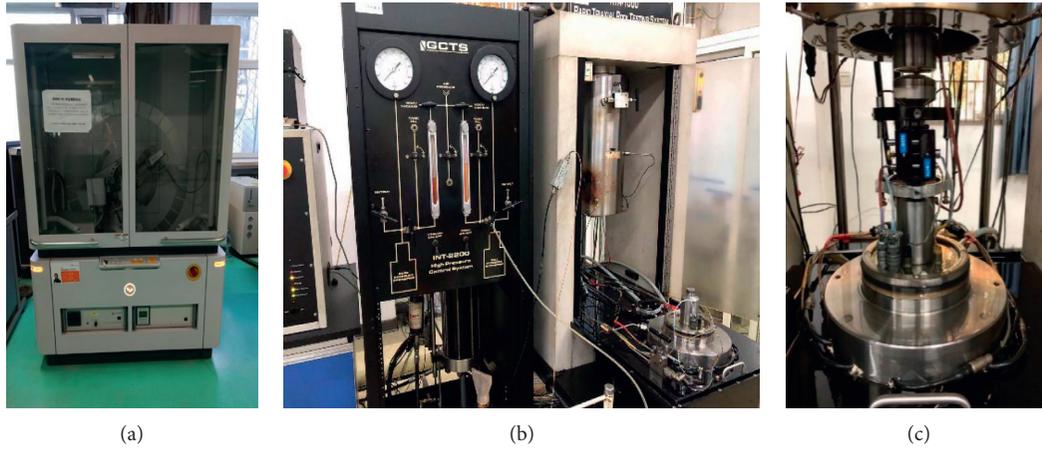


FIGURE 3: Experimental apparatus for sandstone tensile, compressive and mineral components. (a) Malvern Panalytical XRD. (b) Pressure test machine. (c) Rock sample installation.

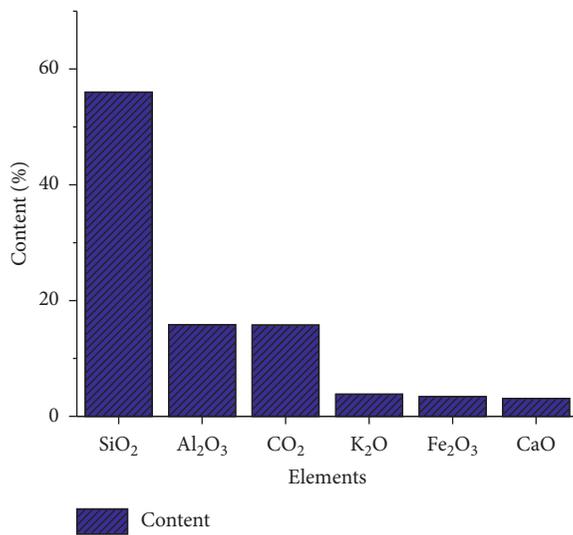


FIGURE 4: S1-1 Mineral composition diagram of deep sandstone reservoir.

TABLE 2: The main mineral composition of deep sandstone reservoir.

Number	SiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	CaO (%)
S1-1	56.01	15.83	3.08
S1-2	54.8	16.5	3.23
S1-3	52.29	15.33	2.31
S1-4	49.35	16.81	2.57
S1-5	50.09	15.95	3.04
S1-6	55.61	15.55	2.88
S1-7	57.97	15.65	2.64
S1-8	53.73	16.35	2.53

of deep sandstone reservoir is from 3.884 to 6.8, with a large degree of dispersion. And the residual strength of deep sandstone reservoirs gradually increases with the increase of Al<sub>2</sub>O<sub>3</sub> content; that is, the Al<sub>2</sub>O<sub>3</sub> content is positively correlated with the residual strength. It can be seen from Figure 8(c) that the residual strength range of deep

sandstone reservoir is from 3.884 to 6.8, with a large degree of dispersion. And the residual strength of deep sandstone reservoirs has a significant negative correlation with the CaO content; that is, the residual strength shows a downward trend with the increase of the CaO content.

