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Research Article

Experimental Study on Dynamic Characteristics of Annular Coal Mine Sandstone after Different Temperatures

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The rock mass is the main carrier of underground engineering. Many rock engineering involves rock mass excavation, and the temperature of deep rock mass increases with the depth rising. The study on the dynamic mechanical properties of annular coal mine sandstone under different temperatures has important guiding significance for mine excavation and rock engineering design and construction. To research the effect of high temperatures on the physical and dynamic mechanical characteristics of annular coal mine sandstone specimens, the physical parameters of the samples after the heating temperature from 25°C to 500°C were tested, and the dynamic splitting tests under the same loading condition were conducted by using SHPB test equipment. The findings indicate that with the temperature rising, the volume of samples increases, the mass and density decrease, and the change rate of the physical parameters of the annular sample is a little greater than that of the intact sample; as the temperature goes up, the dynamic tensile strength increases first and then decreases, there is a quadratic polynomial relationship with temperature; both the dynamic strain and the average strain rate decrease first and then increase as the temperature grows, showing a quadratic polynomial relationship with temperature; the damage degree of the annular and intact samples become worse as the temperature improved, and the fragments of specimen increase obviously after 200°C.

1. Introduction

At present, underground space has been continuously expanded and developed. Shallow mineral resources have been unable to meet human needs, and deep mining has become an inevitable trend of mining development. The underground high temperature and strong disturbance aggravate the possibility of frequent disasters in deep engineering and the difficulty of prediction, and the geological environment of many rock engineering involves the mechanical properties of rock after high temperature. Rock mass excavation is often needed in tunnels, mine tunnels, and underground chambers. With the mining depth increasing, the temperature of deep rock mass will also increase, which can reach dozens or even several hundred degrees. When rock engineering is subjected to fire, explosion, and complex geothermal geological conditions, the mechanical characteristics of rock after different temperatures should be considered. Therefore, the research on the dynamic mechanical properties of annular coal mine sandstone after different temperatures has important guiding significance for the safety production and disaster prevention of rock engineering.

Scholars at home and abroad have conducted a lot of experimental research studies on the mechanical properties of rock under and after high temperature. In static mechanics, You [1] used marble samples with different inner diameters to conduct conventional triaxial compression tests

when the inner pore pressure was 0 and analyzed the influence of nonuniform stress distribution in the sample on the carrying capacity and deformation characteristics of the test piece. Xiao et al. [2] carried out uniaxial acoustic emission experiments on rock test pieces with holes and analyzed the relationship between the mechanical properties of rock samples and the position and diameter of holes. Yang [3] analyzed the crack propagation process of marble under different stresses by conducting a uniaxial compression test on samples with a single hole. Lian [4] performed uniaxial and triaxial compression experiments on granite test pieces with different apertures to analyze the intensity, deformation, and damage characteristics of granite test pieces under different confining pressure conditions. Wu et al. [5] conducted loading and unloading tests on thick-walled cylindrical limestone samples under different internal pressures and analyzed the failure mechanism of the samples under pressure relief conditions in holes. Zhu et al. [6] studied the influence of pore core distance and dip angle on sandstone intensity, deformation characteristics, and fracture evolution process by carrying out a uniaxial compression experiment on plate test pieces with prefabricated double circular holes. Du et al. [7] implemented uniaxial compression experiments on slab sandstone samples with prefabricated oval holes and discovered that the strength and deformation parameters of sandstone test pieces with holes were reduced compared with intact sandstone. The crack propagation process is described from the macroscopic point of view, without in-depth analysis from the microscopic point of view. Zhang et al. [8] performed uniaxial compression experiments on the marble of different numbers and diameters of holes and found that the peak strength of samples gradually decreased with the numbers and diameters of holes increasing. Su et al. [9] researched the relationship between mechanical characteristics and temperature by carrying out a uniaxial compression experiment on fine sandstone samples after high temperatures from 400°C to 1000°C. Du et al. [10] investigated the variation law of mechanical properties of granite with temperature by conducting a uniaxial compression experiment on granite cylindrical test pieces at room temperature and after high temperature treatment from 200°C to 800°C. The test pieces used in the experiment are not from the same rock, and the mineral composition inside the rock is different, which may cause the deviation and dispersion of the results. Zhang [11] carried out 5-stage uniaxial compression experiments under different loading rates on limestone samples at 200°C. Zhu et al. [12] performed a uniaxial compression experiment on test pieces from room temperature to 800°C and analyzed the deformation, intensity, and damage properties of fractured sandstone. Zhao [13] conducted uniaxial compression experiments on brittle rocks with circular holes and studied the fracture evolution process of brittle rocks with prefabricated circular holes. Chen [14] implemented uniaxial compression experiments on dry and saturated rock samples, respectively, and investigated the influence of saturated water on mechanical parameters of complete disc and ring rock samples.

