

Experimental investigation of the influence of microwave heating on the physical and mechanical properties of phyllite

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Abstract

This study aimed to investigate the influence of microwave heating on the physical and mechanical properties of phyllite with different bedding angles. This research is based on wave velocity and uniaxial compression tests conducted on phyllite samples that were previously subjected to microwave heating. The results show that some samples experience microcracks, fragmentation, and melting after microwave heating. Microcracks tend to appear along bedding planes. The wave velocity of the sample decreases rapidly after microwave heating with increasing microwave power and irradiation time. For the same microwave heating time, the uniaxial compressive strength initially increases but then decreases with increasing microwave power. For the same microwave power, the uniaxial compressive strength decreases with increasing microwave time. When the microwave power reaches 4 kW for 4 min, the uniaxial compressive strength of the samples decreases by a maximum of 30.53%. The uniaxial compressive strength of the sample with a bedding angle of 30° decreases the most, by 31.97%. The uniaxial compressive strength of phyllite is closely related to the bedding angle. Moreover, microwave radiation has a slight effect on the fracture modes of the samples. Under high-power microwave heating, the minerals in the phyllite undergo phase changes and compositional changes, resulting in damage to the phyllite.

Keywords

Microwave, Phyllite, Bedding angle, Wave velocity, uniaxial compressive strength



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Introduction

Microwave radiation generates rapid heating of the rock, resulting in thermal stress within the rock. Under the influence of high temperatures, the internal structure and mineral composition of rock change, thus causing damage to or fracture of the rock (Kingman et al., 2000; Xu et al., 2021). Therefore, microwave-assisted rock breaking is considered a technology that reduces the tool wear rate and improves rock breaking efficiency (Haque, 1999a).

Scholars have recently conducted many experimental and theoretical studies on the influence of microwave radiation on the physical and mechanical properties of rock (Tab. 1). Satish et al. (2006), Hassani et al. (2016), Yao et al. (2023) studied the physical properties of rocks under microwave heating and discussed the variation of rock strength under microwave heating. Hartlieb et al. (2012) compared the experimental results with those from the numerical model. Due to the temperature gradient in the samples induced by microwave irradiation, significant damage is indicated by a reduction in sound velocity, ultimately leading to the formation of cracks. The study of Feng et al. (2021) showed that true triaxial stress can inhibit the development and distribution of thermal cracks during microwave-induced surface fracturing.

The effects of microwaves on rock are affected by several factors. Scholars have found that the effects of microwave heating on rock are affected by moisture (Peinsitt et al., 2010), microwave heating path (Gao et al., 2020), types of rock-forming minerals (Lu et al., 2017), types of rocks (Gao et al., 2022), particle size and morphology (Lin et al., 2023).

Scholars have also explored the mechanism of the effects of microwave radiation on rocks from a microscopic perspective (Lan et al., 2020; Yao et al., 2021; Zhang et al., 2023). They have studied the effect of microwave heating on the microstructure of rocks using computed tomography (CT), scanning electron microscopy (SEM), and nuclear magnetic resonance (NMR).

Tab. 1. The influence of microwave radiation on the physical and mechanical properties of rock

The subject of the study	Researchers	Findings
The strength of basalt before and after microwave radiation through point load tests	Satish et al. (2006)	Basalt is extremely sensitive to microwave radiation
The effect of microwave heating on basalt	Hartlieb et al. (2012)	The temperature gradient caused by microwave radiation leads to significant damage to basalt samples
The effects of microwave radiation on the strength reduction of different types of hard rock	Hassani et al. (2016)	The uniaxial tensile and compressive strengths of rock decreased with increasing microwave radiation time and power level
The effect of microwave on the physical and mechanical properties of sandstone	Yao et al. (2023)	The uniaxial compressive strength of sandstone initially increased but then decreased with increasing microwave radiation time and power
A test system for microwave-induced fracturing of hard rocks under true triaxial stress	Feng et al. (2021)	The mechanism of rock fracture damage under actual triaxial stress under microwave radiation
The impact of moisture on the heating rate, wave velocity, and strength of various types of rock under microwave radiation	Peinsitt et al. (2010)	The microwave heating rates in dried and water-saturated samples of basalt, granite, and sandstone were largely different
The effect of microwave heating paths on the temperature response of rock	Gao et al. (2020)	The surface temperature gradually decreased from the center to the edge in the radial direction
The interaction effect between microwaves and the main rock-forming minerals	Lu et al. (2017)	Different rock-forming minerals presented very different susceptibility induced by microwave treatment.
The fracture characteristics of sandstone, granite, and gabbro after microwave irradiation	Gao et al. (2022)	The fracture characteristics of the rock were closely related to the main components, the rock-forming minerals content, and the moisture content
The influence of particle size and morphology on the mechanism of microwave heating on micro-cracks in coal and rock	Lin et al. (2023)	The change in morphology of the ore affected the microwave cracking characteristics
The mechanism of microwave heating on micro-cracks in coal and rock	Lan et al. (2020)	Three main generation mechanisms of micro-cracks in coal and rock were obtained
Thermal properties of sandstone under microwave radiation	Yao et al. (2021)	The rock damage was a result of the development of intragranular fractures
The evolution of seepage characteristics of oil shale under microwave radiation	Zhang et al. (2023)	Microwave power had a significant effect on the pore structure and permeability of oil shale