**4.3. Effect of Mineral Composition on Deformation Modulus.** The fitting curve of Al<sub>2</sub>O<sub>3</sub> content and deformation modulus is shown in Figure 9; it can be seen that the deformation modulus of deep sandstone reservoirs is between 6.53 GPa and 10.48 GPa, with a large dispersion. The deformation modulus of deep sandstone reservoirs shows an overall downward trend as the Al<sub>2</sub>O<sub>3</sub> content increases, but the decrease rate is slow.

**4.4. Effect of Mineral Composition on Failure Mode.** The failure modes of deep sandstone reservoir samples with different mineral contents are obviously different. The relationship between SiO<sub>2</sub> content and failure angle is shown in Figure 10. It can be seen that the failure angle of samples shows an obvious downward trend with the increase of the SiO<sub>2</sub> content; that is, the SiO<sub>2</sub> content and the failure angle show an obvious negative correlation.

Among the samples in the uniaxial compression test, the failure modes of samples with high SiO<sub>2</sub> content are mainly shear failure, with fewer cracks after failure, and the failure modes of samples with low SiO<sub>2</sub> content are mainly tensile failure, with more cracks after failure. In the Brazilian split test, the failure modes of the sample are mainly shear failure. It can be seen that the mineral composition has a great influence on the failure mode and failure state of deep sandstone reservoirs.

## 5. Discussion

**5.1. Calculation Method and Results of Brittleness.** The brittleness of rock refers to the property that the rock is directly failed without obvious plastic deformation under load. The brittleness degree is generally used to measure the