In terms of dynamic mechanics, Sha [15] simulated the destruction process of rock ring samples to analyze the influence of the ratio of inner and outer diameter and loading rate of rock ring samples on the failure form of the sample. You [16] conducted a Brazilian splitting test on intact and annular specimens with different inner diameters of four rocks, to investigate the effect of water saturation on the intensity of rocks. Huang [17] carried out Brazilian splitting tests on intact and porous granite disc test pieces at normal temperature and after high temperature treatment from 150°C to 900°C, to research the relationship between mechanical properties and temperature. Zhang et al. [18, 19] performed Brazilian splitting tests on complete disc and annular sandstone samples with different pore sizes, the influence of the ratio of inner and outer pore sizes on the mechanical properties and damage characteristics of rock samples were studied. The effect of temperature change on rock mechanical properties is not involved. Wang et al. [20] carried out a radial compression test of annular granite under temperature-humidity cycling conditions by cooling the ring granite after being treated at a high temperature from 100°C to 700°C and immersing it in water temperature from 10°C to 70°C for maintenance. Ping et al. [21] used SHPB test equipment to carry out impact compression experiments on limestone specimens after temperature treatment from 25°C to 800°C under the same loading conditions, and the influence law of temperature on dynamic mechanical parameters was analyzed. Chen [22] conducted Brazilian splitting experiments on sandstone samples after different high temperatures and analyzed the damage evolution mechanism of sandstone under different temperatures. Xu and Liu [23] researched the changing rules of dynamic mechanical parameters by conducting impact compression tests on marble after different temperature treatments from 25°C to 1000°C. Ping et al. [24] conducted impact compression experiments on the coal mine roadway sandstone treated with water bath at different temperatures and analyzed the effects of water bath at different temperatures on the physical and dynamic mechanical characteristics of the rock. Du et al. [25] operated impact compression experiments on red sandstone samples and studied the relationship between dry wet cycle and mechanical characteristics of samples. Li et al. [26] conducted static and dynamic splitting experiments on marble annular samples of different inner diameters and analyzed the relation between the intensity and the ratio of internal diameter to external diameter under different loading rates.

The above-mentioned scholars have done a large number of experimental researches in exploring the static mechanical characteristics of rocks with holes and the static and dynamic mechanical characteristics of intact rocks after high temperatures, but the dynamic characteristics of rocks with holes after different heating temperatures need to be further studied. To analyze the effect of different heating temperatures on the physical and dynamic properties of annular sandstone, the physical parameters of annular and intact samples at normal temperature and after temperature treatment from 100°C to 500°C were measured before and after different temperatures. Under the same loading conditions, dynamic splitting tests of sandstone samples after different heating

temperatures were conducted by using SHPB test equipment.

2. Specimen Preparation and SHPB Test Device

2.1. Specimen Processing. The sandstone used in this test comes from Dingji Coal Mine in Huainan City. To strengthen the contrast of experiments, all samples are taken from the same stone. Based on the experiment procedure [27, 28], the intact sample with a diameter of 50 mm and a height of 25 mm and the annular sample with an external diameter of 50 mm, a height of 25 mm, and an inner diameter of 10 mm are processed from the same rock block.

2.2. Specimen Heating. Sandstone specimens are heated at high temperatures in a box-type resistor furnace. Firstly, there is a certain gap between the test pieces, and the annular and intact sandstone test pieces are evenly placed in the furnace. Close the furnace door and heat until the specified temperature is reached. Temperature setting points are 100°C, 200°C, 300°C, 400°C, and 500°C, respectively, and a group of normal temperature specimens are added for a comparative test, a totally 6 kinds of temperature gradients. In order to heat the specimens evenly and have the same temperature field inside and outside, the specimens are heated to a set temperature and kept at a constant temperature for 3 h. Finally, close the heating system and let the heated sandstone samples cool naturally to normal temperature in the furnace, open the furnace door and take out the samples, and record the quality, diameter, height, and aperture of samples.

2.3. SHPB Test Equipment. The SHPB test equipment of the State Key Laboratory of Mining Response and Disaster Prevention and Control of Deep Coal Mine is used to conduct dynamic splitting tests on annular and intact sandstone samples after experiencing different temperatures.

This experimental equipment consists of an incident rod, transmission rod, absorber rod, oscilloscope recorder, and super dynamic strain gauge. During the test, a spindle-type bullet is used and the bullet is pushed into the same location in the launching chamber tube every time, and impact pressure is adjusted to 0.3 Mpa each time, the sandstone samples are subjected to dynamic splitting tests under the same loading conditions, the sample holds as shown in Figure 1.

Figure 1: The clamping state of specimens.

3. Basic Physical Characteristics of Samples after Different Heating Temperatures

3.1. The Change of Sample Color. The color changes of annular sandstone samples after different treating temperatures are shown in Figure 2.

Figure 2 shows that the color of the specimen does not change significantly if the heating temperature is below 200°C. When the temperature reaches 300°C, the color of the sandstone surface begins to change, from gray-black to light reddish-brown. As the temperature goes up, the color gradually changes to dark reddish-brown, tapping the specimen gently makes a crisp sound.

3.2. The Basic Physical Parameters of Samples. The size and mass of annular and intact sandstone specimens at normal temperature and after different temperatures are measured one by one. The basic physical parameters are shown in Tables 1 and 2.

3.3. Specimen Volume, Mass, and Density Change. The change of volume expansion rate of a specimen with temperature is shown in Figure 3.