Rocks in nature are not homogeneous, and the mechanical properties of some rocks with bedding structures are significantly affected by bedding. Deng et al. (2018) reported that the bedding angle affects the strength and

failure mode of rock. Chen et al. (2005) discussed the anisotropic strength criterion of a jointed rock mass. Chen et al. (2014) conducted triaxial compression tests on black shale samples with different bedding angles. They discussed the influence of bedding angle and confining pressure on the mechanical behavior and failure mode of black shale. Zhao et al. (2012) conducted a three-point bending test on layered marble and observed the test in real time via electron microscope scanning. The strength characteristics and fracture mechanism of layered marble in different stress directions were analyzed.

In summary, scholars have researched the weakening of the law and the mechanism of rock mechanical properties after microwave radiation and have achieved many results. Microwaves are characterized by selective heating (Haque, 1999b). Few studies have been conducted on the response characteristics of heterogeneous rock with bedding under microwave radiation. Therefore, this work aims to fill this gap by exploring the influence of microwave heating on the mechanical properties of layered rock, thereby evaluating the industrial applicability of microwave-assisted rock breakage technology. Combined with thermogravimetric tests, the thermal damage mechanism of microwaves on phyllite was also analyzed.

Experimental Materials and Methodology

Rock Samples

The phyllite sample is dark gray. Mineral compositions of the phyllite were determined through X-ray diffraction (XRD) test. The XRD pattern (Fig. 1) demonstrates that the phyllite mainly consists of 30.0% quartz, 34.5% chlorite, 28.2% muscovite, and 7.3% feldspar. The rock is cored to obtain standard cylindrical samples with a diameter of 50 mm and a height of 100 mm. When drilling the core, different bedding angles are considered, and five cases of $\beta = 0^\circ, 30^\circ, 45^\circ, 60^\circ$, and 90° are taken, as shown in Fig. 2.

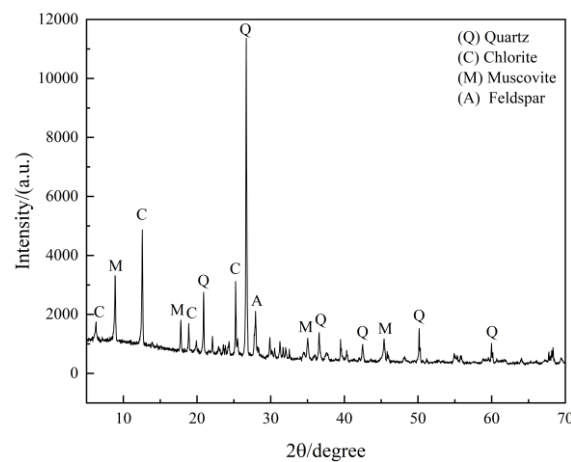


Fig. 1. XRD analysis of phyllite



Fig. 2. Schematic diagram of a typical sample

Fig. 3 shows the thermogravimetric curves and differential thermal curves of the phyllites in the range of 25–1000°C. In the range of 0–400°C, the thermogravimetric curve decreased slowly, and the mass decreased by only 0.03%. The main reason for the mass loss was the evaporation of bound water in the sample.

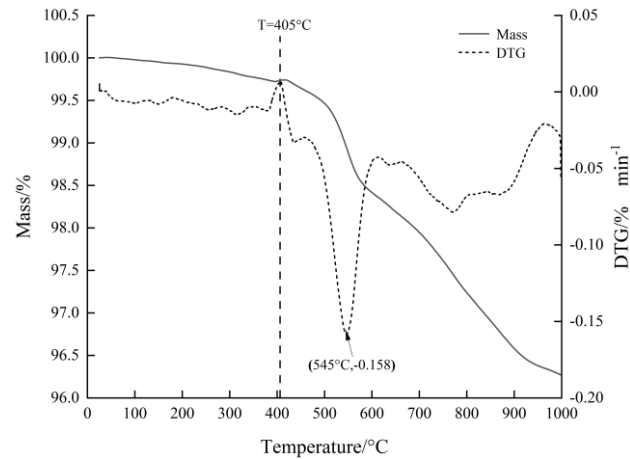


Fig. 3. Thermogravimetric curve of phyllite

As shown in Fig. 3, in the range of 400~900°C, the decrease rate of the thermogravimetric curve increased significantly, and the mass decreased by 3.4%. When the temperature exceeds 405°C, the phyllite enters the weight-loss stage, especially above 421°C. Table 2 summarizes the thermal reactions of minerals in phyllite. The structural water loss of chlorite and muscovite occurs at 550°C and 750°C, respectively. Quartz undergoes a phase transition from the α phase to the β phase at 573°C. The primary reason for the mass loss is that high temperatures induce phase changes or compositional changes in the mineral composition of the phyllite.