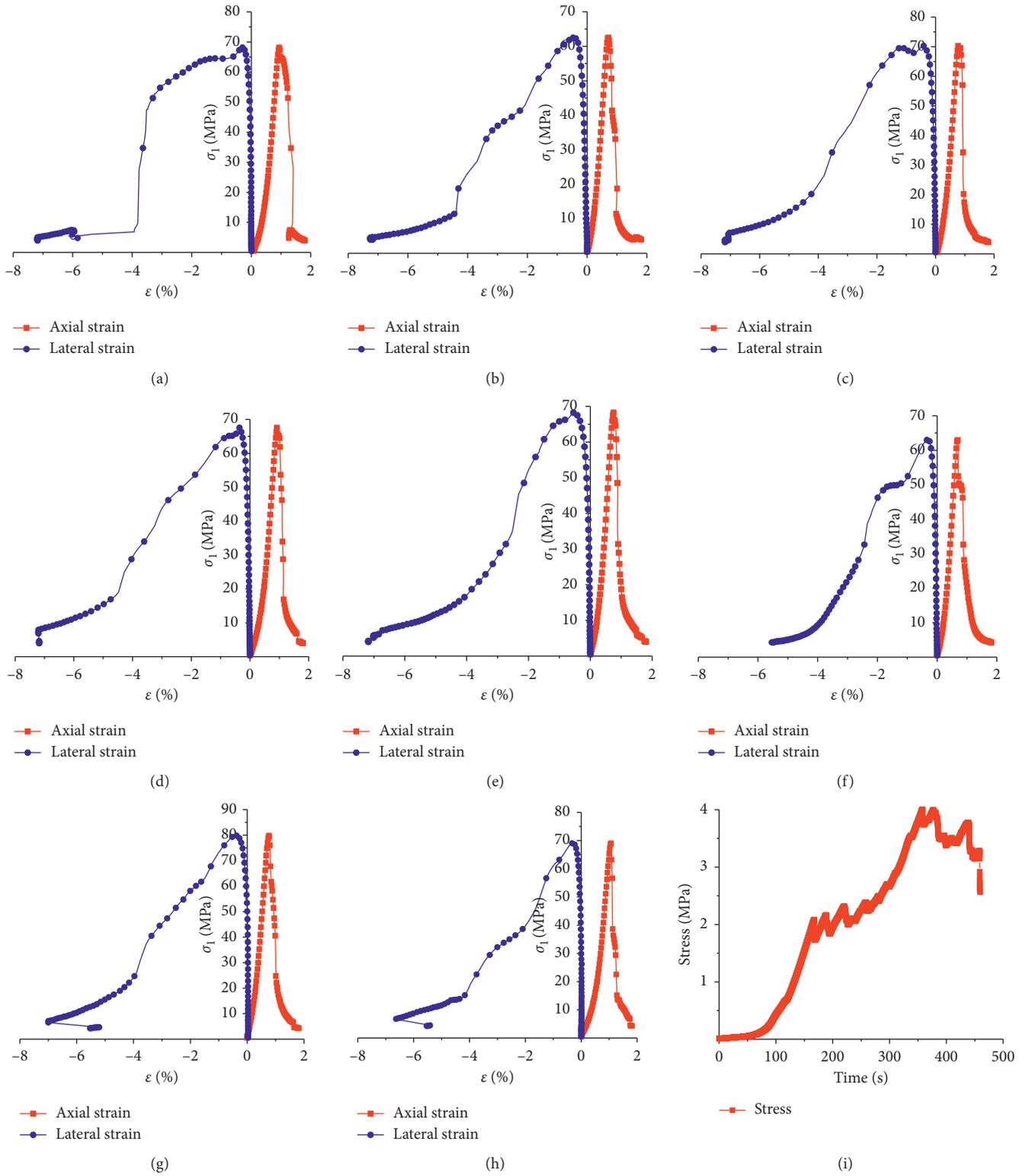


FIGURE 5: Continued.

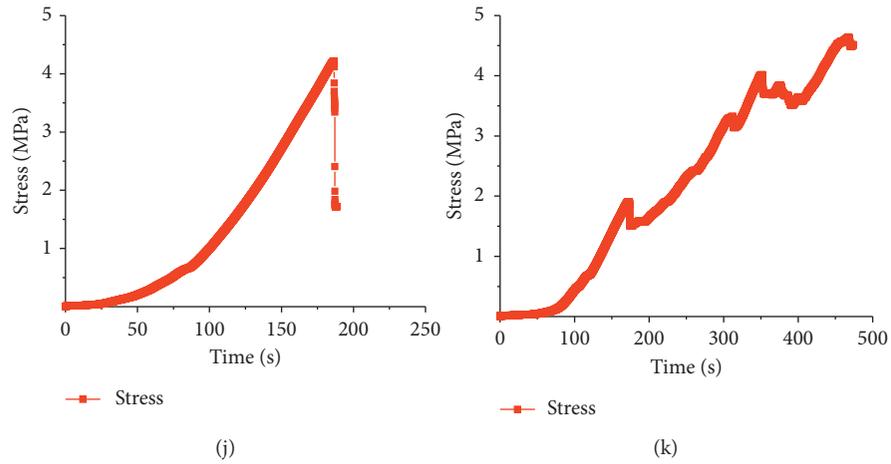


FIGURE 5: Deep tight sandstone tensile - compressive stress - strain curve. (a) S1-1. (b) S1-2. (c) S1-3. (d) S1-4. (e) S1-5. (f) S1-6. (g) S1-7. (h) S1-8. (i) Sm-1. (j) Sm-4. (k) Sm-5.

TABLE 3: Mechanical parameters of deep sandstone reservoir.