Figure 3 shows that the volume expansion rates of both specimens increase as the temperature improved. The volume of the two specimens is not significantly affected by temperature, and the volume expansion rate is relatively small in the range of 100°C~200°C, which may be due to the expansion of mineral grains in the sandstone when they are heated, occupying the initial micropores and microcracks inside samples, therefore, the volume increase rate is relatively small. The volume increase rate of the two specimens grows relatively fast if the temperature exceeds 200°C. As the temperature rises, the original micropores and cracks in the sample exceed the thermal stress limit of the structure, and new micropores and microcracks begin to emerge in the sandstone, resulting in a relatively large volume increase rate of samples. Besides, the volume increase rate of the annular test piece is a little higher than that of the intact test piece.

The relation between volume expansion rate and temperature is a quadratic polynomial, as shown in the following formula:

$$\begin{cases} V_{T1} = 1.0414 \times 10^{-6} T^2 + 0.0018T - 0.0230 \left(R^2 = 0.9877\right), \\ V_{T2} = 1.5020 \times 10^{-6} T^2 + 0.0012T - 0.0154 \left(R^2 = 0.9837\right), \end{cases} \tag{1}$$

where V_{T1} and V_{T2} are the volume expansion rate of annular and intact specimens, respectively, and T is the treating temperature.

The change of mass loss rate of samples with temperature is shown in Figure 4.

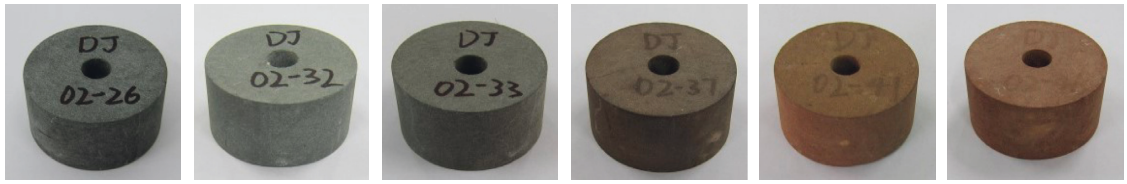

Figure 2: Color change of annular samples with the heating temperature: (a) 25°C, (b) 100°C, (c) 200°C, (d) 300°C, (e) 400°C, and (f) 500°C.

Table 1: Basic physical parameters of annular samples.

Temperature/°C	Specimen number	Before heating				After heating			
		Aperture (mm)	Diameter (mm)	Height (mm)	Quality (g)	Aperture (mm)	Diameter (mm)	Height (mm)	Quality (g)
25	DJ02-25	9.97	50.01	24.97	119.59	Unheated			
	DJ02-26	10.02	50.09	24.88	118.98				
100	DJ02-29	10.03	50.04	24.99	119.88	9.98	50.08	25.02	117.97
	DJ02-30	9.91	50.09	25.02	119.42	9.90	50.11	25.05	117.69
200	DJ02-35	10.05	50.03	25.03	119.95	9.98	50.01	25.12	116.53
	DJ02-36	9.94	50.09	24.99	118.75	9.85	50.11	25.05	115.30
300	DJ02-38	9.94	50.09	25.01	119.78	9.81	50.13	25.11	115.73
	DJ02-39	10.02	50.12	25.00	121.49	9.91	50.12	25.10	117.53
400	DJ02-41	10.02	50.14	24.96	120.67	9.86	50.21	25.08	116.23
	DJ02-42	9.95	50.08	25.03	118.08	9.79	50.18	25.13	114.07
500	DJ02-46	10.04	50.08	25.00	119.99	9.80	50.20	25.10	114.72
	DJ02-47	9.93	50.07	24.98	119.39	9.74	50.17	25.13	113.98

Table 2: Basic physical parameters of intact samples.

Temperature/°C	Specimen number	Before heating			After heating		
		Diameter (mm)	Height (mm)	Quality (g)	Diameter (mm)	Height (mm)	Quality (g)
25	DJ02-01	50.04	24.95	125.81	Unheated		
	DJ02-02	50.05	24.92	122.17			
100	DJ02-07	50.08	24.92	125.82	50.07	24.96	124.15
	DJ02-08	50.08	24.91	125.48	50.11	24.92	123.70
200	DJ02-09	50.06	24.91	125.21	50.05	24.96	120.68
	DJ02-10	50.03	24.95	125.38	50.06	24.97	121.88
300	DJ02-13	50.10	24.91	124.61	50.14	25.01	120.43
	DJ02-16	50.08	25.08	126.94	50.10	25.18	122.93
400	DJ02-18	50.08	25.00	125.76	50.15	25.13	121.41
	DJ02-19	50.10	25.05	125.14	50.19	25.14	120.62
500	DJ02-21	50.07	24.90	121.30	50.18	25.03	116.63
	DJ02-22	50.04	24.94	125.05	50.14	25.11	119.84

Figure 4 shows that the mass loss rate of both specimens rises as the temperature goes up, and the mass loss rate of specimens increases greatly when the temperature rises from normal temperature to 300°C. When the temperature exceeds 300°C, the increase in mass loss rate is relatively small. Analysis reasons: when the temperature is low, the free water and bound water in the specimen evaporate and escape, and when the temperature continues to rise, the cracks in the specimen increase, the structure deteriorates, and the separation of granular debris, leading to the mass loss of samples.

The mass loss rate of the test piece has a quadratic polynomial relationship with the heating temperature, as shown in the following formula:

$$\begin{cases} M_{T1} = -1.7842 \times 10^{-5} T^2 + 0.0179T - 0.2756 \left(R^2 = 0.9794\right), \\ M_{T2} = -2.0265 \times 10^{-5} T^2 + 0.0182T - 0.3291 \left(R^2 = 0.9813\right), \end{cases} \quad (2)$$

where M_{T1} and M_{T2} are the mass loss rate of annular and intact specimens, respectively, and T is the heating temperature.