Tab. 2. Thermal reactions and corresponding temperatures of the minerals

Mineral type	Temperature/(°C)	Thermal reaction	Researchers
Quartz	573	Gradual transformation from the α phase to the β phase	Geng & Sun, 2018
Chlorite	550	Constitution water losses	Zanazzi et al., 2009
Muscovite	750	Constitution water losses	Guggenheim et al., 1987
Feldspar	1134	Melt	Johnson & McCauley, 2005

Experimental Methodology

To avoid the influence of the moisture content of the sample on the test, the sample was placed in an oven before the test, dried at 110°C for 24h, and then placed in a drying dish and cooled to room temperature. Before microwave heating, samples with the same bedding angle were tested for wave velocity, and samples with large differences in wave velocity were eliminated. The wave velocity test used a non-metallic ultrasonic detector ZBL-U5100, and the test method was based on the "Standard for test method of engineering rock mass" (GB/T 50266-2013).

The microwave heating test instrument used was a CM-06S multimode resonant cavity industrial microwave oven. The microwave frequency is 2.45 GHz, and the power is adjustable from 0 kW to 6 kW. The higher the microwave power, the more significant the damage to the rock (Hassani et al., 2016). Therefore, taking 4 kW as the experimental basis, considering the number of experimental materials in this batch, 2 kW and 4 kW were selected as the microwave powers for the test.

After heating to a predetermined time at a constant microwave power, the sample was placed in a dry dish and cooled to room temperature for wave velocity and uniaxial compression tests. The uniaxial compression test used the IRSM-RC-1500 rock uniaxial compression and shear apparatus, which was controlled at a displacement loading rate of 0.06 mm/min. Some samples were broken or melted at the end of microwave heating, and no mechanical tests were carried out on these samples. The influence of microwave heating on the physical and mechanical properties of phyllite was investigated by analyzing morphology, wave velocity, uniaxial compressive strength, and failure modes of samples under different microwave powers and heating times.

Results and Analysis

Morphology

Table 3 summarizes the morphological changes in the phyllite samples after microwave heating. Under the condition of 2 kW heating for 4 min, 4 of the 6 samples had no noticeable change in morphology, and microcracks along the bedding plane appeared on the surface of 2 samples, as shown in Fig. 4 (a). Under the condition of 4 kW heating for 2 min, 8 of the 20 samples showed irregular microcracks, as shown in Fig. 4 (b), and four samples were broken along the bedding plane, as shown in Fig. 4 (c). In the case of 4 kW heating for 4 min, 2 of the nine samples

appeared to melt and crush. As shown in Fig. 4(d), the sample was accompanied by a prominent rock burst sound before melt crushing. One sample broke along the bedding plane, and the remaining samples produced more obvious microcracks.

Tab. 3. Morphological changes in phyllites with different bedding angles after microwave irradiation

Microwave power	Bedding angle/(°)	Number	Morphology change	Whether to carry out a mechanical test
2 kW, 4 min	0	P2	Microcracks along the bedding plane	Yes
	0	P3	No significant change	Yes
	0	P4	Microcracks along the bedding plane	Yes
	90	V2	No significant change	Yes
	90	V3	No significant change	Yes
	90	V4	No significant change	Yes
4 kW, 2 min	0	P5	No significant change	Yes
	0	P6	No significant change	Yes
	0	P7	Irregular microcracks	Yes
	30	A2-4	No significant change	Yes
	30	A2-5	Irregular microcracks	Yes
	30	A2-6	Irregular microcracks	Yes
	45	A3-4	Crushing along the bedding plane	No
	45	A3-5	Irregular microcracks	Yes
	45	A3-6	Irregular microcracks	Yes
	45	A3-7	Crushing along the bedding plane	No
	45	A3-8	Crushing along the bedding plane	No
	45	A3-9	Crushing along the bedding plane	No
	45	A3-10	Microcracks along the bedding plane	Yes
	45	A3-11	Microcracks along the bedding plane	Yes
	60	A4-4	Irregular microcracks	Yes
	60	A4-5	Irregular microcracks	Yes
	60	A4-6	Irregular microcracks	Yes
	90	V5	Microcracks along the bedding plane	Yes
4 kW, 4 min	90	V6	No significant change	Yes
	90	V7	No significant change	Yes
	0	P9	Microcracks along the bedding plane	Yes
	0	P10	Melting fragmentation	No
	0	P11	Crushing along the bedding plane	No
	0	P12	Irregular microcracks	Yes
	0	P13	Irregular microcracks	Yes
	90	V8	Microcracks along the bedding plane	Yes
	90	V9	Melting fragmentation	No
	90	V10	Microcracks along the bedding plane	Yes
	90	V11	Microcracks along the bedding plane	Yes