Number	Compressive strength (MPa)	Residual strength ( MPa )	Secant modulus (GPa)	Deformation modulus (GPa)	Tensile strength (MPa)
S1-1	68.156	3.978	5.271	7.218	
S1-2	62.612	3.884	7.273	8.918	
S1-3	70.296	4.496	6.870	9.077	
S1-4	67.835	6.800	5.442	7.289	
S1-5	68.266	5.205	7.273	9.057	
S1-6	63.144	4.281	7.308	9.239	
S1-7	80.103	4.460	8.711	10.480	
S1-8	69.170	6.719	4.671	6.530	
Sm-1					3.960
Sm-4					4.190
Sm-5					4.626

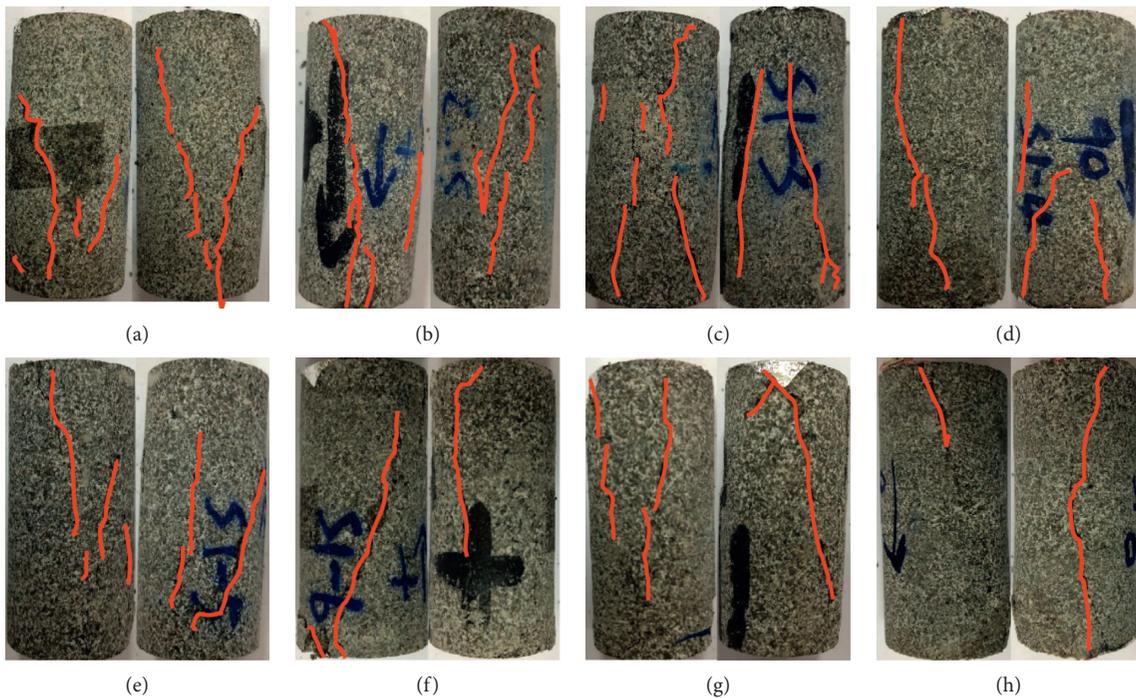


FIGURE 6: Continued.

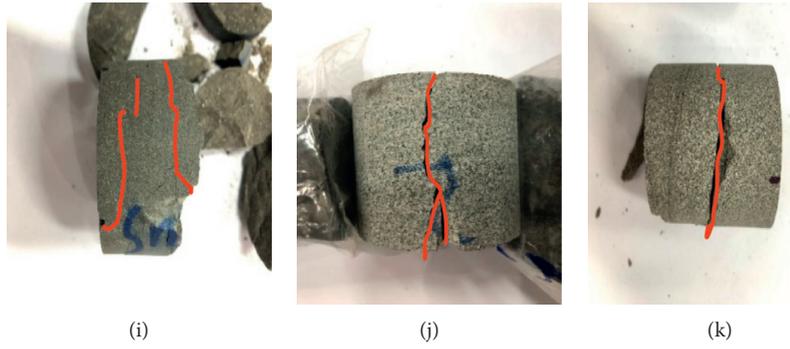


FIGURE 6: Failure mode diagram of deep sandstone compressive - tensile test. (a) S1-1 Shear failure. (b) S1-2 Tensile failure. (c) S1-3 Tensile failure. (d) S1-4 Tensile failure. (e) S1-5 Tensile failure. (f) S1-6 Shear failure. (g) S1-7 Shear failure. (h) S1-8 Tensile failure. (i) Sm-1 Shear failure. (j) Sm-4 Tensile failure. (k) Sm-5 Shear failure.