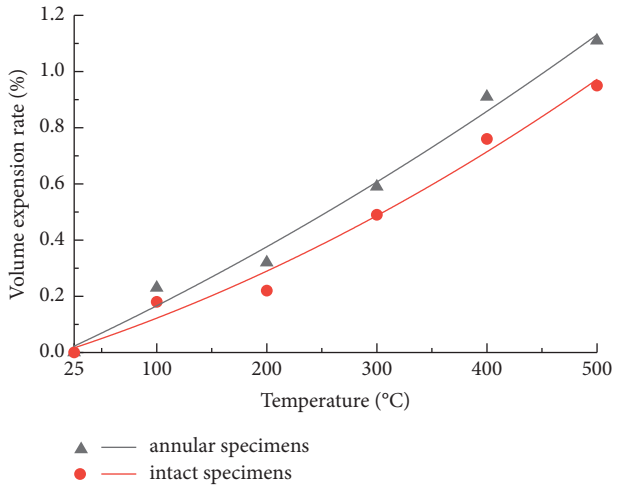

Figure 3: Volume expansion rate of samples after different temperatures.

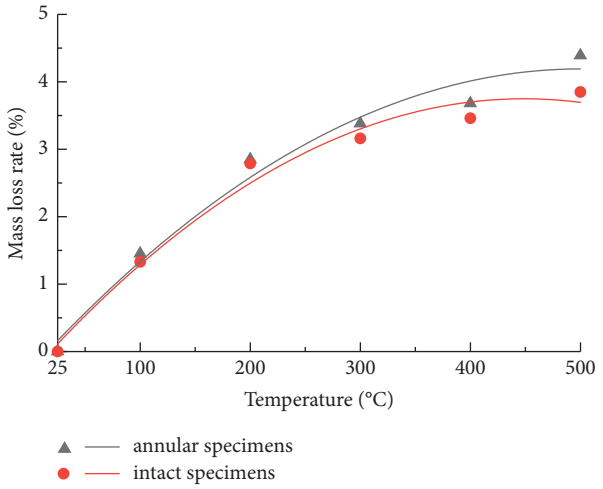

Figure 4: Variation in the mass of samples with heating temperature.

The change of density reduction rate of the specimen with temperature is shown in Figure 5.

Figure 5 shows that the density reduction rate of the annular specimen is slightly greater than that of the intact specimen, and the density reduction rate of both specimens increases as the temperature grows. The density reduction rate of the two kinds of specimens increases greatly when the temperature changes from room temperature to 300°C, and if the temperature exceeds 300°C, the density reduction rate of the two kinds of specimens increases relatively small. The decrease of specimen density is caused by the mass and volume changes of the specimen under the effect of temperature. As the temperature goes up, the mass of the specimen decreases and the volume increases, resulting in a decrease in the density of the specimen.

The decrease rate of specimen density increases as a quadratic function of temperature, as shown in the following formula:

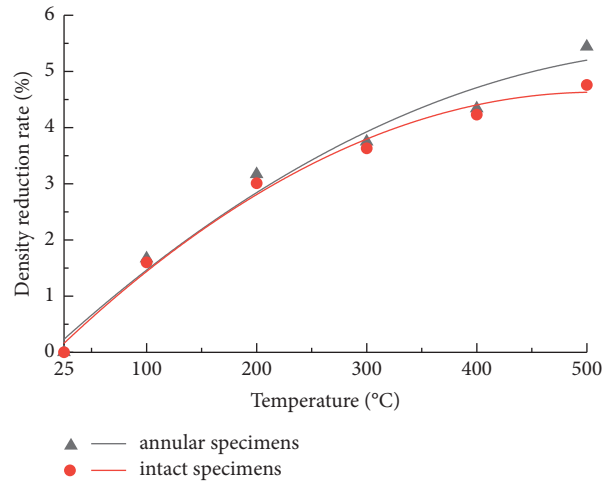

Figure 5: Density reduction rate of sandstone specimens after different temperatures.

$$\begin{cases} \rho_{T1} = -1.4844 \times 10^{-5} T^2 + 0.0183T - 0.2155 \left(R^2 = 0.9774\right), \\ \rho_{T2} = -1.9059 \times 10^{-5} T^2 + 0.0194T - 0.3138 \left(R^2 = 0.9894\right), \end{cases} \tag{3}$$

where ρ_{T1} and ρ_{T2} are the density reduction rates of annular and intact specimens, respectively, and T is the treating temperature.

3.4. Mineral Composition and Microstructure of Sample. X-ray diffraction and scanning electron microscope experiments were performed on SHPB impact test sandstone fragments at normal temperature and after high temperature. The typical XRD patterns and SEM pictures of sandstone after different temperatures are shown in Figures 6 and 7.

Figure 6 shows that the components of sandstone are mainly Quartz-SiO_2, Kaolinite-$Al_4(OH)_8(Si_4O_{10})$, Albite-$Na(AlSi_3O_8)$, and illite-$K(Al_4Si_2O_9(OH)_3)$ at normal temperature, accounting for 29.5%, 31.2%, 14.0%, and 25.3%, respectively. Microcline-$K(AlSi_3O_8)$ is formed when the temperature rises to 200°C. The composition of sandstone at 500°C is basically the same as that at normal temperature, but the content is different.