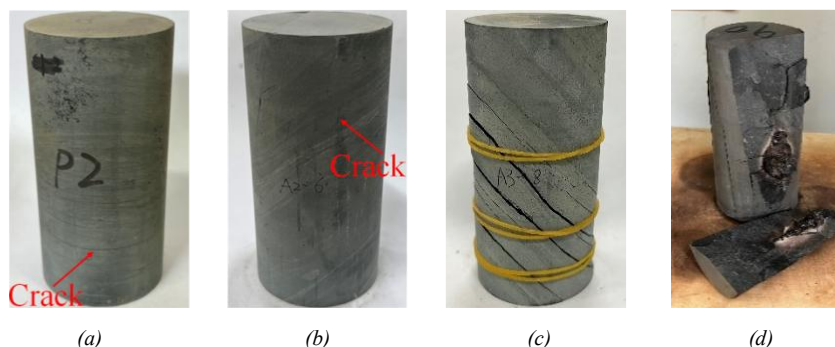


Fig. 4. Morphological changes in phyllite after microwave heating: (a) Microcracks along bedding planes (after 2 kW, 4 min); (b) Irregular microcracks (after 4 kW, 2 min); (c) Crushing along bedding planes (after 4 kW, 2 min); (d) Melting fragmentation (after 4 kW, 4 min)

From the perspective of crack initiation, the cracks generated by a sample after microwave heating are carried out randomly along the bedding. Nevertheless, the probability of cracks occurring along bedding planes is greater, especially when a sample is broken during microwave heating, and fracture surfaces expand along bedding planes (as shown in Fig. 4 (c)). The reason for this phenomenon is related to the structure of the bedding plane. Deng et

al. (2018) reported that microscopic pores and cracks have developed in the bedding planes, while the mineral particles in the matrix structure are closely arranged, resulting in few pores and cracks. Under microwave radiation, rock minerals absorb microwave energy and convert it to heat energy. As the temperature of a sample increases, the incompatibility of the thermal expansion of minerals inside the rock will produce thermal stress, which will induce cracks. For rocks with apparent bedding, cracks can quickly expand along bedding planes with noticeable microscopic pores and cracks. Different minerals have different microwave absorption capacities. The inhomogeneous distribution of minerals in the rock increases the local temperature of the sample in the area where the minerals with strong microwave absorption capacity are concentrated, resulting in melting failure. Lu et al. (2017) found similar results in their study on the thermal properties of the main rock-forming minerals. The strong microwave absorber enstatite started to melt after 2 minutes of microwave treatment.

Some studies have also shown that microwave heating can cause cracks or even rock melting. After the basalt in Lu et al. (2020) is irradiated by microwaves, the crack propagation at both ends of the sample is radial at the approximate center position. The main crack is approximately parallel to the cylindrical busbar, and the central and branch cracks run through the entire sample surface. With increasing irradiation time, the sample cracked and broke. The sandstone studied by Yang et al. (2022) developed macroscopic cracks extending along the axial direction after high-power, short-term microwave heating. In contrast, high-power, long-term microwave heating caused the sandstone sample to melt and be destroyed. For the phyllite in this work, because the sample has prominent bedding characteristics, it is more likely to have macroscopic cracks and fracture surfaces along bedding planes. Melting failure may also occur under high-power and long-term microwave irradiation. For example, samples P10 and V9 melted after heating for 4 min at a microwave power of 4 kW. The rock materials are highly complex and heterogeneous (Lu et al., 2017), which is why other samples did not melt under the same microwave power and heating time.

Wave Velocity

Microwave heating causes different degrees of damage inside rock. The longitudinal wave velocity of rock can better reflect the damage to the rock. Taking the unbroken samples at 0° and 90° as examples, the wave velocities of the tested samples before and after microwave heating are shown in Fig. 5.