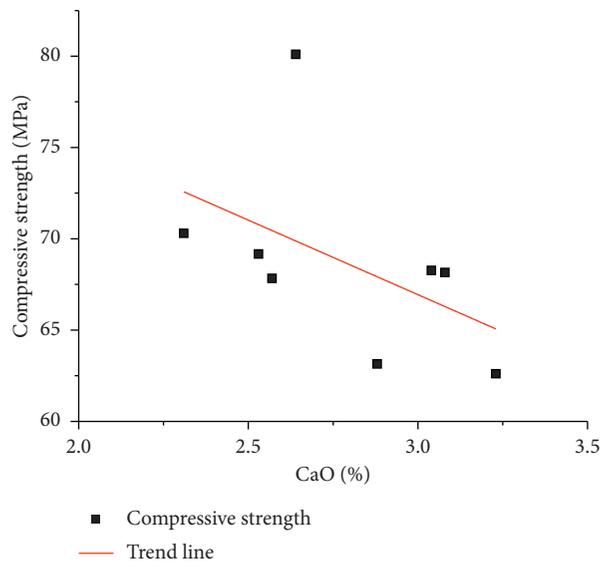


FIGURE 7: Relationship between mineral composition and peak strength in deep sandstone reservoirs.

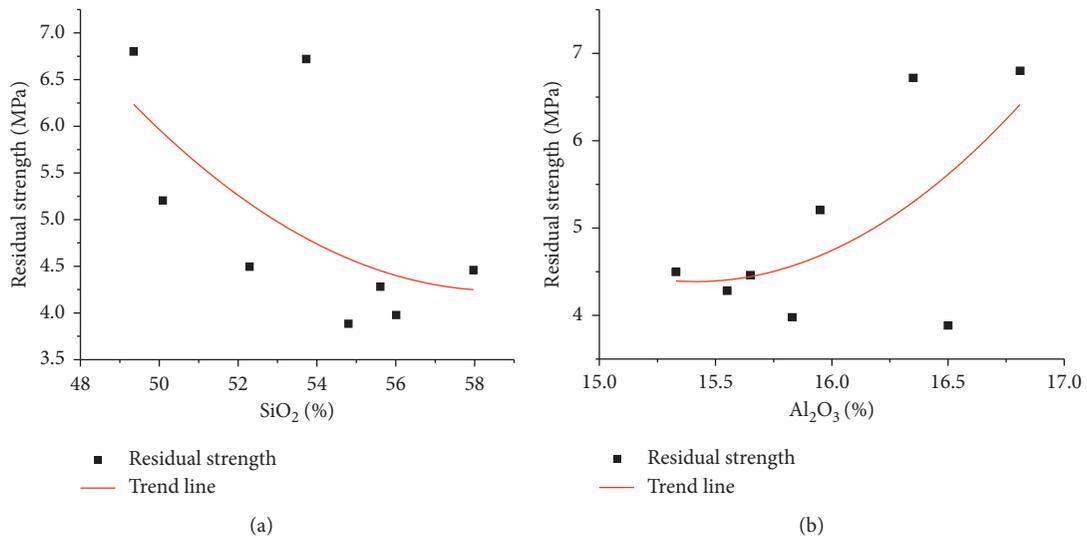


FIGURE 8: Continued.