Figure 7 shows that there are micropores and microcracks in the sandstone at normal temperature. When the heating temperature rises from normal temperature to 200°C, the mineral grains in the sandstone expand when they are heated, occupying the primary micropores and microcracks inside test pieces, so the compactness and internal structure of the test piece are enhanced. When the temperature reaches 300°C, the primary micropores and microcracks in the sandstone test piece surpass the thermal stress limit of the structure, and the test piece begins to generate new microcracks. As the temperature keeps rising, the primary cracks and new cracks in the sandstone expand and connect, and the higher the temperature is, the more obvious the cracks

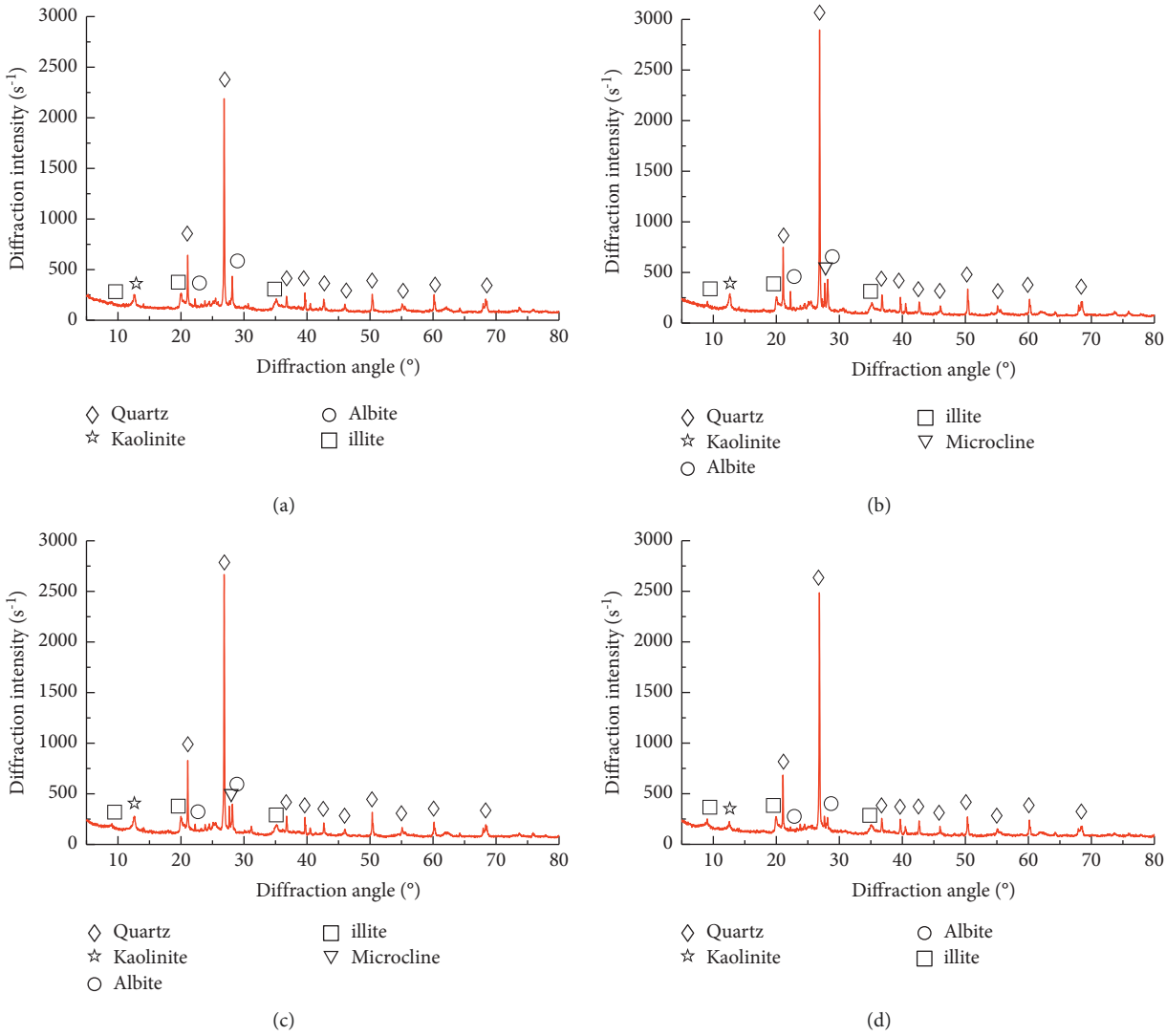

Figure 6: Typical XRD pattern after different temperatures: (a) 25°C, (b) 200°C, (c) 300°C, and (d) 500°C.

appear, and the macroscopic dynamic mechanical properties deteriorate as the temperature goes up.

4. Dynamic Splitting Mechanical Characteristics of Samples after Different Temperatures

4.1. Dynamic Stress-Strain Curve of Specimen. The dynamic stress-strain curves of annular and complete sandstone samples after different heating temperatures under the same loading conditions are shown in the given figures.