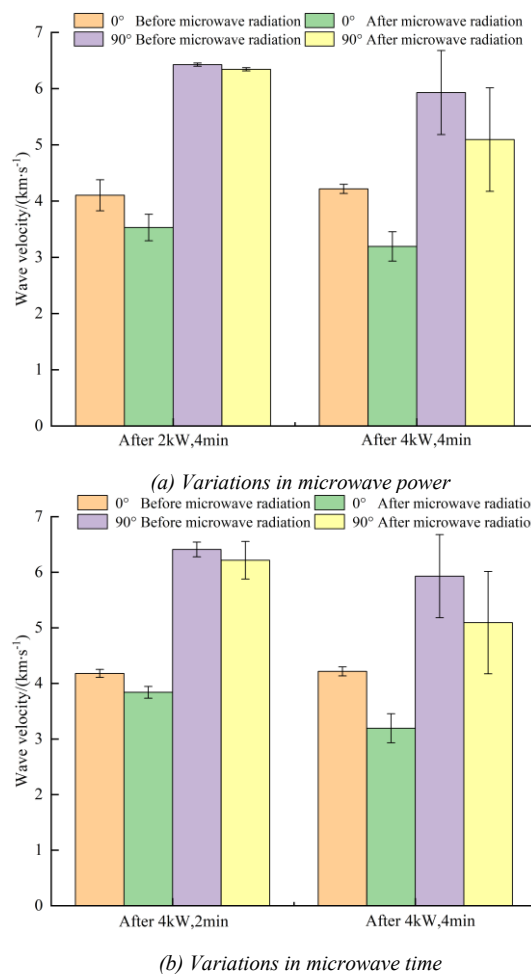


Fig. 5. Variations in the wave velocity of phyllite

Under the same microwave radiation time conditions, as the microwave power increases from 2 kW to 4 kW, the wave velocity of the sample decreases rapidly. Compared with the average wave velocity of the sample before microwave heating, after 2 kW and 4 kW microwave heating, the average decreases in the wave velocity of the 0° sample are 14.0% and 24.3%, respectively, and the average reductions in the wave velocity of the 90° sample are 1.3% and 14.1%, respectively, as shown in Fig. 5 (a). The reduction in the wave velocity of the 0° sample is much greater than that of the 90° sample. For a microwave power of 4 kW, compared with the average wave velocity of the sample before microwave heating, the average decreases in the wave velocity of the 0° sample from 2 min to 4 min are 8.1% and 24.3%, respectively, and the average reduction in the wave velocity of the 90° sample is 3.0% and 14.1%, respectively, as shown in Fig. 5 (b).

The above results show that for the same microwave time, the greater the microwave power, the more significant the decrease in the wave velocity of the sample. For the same microwave power, the longer the microwave irradiation time, the more significant the decrease. Yao et al. (2023) studied the effect of microwave on the physical and mechanical properties of sandstone. Their work also indicated that with an increase in microwave heating power and time, the wave velocity of the sample decreased further.

Compressive strength

Fig. 6 shows the relationships between the uniaxial compressive strengths of the 0° and 90° phyllites and the microwave power after microwave heating for 4 min. Compared with those of the samples without microwave heating, the average uniaxial compressive strengths of the 0° and 90° samples increased by 17.06% and 1.42%, respectively, after 2 kW of microwave heating. After 4 kW of microwave heating, the average uniaxial compressive strengths of the 0° and 90° samples decreased by 30.53% and 23.01%, respectively. These findings indicate that lower-power microwave heating increases the strength of phyllite, which is similar to the strength of sandstone under microwave radiation (Yao et al., 2023). The main reason is that the temperature of the sample does not increase significantly when the microwave power is 2 kW and the heating time is 4 min. Microwave heating does not cause damage to the sample; rather, it increases its strength due to the evaporation of bound water within the sample. When the microwave power increases to 4 kW, the temperature of the sample increases significantly, inducing damage, and its strength decreases accordingly.

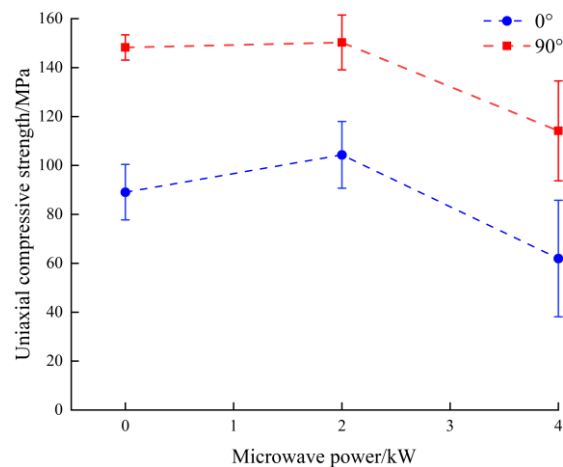


Fig. 6. Relationship between uniaxial compressive strength and microwave power

Fig. 7 shows that when the microwave heating power was 4 kW, the uniaxial compressive strength of the phyllite gradually decreased with increasing microwave irradiation time. Compared with the average value of the sample without microwave heating, the average uniaxial compressive strength of the 0° and 90° samples decreased by 9.09% and 16.94%, respectively, after 2 min of microwave heating. After 4 min of microwave heating, the average uniaxial compressive strengths of the 0° and 90° samples decreased by 30.53% and 23.01%, respectively. Lu et al. (2019) found similar results in their study. The uniaxial compressive strength decreased with increasing irradiation time.

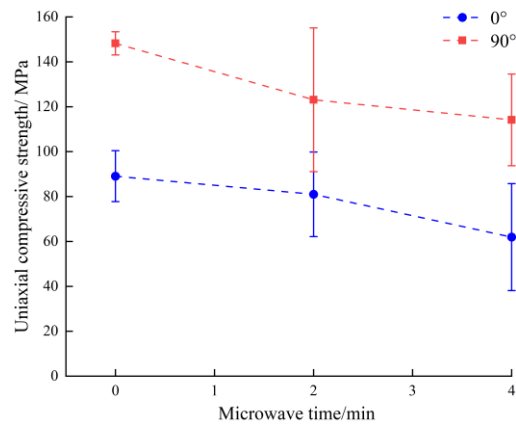


Fig. 7. Relationship between uniaxial compressive strength and microwave time

The relationship between the uniaxial compressive strength and bedding angle of the phyllite after microwave irradiation is shown in Fig. 8. The uniaxial compressive strength of phyllite without microwave radiation is the lowest when the bedding angle is 45° , and the maximum strength occurs when the bedding angle is 90° . The uniaxial compressive strength at 90° is approximately 2.57 times greater than that at 30° , and the variation range of the uniaxial compressive strength is 57.8–148.2 MPa. Chen et al. (2014) and Deng et al. (2018) studied the influence of bedding angle on the mechanical properties of sandstone and shale, respectively. Their work indicated that with an increase in bedding angle, the uniaxial compressive strength of sandstone and shale initially decreased and then increased, a result similar to that of this paper.