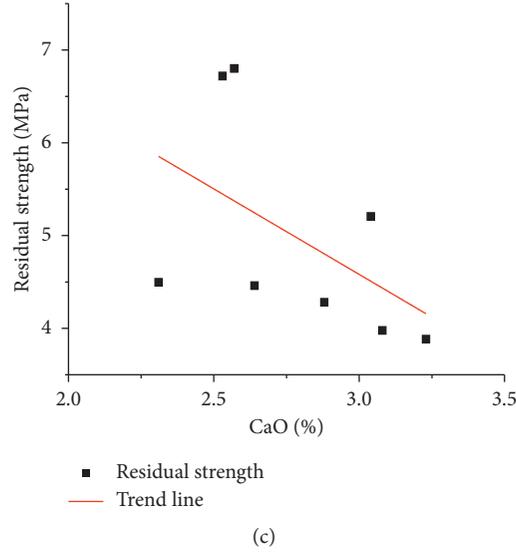


FIGURE 8: Relationship between mineral composition and residual strength of deep sandstone reservoir.

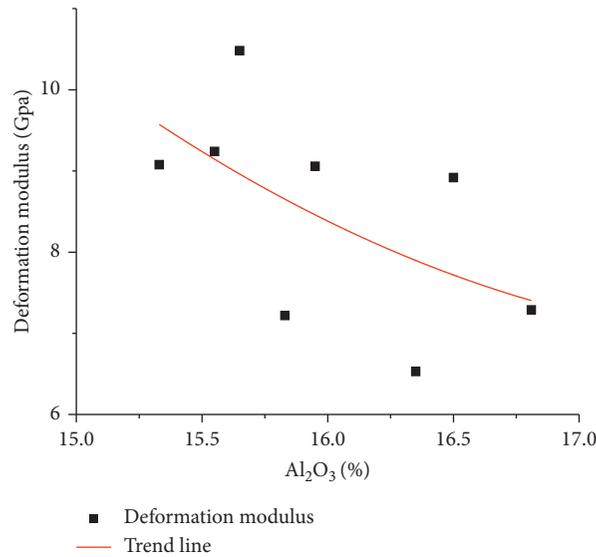


FIGURE 9: Relationship between mineral composition and deformation modulus of deep sandstone reservoir.

size of brittleness. The greater the brittleness, the more obvious the brittle characteristics of the rock, and the more brittle the rock. In this paper, the brittleness index considering the unsteady release of energy after the peak is used to calculate the brittleness of the sandstone sample. The calculation methods are as follows: where  $B_{re}$  is the brittleness,  $\int_0^{\epsilon_B} \sigma d\epsilon$  is the overall integral area of the stress-strain curve,  $(\sigma_B^2/2E_{AO})$  is the stored elastic energy, that is, the red triangle in Figure 11,  $\sigma_B$  is the residual strength,  $E_{AO}$  is the secant modulus, and  $\int_{\epsilon_A}^{\epsilon_B} \sigma d\epsilon$  is the area after the peak of the stress-strain curve.

$$B_{re} = \lg(B_r) = \lg\left(\frac{\int_0^{\epsilon_B} \sigma d\epsilon - \left(\frac{\sigma_B^2}{2E_{AO}}\right)}{\int_{\epsilon_A}^{\epsilon_B} \sigma d\epsilon}\right) \quad (1)$$

This calculation method of brittleness can fully consider the characteristics of a longer nonlinear elastic stage, a smaller plastic stage, etc. The method combines numbers and shapes, is intuitive, and is easy to calculate.

According to (1), the brittleness of each sample with different mineral composition is calculated as shown in Table 4:

**5.2. Effect of Mineral Composition on Brittleness.** The relationship between mineral composition and brittleness of deep sandstone reservoirs is shown in Figure 12.