Figures 8 and 9 show that the dynamic stress-strain curves of annular and intact specimens are basically the same, but with slightly different shapes. Dynamic stress-strain curves of both annular and intact test pieces increase first and then decrease with the rise of dynamic strain. With the temperature increasing, the slope of curves increases firstly, after that, it reduces at the rising stage of both specimens. At the same temperature, the dynamic stress-strain curve of the annular sample is significantly lower than that of the intact sample.

4.2. The Variation Rules in Dynamic Tensile Strength. The relation between the dynamic tensile strength and the heating temperature of sandstone samples is shown in Figure 10.

Figure 10 shows that the dynamic tensile strength of both specimens increases first and then decreases with the temperature growth. The dynamic tensile strength of the two specimens reaches the maximum value at 200°C. Analysis reasons: after the specimen is heated, the internal mineral particles expand and fill the initial micropores and microcracks inside the sample, the compactness and internal structure of the sample are enhanced, so the tensile strength of the specimen is improved. As the treating temperature keeps rising, new microcracks occur in the

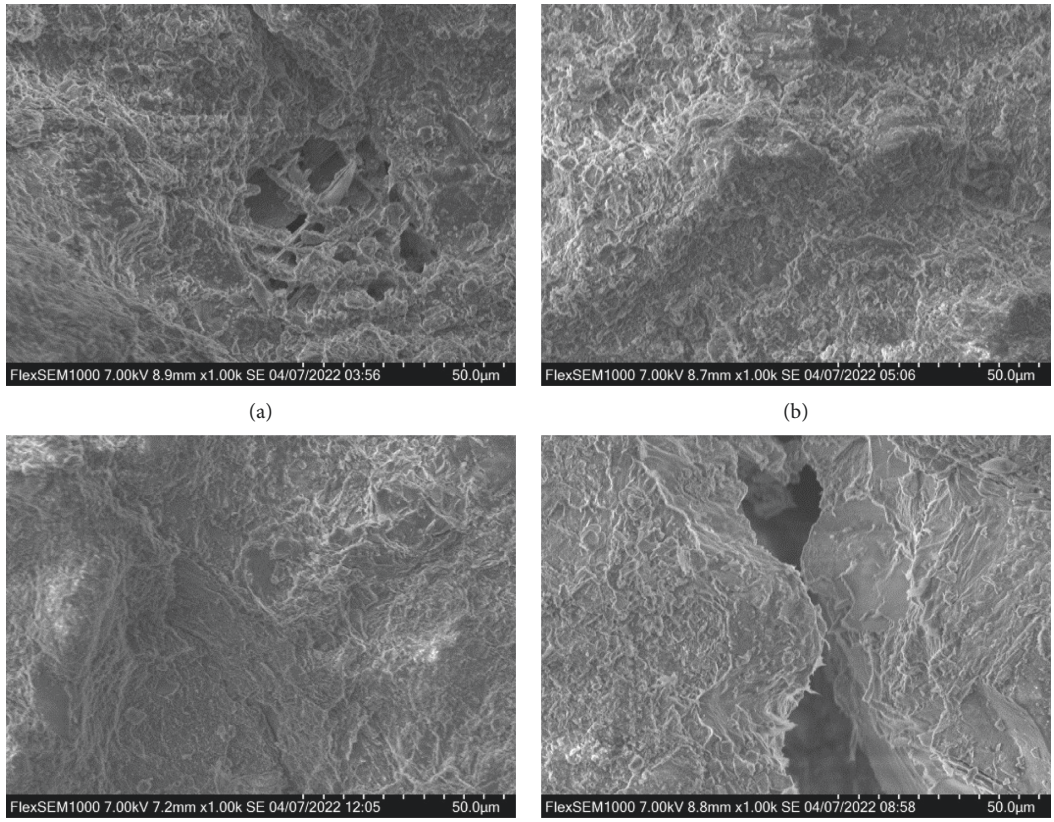

Figure 7: SEM images of sandstone after different temperatures (×1000): (a) 25°C, (b) 200°C, (c) 300°C, and (d) 500°C.

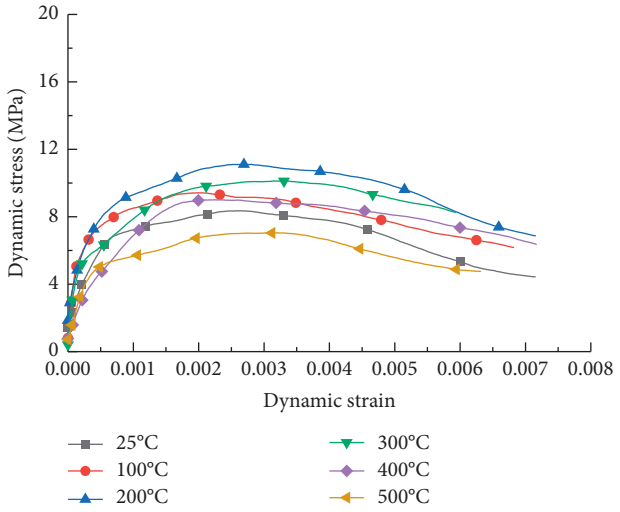

Figure 8: Dynamic splitting stress-strain curves of annular sandstone samples.