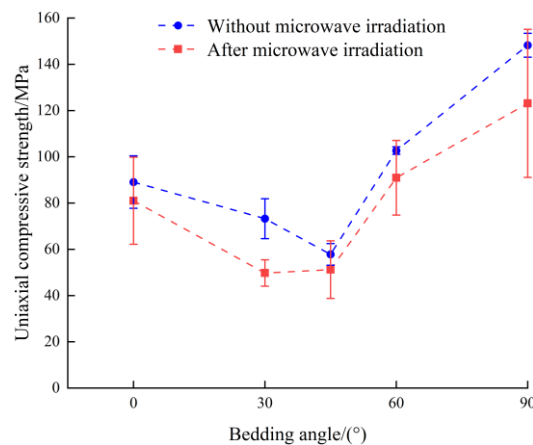


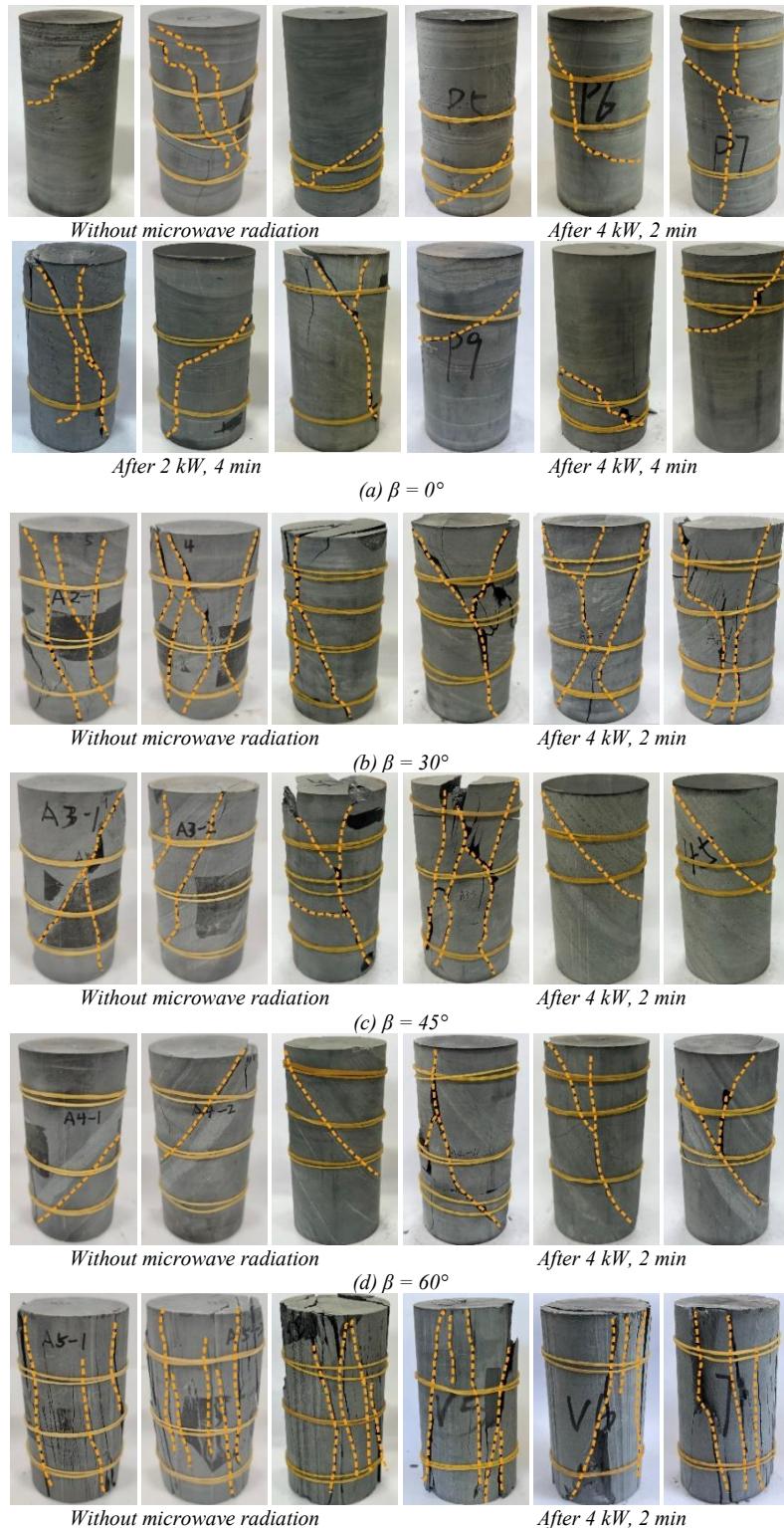
Fig. 8. Relationships between uniaxial compressive strength and bedding angle of phyllite with and without microwave radiation

After heating for 2 min at a microwave power of 4 kW, the uniaxial compressive strength of all the samples tended to decrease. The uniaxial compressive strength of the sample with a bedding angle of 30° decreased the most, by 31.97%. The uniaxial compressive strength of phyllite under microwave irradiation is the lowest when the bedding angle is 30° and the highest when the bedding angle is 90° . The uniaxial compressive strength of the samples subjected to microwave radiation is similar to that of the samples without microwave radiation, and the uniaxial compressive strength is closely related to the bedding angle.