The relationship between SiO<sub>2</sub> content and brittleness is shown in Figure 12(a), and the relationship between Al<sub>2</sub>O<sub>3</sub> content and brittleness is shown in Figure 12(b). It can be

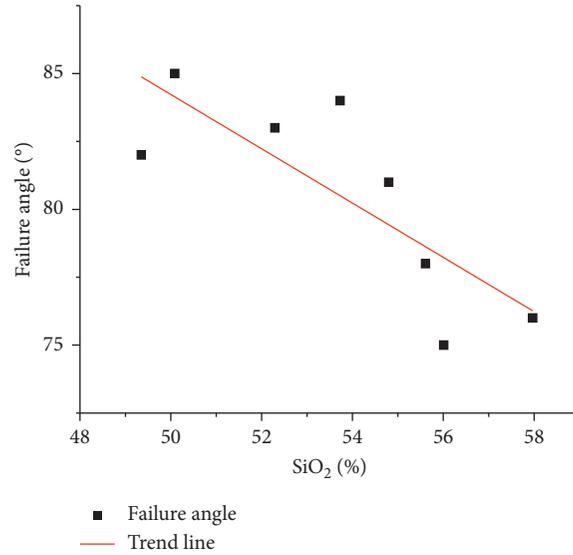


FIGURE 10: Relationship between mineral composition and failure angle of deep sandstone reservoir.

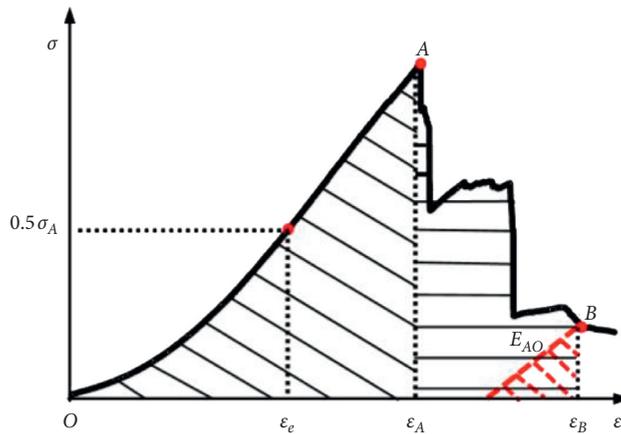


FIGURE 11: A geometric model for brittleness calculation [20].

TABLE 4: Brittleness calculation table of deep sandstone.

Number	$\int_0^{\varepsilon_B} \sigma d\varepsilon$	$\int_{\varepsilon_A}^{\varepsilon_B} \sigma d\varepsilon$	$(\sigma_B^2/2E_{AO})$	Brittleness
S1-1	49.107	26.343	1.501	0.0637
S1-2	34.854	16.252	1.037	0.094
S1-3	37.204	16.609	1.471	0.0935
S1-4	39.836	15.853	4.248	0.0979
S1-5	38.743	17.809	1.863	0.088
S1-6	36.863	19.560	1.254	0.0793
S1-7	47.819	21.307	1.142	0.0783
S1-8	39.869	13.704	4.832	0.1127

seen that the SiO<sub>2</sub> content in the deep sandstone reservoir samples of this experiment is between 49.35% and 57.97%, the Al<sub>2</sub>O<sub>3</sub> content is between 15.33% and 16.81%, and the brittleness is between 0.0637 and 0.1127. For the convenience of analysis, the Y-axis selection range is small, and it

can be seen that the variation range of sandstone reservoir brittleness is very small under different mineral contents. It can be seen from Figure 12(a) that the change of SiO<sub>2</sub> content has little effect on the brittleness of deep sandstone reservoirs, and the brittleness decreases slightly with the