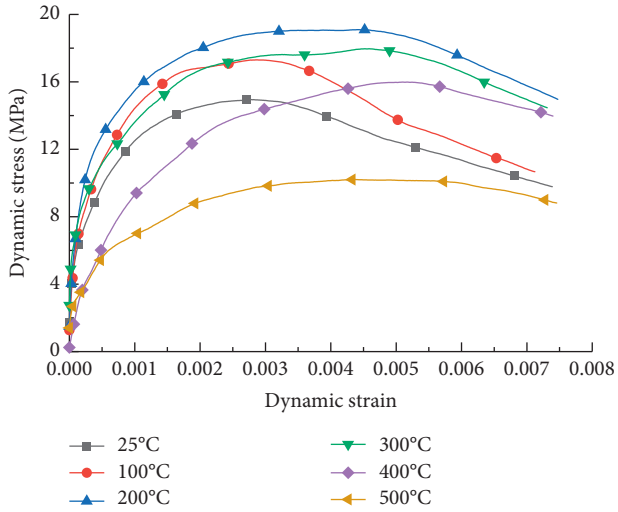

Figure 9: Dynamic splitting stress-strain curves of intact sandstone samples.

sample, the carrying capacity decreases, the microcracks increase, the structure further weakens, and the tensile strength of the test piece gradually decreases. The tensile strength of the annular test piece is lower than that of the intact test piece at the same temperature, indicating that the prefabricated holes reduce the bearing capacity of the sandstone specimens. There is a quadratic polynomial relationship between tensile strength and temperature, as shown in the following formula:

$$\begin{cases} \sigma_{T1} = -4.2202 \times 10^{-5} T^2 + 0.0192T + 8.9024 \left(R^2 = 0.9913\right), \\ \sigma_{T2} = -1.0502 \times 10^{-4} T^2 + 0.0447T + 14.7710 \left(R^2 = 0.9739\right), \end{cases} \tag{4}$$

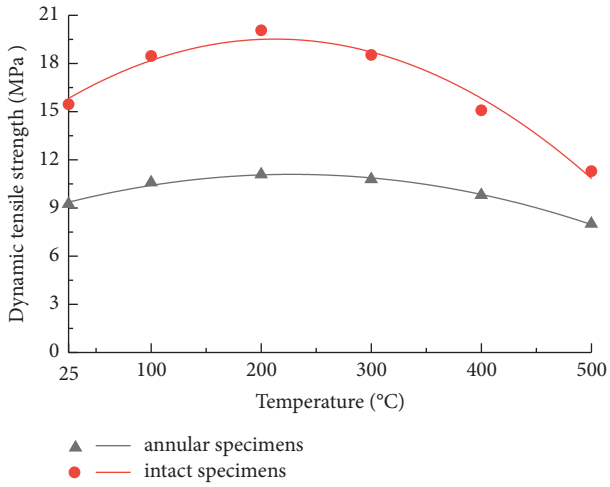

Figure 10: Dynamic tensile strength of samples after different temperatures.

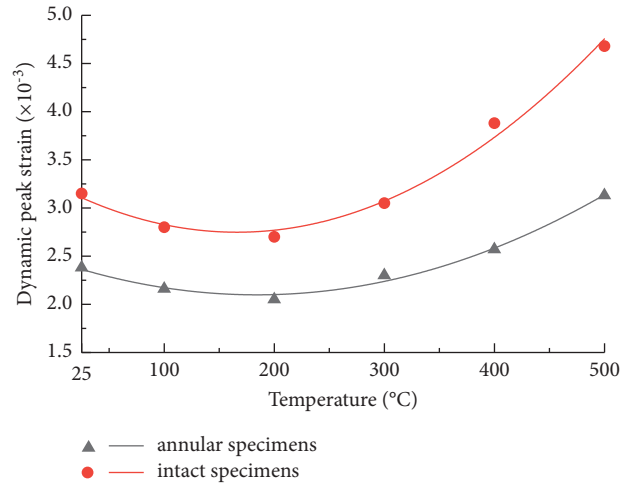

Figure 11: Dynamic peak strain of samples after different temperatures.

where σ_{T1} and σ_{T2} are the dynamic tensile strength of annular and intact test pieces, respectively, and T is the heating temperature.

4.3. The Variation in Peak Strain of Samples. The relation between the dynamic strain of samples and the heating temperature is shown in Figure 11.

Figure 11 shows that the peak strain of both specimens decreases firstly, after that, it increases as the temperature improved. The peak strain of the annular sample is smaller than that of the intact sample at the same temperature. Cause analysis: in the range of normal temperature to 200°C, mineral particles expand when heated, some primary microfractures are closed, and the number and area of defects are reduced to a certain extent, which makes the dynamic strain of sandstone samples show a decreasing trend. As the acting temperature continues to rise, new micropores and microcracks are generated in the sample and gradually expand and increase, resulting in the increase of dynamic strain. At 200°C, the dynamic peak strain of annular and intact samples reaches the minimum, which is 2.05×10^{-3} and 2.7×10^{-3}, respectively. The dynamic strains of annular and intact samples are 3.13×10^{-3} and 4.68×10^{-3} at 500°C, respectively, which are 32% and 49% higher than those at room temperature.