Analysis of the Sample Failure Mode

The damage photos of typical rock samples are shown in Fig. 9. When $\beta = 0^\circ$, there is no uniform form. Shear cracks and tensile cracks through bedding planes lead to the instability and failure of the sample. The shear crack angle of most samples is slight, and some samples are damaged locally. After microwave heating, microcracks along the bedding plane appear in specimen P9, and the fracture surface develops along the microcracks when the sample is destroyed. When $\beta = 30^\circ$, the shear crack and tensile crack also cut through the bedding plane, which led to the instability and failure of the sample. The sample exhibits multiple fracture surfaces, resulting in shear failure across multiple bedding planes. Irregular microcracks were generated in sample A2-6 after microwave heating. When the sample was destroyed, a fracture surface developed along the microcracks. When $\beta = 45^\circ$, the sample is dominated by shear failure; some are single fracture surfaces, and some have multiple fracture surfaces. Sample A3-5 produced irregular microcracks after microwave heating. When the sample was destroyed, numerous fracture surfaces developed along the microcracks. Sample A3-10 produced

microcracks along bedding planes after microwave heating. When the sample was destroyed, there was only one fracture surface, and the fracture surface developed along the microcracks. When $\beta = 60^\circ$, the sample is also dominated by shear failure, and the fracture form is relatively simple. The sample without microwave radiation has only a single shear fracture surface. The sample heated at 4 kW for 2 min exhibited a Y-shaped failure formed by shear and tensile cracks. Irregular microcracks appeared in samples A4-4, A4-5, and A4-6 after microwave heating, and the fracture surfaces of the samples developed along the microcracks when they were destroyed. When $\beta = 90^\circ$, the significant feature of sample failure is splitting tensile failure along bedding planes, with multiple fracture surfaces. After microwave heating, microcracks along the bedding plane appear in sample V5, and the fracture surface develops along the microcracks when the sample is destroyed.



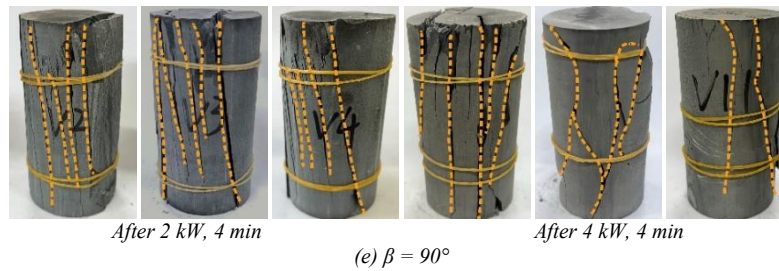


Fig. 9. Failure modes of the phyllite samples with different bedding angles

Overall, the fracture mode of phyllite is affected mainly by the bedding angle, and the effect of microwave radiation on the fracture mode of the sample is insignificant. For some samples, new cracks are generated during microwave irradiation, which affects the mode of uniaxial compression fracture. However, some samples did not produce microcracks during microwave irradiation, which did not significantly affect their uniaxial compression fracture mode.

Analysis of the thermal damage mechanism

The damage to the phyllite samples caused by microwave radiation was caused mainly by temperature. Microwave radiation significantly increases the temperature of a sample. On the one hand, thermal stress will be generated within the rock; on the other hand, the minerals that comprise the rock will undergo phase changes and compositional changes, which will cause damage to the rock.

The sensitivity of rock-forming minerals to microwaves is the main factor for the heating characteristics of rocks. Table 4 shows the dielectric constant and thermal expansion coefficient of the main minerals of phyllite. The dielectric constants of different minerals vary, and their absorption capacities for microwave energy differ, resulting in varying temperatures for various minerals under the same microwave radiation conditions. The thermal expansion coefficients of different minerals also differ, and the expansion deformation under the action of temperature significantly differs. Therefore, the sample generated thermal stress during the microwave radiation process, resulting in both macroscopic and microscopic cracks, which led to a decrease in the strength of the phyllite, especially under high microwave radiation power conditions for prolonged periods.

