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Research Paper

Experimental study on mechanical and porous characteristics of limestone affected by high temperature

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HIGHLIGHTS

- The thermal effect (25–600 °C) on both porous and mechanical parameters of limestone was studied.
- The critical point of the variation of several parameters of samples was found.
- The change law of the porous and mechanical parameters versus temperature was divided into several phases to discuss.

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ABSTRACT

This paper experimentally studied the changes in mechanical and porous characteristics of limestone heated to high temperature (up to 600 °C). The results showed that ① 200 °C and 500 °C are two special temperature point of limestone under the high temperature effect, and the most mechanical and pore parameters change a lot before and after them; ② Below 200 °C, the mechanical and porous characteristics of limestone samples hardly change; ③ In 200–500 °C, the cumulative pore volume, porosity, and pore volume fractal dimension rapidly increase, among which, the porosity increases by about 900%; the peak strength and elastic modulus suddenly decrease by 31.2%, and the peak strain sharply rises by 65.4%; ④ In 500–600 °C, the porous parameters are relatively stable; the peak strength slowly decreases, while the peak strain continuously increases; the elastic modulus continues to decline quickly, the Poisson's ratio drops suddenly, and the hardness decreases from mid-hard to soft. This research is of significance for the variation of physical and mechanical properties in response to thermal treatment of the rock.

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1. Introduction

With science and technology rapidly developing in recent years, nuclear engineering construction, underground coal gasification and geothermal resource development doom quickly. All these directly and indirectly heat underground rock strata and lead to great changes in physical and mechanical properties of rocks affected by high temperature, which put forward a difficult problem in the field of rock mechanics necessary to be solved [15,8].

Many researchers have studied this problem and achieved some progresses. Wu and Qin [12], Wu et al. [13] experimentally investigated changes in mechanical properties of rocks heated by different temperatures, such as its compressive strength and deformation parameters (such as strain, the number of cracks, porosity) as well as the evolution of ultrasonic wave velocity in it. Sergio and Ernest [11] studied and analyzed the localization characteristics of strain caused by Solnhofen limestone under 600 °C in the process of direct shear. In their three point bending test, Zuo et al. [16] studied the changes in fracture, elastic modulus, and ductility ratio of sandstone subject to different temperatures. Homandetienne and Houpert [4] qualitatively and quantitatively studied the effects of microstructure damage of Senones and Remirement granite at 20–600 °C on their mechanical properties. Chen et al. [2] dealt with the changes in swelling characteristics and microstructures of limestone and sandstone.

Due to different diagenetic environments, physical and mechanical properties of the same kind of rocks at different places are often different [18]. In this respect, few were reported on physical and mechanical properties of sedimentary rocks such as limestone subject to high temperature treatment [6,5,9,10]. Based on this, the paper centered its attention on the variation in mechanical and porous properties of limestone (which is one of the most

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widely distributed rocks in the earth's crust) at temperature from 25 °C to 600 °C. The results can be used to predict and evaluate the stability and safety risks of underground engineering projects after fire disaster, and provide a theoretical basis for their repair, reinforcement, support, and so on.

2. Experimental studies

2.1. Description of rock samples

The limestone samples used in this study were taken from Linyi, Shandong Province, China. They are grey at room temperature, and oolitic veins can be found on some of their surface. The test specimens with average density of 2.71 g/cm^3 have uniform texture and were cut into normative Φ50 × 100 mm cylinders. The height allowed error is about 5 mm, the diameter error is not more than 0.3 mm, and the maximum no parallelism of end faces is 0.05 mm. The end faces should be perpendicular to the specimen axis, and the maximum deviation is less than 0.25°. The porosity of limestone samples is very small at room temperature, and the data inferred from mercury injection test is 0.17%. The micro-structural image (as shown in Fig. 1) also shows that crystal grains are complete and closely packed, and the original fracture is poor developed. The main components are calcite and dolomite inferred from the X-ray diffraction teat, as shown in Fig. 2.