The dynamic peak strain of the specimen is a quadratic function of temperature, as shown in the following formula:

$$\begin{cases} \varepsilon_{T1} = 1.0421 \times 10^{-5} T^2 - 0.0038T + 2.4517 \left(R^2 = 0.9905\right), \\ \varepsilon_{T2} = 1.8008 \times 10^{-5} T^2 - 0.0060T + 3.2450 \left(R^2 = 0.9879\right), \end{cases} \tag{5}$$

Where ε_{T1} and ε_{T2} are the peak strain of the annular and intact samples, respectively, and T is the heating temperature.

4.4. The Variation Law of Average Strain Rate. The relation between the average strain rate of the test piece and the treating temperature is shown in Figure 12.

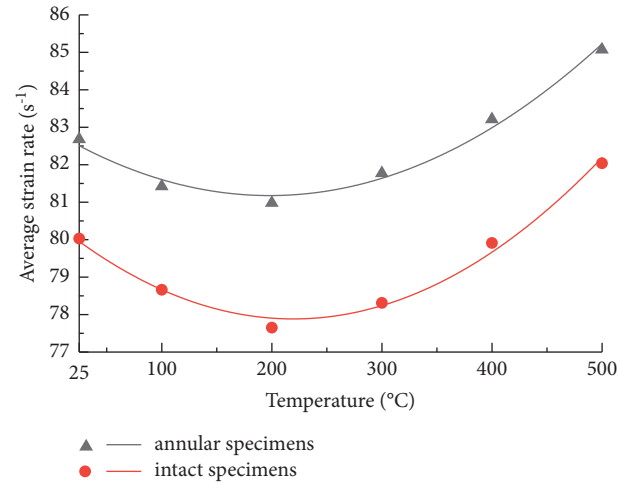

Figure 12: Average strain rate of sandstone specimens after different temperatures.

Figure 12 shows that the average strain rates of both samples decrease first and then increase as the temperature improved. The mean strain rate of the annular test piece is larger than that of the intact test piece under the same temperature condition. Average strain rates of both annular and intact specimens reach the lowest values at 200°C, 80.98s^{-1}, and 77.65s^{-1}, respectively. Analysis reasons: the average strain rate varies with temperature when the same impact pressure is used in the test. In the range of normal temperature to 200°C, the strength of the test piece rises with the temperature increasing and the average strain rate also increases. When the temperature surpasses 200°C, the strength of the test piece decreases as the temperature rises and the average strain rate also decreases. There is a quadratic polynomial relation between the average strain rate and temperature, as shown in the following formula:

Figure 13: Failure modes of annular and intact sandstone specimens after different temperatures: (a) 25°C, (b) 100°C, (c) 200°C, (d) 300°C, (e) 400°C, and (f) 500°C.

$$\begin{cases} \dot{\varepsilon}_{T1} = 4.4412 \times 10^{-5} T^2 - 0.0176T + 82.9182 \left(R^2 = 0.9826\right), \\ \dot{\varepsilon}_{T2} = 5.4698 \times 10^{-5} T^2 - 0.0240T + 80.5175 \left(R^2 = 0.9873\right), \end{cases} \tag{6}$$

where $\dot{\varepsilon}_{T1}$ and $\dot{\varepsilon}_{T2}$ are the average strain rate of the annular and the intact specimen, respectively, and T is the heating temperature.

4.5. Failure Mode of Specimens. The impact failure mode of annular and intact samples after experiencing different temperatures is shown in Figure 13.

As can be seen from Figure 13, The failure degree of the two specimens does not change significantly when the temperature rises from 25°C to 200°C. If the temperature exceeds 200°C, the damage degree of the two specimens becomes more and more serious as the temperature improved, and the fragments of the specimens gradually increase. Analysis reasons: when the temperature rises from normal temperature to 200°C, the sandstone mineral particles expand and fill the primary microcracks in the specimen, leading to the sample becoming denser and improving the intensity of the sample, thus reducing the failure degree of the sample. When the heating temperature surpasses 200°C, the expansion stress in the sample becomes larger and begins to produce new fractures. The primary fractures and new fractures in the sandstone expand and connect, resulting in structural deterioration and reducing the intensity of the specimen, thus aggravating the damage degree of the sample.

5. Conclusion

(1) The total porosity of the sandstone test piece increases as the temperature improved. The micropores and small cracks in sandstone gradually increase with the temperature rising. When the temperature surpasses 200°C, the cracks develop more fully and the primary cracks and new cracks in sandstone expand and connect, forming larger cracks, leading to structural deterioration.

(2) With the temperature rising, the volume of annular and intact specimens increases, while the mass and density decrease. In the range of room temperature to 500°C, the volume increase rate, mass loss rate, and density reduction rate of the two kinds of specimens increase with the rise of temperature and the change rate of physical parameters of the annular sample is slightly higher than that of the intact sample.

(3) The dynamic tensile strength of annular and intact samples increases firstly, after that, it decreases as the temperature improved and achieves the maximum at 200°C. The tensile strength of the annular sample is obviously lower than that of the intact sample at the same temperature.

(4) As the temperature improved, the peak strain and average strain rate of annular and intact samples decrease first and then increase. The peak strain of the annular sample is smaller than that of the intact sample, and the average strain rate is larger than that of the intact sample at the same temperature.

(5) As the temperature goes up, the damage degree of the annular and intact samples increases and the damage degree of the annular sample is slightly smaller than that of the intact sample. After 200°C, the fragments of the two specimens increase obviously.

Data Availability

The data used to support the study are included in the paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest in publishing this paper.

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