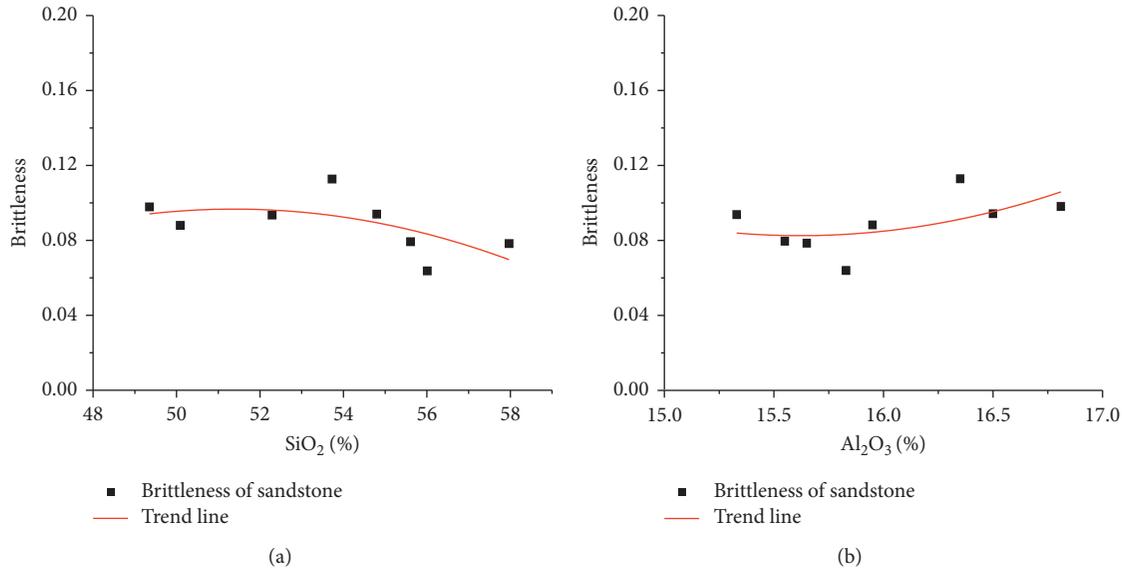


FIGURE 12: Relationship between mineral composition and brittleness of deep sandstone reservoirs.

increase of SiO<sub>2</sub> content. It can be seen from Figure 12(b) that the change of Al<sub>2</sub>O<sub>3</sub> content has little effect on the brittleness of deep sandstone reservoirs, and the brittleness increases slightly with the increase of Al<sub>2</sub>O<sub>3</sub> content.

## 6. Conclusion

In this paper, uniaxial compression tests, Brazilian splitting tests, and XRD are performed on deep sandstone reservoir samples with different mineral compositions. The effects of mineral composition on the compressive strength, tensile strength, residual strength, deformation modulus, secant modulus, brittleness, and other mechanical properties of deep sandstone reservoirs are compared and analyzed. The conclusions are as follows:

- (1) The XRD results show that the mineral compositions of deep sandstone reservoirs are mainly three kinds of oxides: SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO. The failure modes of deep sandstone reservoir samples under uniaxial compression are more complicated, with tension failure and shear failure each accounting for half. In the Brazilian split test, the failure modes of sandstone samples are mainly shear failure.
- (2) The CaO content has great influence on the compressive strength of deep sandstone reservoir, and the compressive strength decreases obviously with the increase of CaO content. The contents of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO all have a great influence on the residual strength of deep sandstone reservoirs. Al<sub>2</sub>O<sub>3</sub> has a great influence on the deformation modulus of sandstone. With the increase of Al<sub>2</sub>O<sub>3</sub> content, the deformation modulus decreases gradually.
- (3) Under the experimental conditions, the analysis of the mineral content and brittleness shows that SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> have little effect on the brittleness of deep sandstone reservoirs. The content of SiO<sub>2</sub> increases,

while the brittleness increases slightly. The content of Al<sub>2</sub>O<sub>3</sub> increases, while the brittleness decreases slightly.

- (4) Considering factors such as mineral composition, uniaxial compression test, Brazilian split test, and brittleness, SiO<sub>2</sub> content has the greatest influence on the mechanical properties of deep sandstone reservoirs, followed by Al<sub>2</sub>O<sub>3</sub> content, and CaO content has the least influence.

## Data Availability

All the data included in this study are available upon request to the corresponding author.

## Conflicts of Interest

There are no conflicts of interest.

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