Tab. 4. Thermal expansion coefficient and dielectric constant of minerals

Mineral type	Thermal expansion coefficient (1/K)	Dielectric constant	Researchers
Quartz	1.60×10^{-5}	4.72	Pressacco et al., 2023
Chlorite	1.11×10^{-5}	8.63	Li et al., 2019
Muscovite	3.57×10^{-5}	6.50	Ulian & Valdrè, 2015
Feldspar	7.50×10^{-6}	5.55	Pressacco et al., 2023

Additionally, high temperatures caused by microwave radiation can lead to phase changes or compositional changes in rock minerals. After heating at a microwave power of 2 kW for 4 min, 33.3% of the phyllite samples exhibited microcracks, and the mineral temperature did not increase significantly. The above test revealed that the uniaxial compressive strength of the sample increased after heating for 4 min at a microwave power of 2 kW, and microwave heating did not cause damage to the sample. When the microwave parameters were further increased to 4 kW, 2 min, 4 kW, and 4 min, the temperature of the phyllite minerals further increased. After heating for 2 min and 4 min at a microwave power of 4 kW, 75% and 77.8% of the phyllite samples showed microcracks or breakage, respectively. The diffraction peaks of chlorite, muscovite, and feldspar in the X-ray diffraction pattern have disappeared after heating for 4 min at a microwave power of 4 kW, as shown in Fig. 10. The diffraction intensity of quartz decreased, which was caused by the phase transition of quartz (Zhang, 2017). This is the same as the result of the previous thermogravimetric analysis. The mineral composition of the phyllite caused phase transitions and composition changes due to high temperatures, resulting in damage to the sample and a significant reduction in its uniaxial compressive strength.

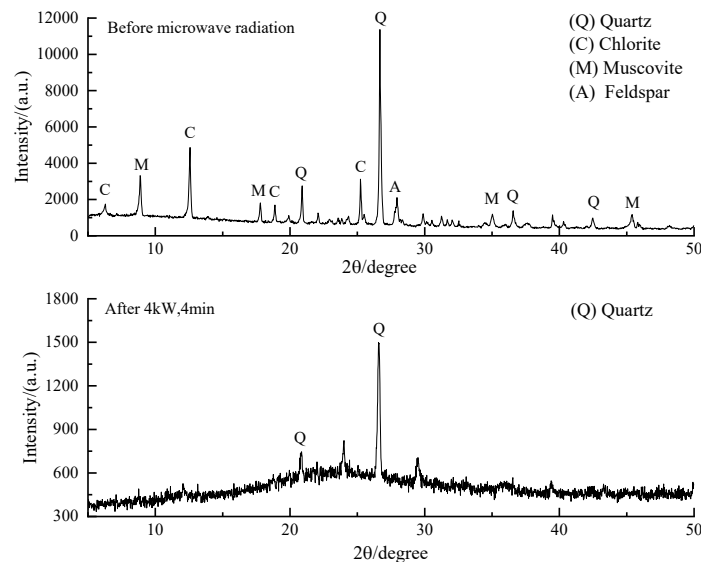


Fig. 10. X-ray diffraction patterns of phyllite with and without microwave radiation

Conclusions

This paper describes the influence of microwave heating on the physical and mechanical properties of phyllite. Tests were conducted for bedding angles of 0°, 30°, 45°, 60°, and 90°. The test results are as follows:

(1) After microwave heating, some samples experienced microcracks, fragmentation, and melting; microcracks and fracture surfaces extended along bedding planes; and the wave velocity decreased rapidly. The wave velocity decreased with increasing microwave heating power and time.

(2) For the same microwave heating time, the uniaxial compressive strength initially increased but then decreased with increasing microwave power. For the same microwave power, the uniaxial compressive strength decreased with increasing microwave time. When the microwave power reached 4 kW for 4 min, the uniaxial compressive strength of the samples decreased by a maximum of 30.53%. Low-power microwave heating increased the uniaxial compressive strength of the phyllite due to the evaporation of bound water in the sample. High-power microwave heating caused damage to the sample, resulting in a significant decrease in its uniaxial compressive strength. When the microwave power reached 4 kW for 2 min, the uniaxial compressive strength of all the samples tended to decrease. The uniaxial compressive strength of the sample with a bedding angle of 30° decreased the most, by 31.97%. The uniaxial compressive strength after microwave irradiation is closely related to the bedding angle.

(3) The fracture mode of phyllite is affected mainly by the bedding angle; the effect of microwave radiation on the fracture mode of the sample is insignificant. Some phyllite samples produced new cracks during microwave irradiation, and the mode of uniaxial compression fracture was affected.

(4) The dielectric constants and thermal expansion coefficients of different minerals in phyllite are different, which leads to thermal stress during microwave irradiation, resulting in macroscopic and microscopic cracks and reduced phyllite strength. Under high-power microwave heating, the minerals in the phyllite undergo phase changes and compositional changes, resulting in damage to the phyllite.

High-power microwave heating will cause damage to the rock, resulting in a significant decrease in its uniaxial compressive strength. The combination of microwave heating technology and mechanical rock breaking technology can address the issue of tool wear in mechanical rock breaking equipment, which has a significant impact on drilling, tunnel boring machines (TBMs), and continuous mining of ore.

This study only considers dry phyllite, which is a discussion under certain conditions. In practical engineering, rock contains a certain amount of water, and its response to microwave heating needs further experimental analysis and discussion.

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