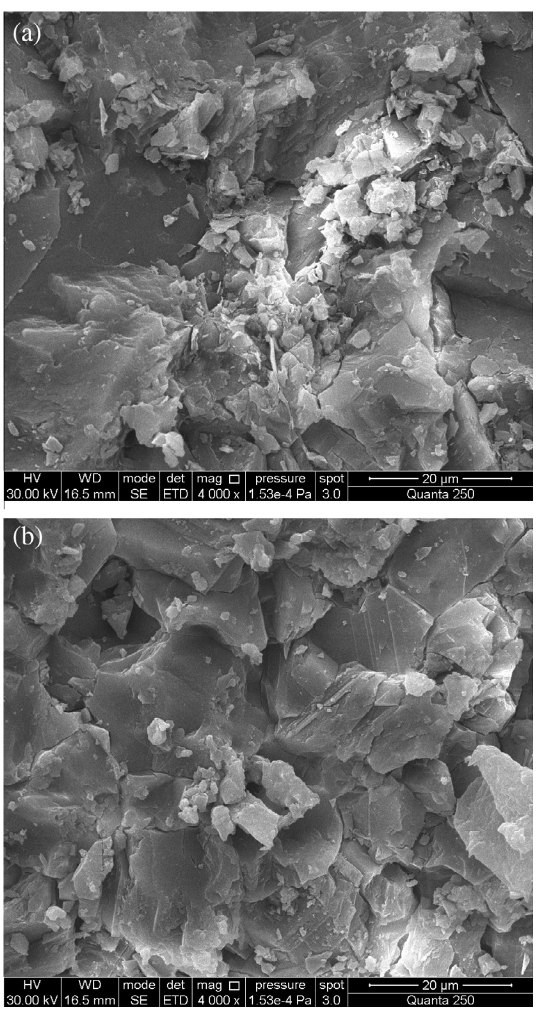

Fig. 1. Micro-structural image of sample at room temperature.

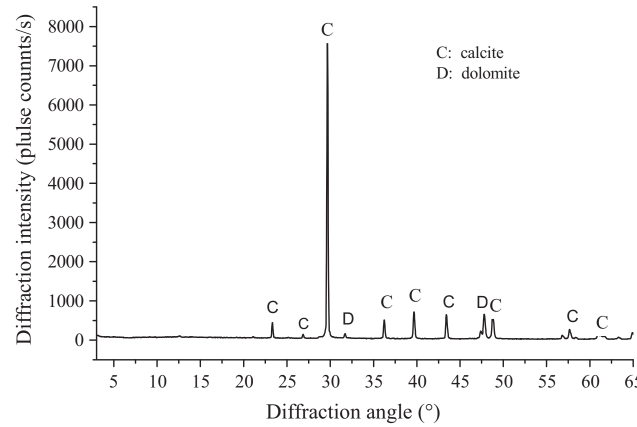

Fig. 2. The main components of limestone sample at room temperature inferred from X-ray diffraction test [17].

2.2. Experimental instruments

Heating treatment was carried out in a CTM300A high temperature furnace (as shown in Fig. 3a) made by Xuzhou Weike Technology Company. Its main parameters as follows: less than 1000 °C, the resolution is 1 °C, the precision of temperature control is 5 °C, the furnace size is 200 mm × 130 mm × 300 mm (width × depth × height). The pore characteristic parameters (porosity, volume of different size pores, fractal dimension) of the specimens was measured using an Auto-Pore IV 9510 automatic mercury injection apparatus (as shown in Fig. 3c) made by Micromeritics Instrument Company of America. The mechanical characteristic parameters (such as compressive strength, strain, elastic modulus, Poisson's ratio) of the specimens were observed using a WES-D1000 electro-hydraulic servo universal testing machine (as shown in Fig. 3b).

2.3. Experimental procedure

Seven sets (three samples a set) of limestone samples were heated to seven levels of temperature (25 °C, 100 °C, 200 °C, 300 °C, 400 °C, 500 °C and 600 °C) respectively. The process of thermal treatment was composed of three stages: firstly, the rock specimens were heated in the furnace at low heating rate of 5 °C/min until the targeted temperature was reached; secondly, the targeted temperature was held constant for 2 h to ensure that the inside of the samples was heated evenly; lastly, the furnace was cooled down to room temperature at the same rate (5 °C/min) in order to maintain a homogeneous distribution of temperature in the samples and keep away thermal shock during heating and cooling. Then the mechanical tests were carried out on the cooled down samples and the samples were loaded at a constant stress rate of 500 N/s. At the loading process, the strain was tested by the strain gauge attached to the samples. Each specimen glued four strain gauges, and two measuring axial strain, the other two measuring vertical strain. From the stress, axial strain and vertical strain, the peak strength, peak stress, elastic modulus and Poisson's ratio can be calculated. At last, the pore characteristic parameters were test by mercury injection experiment.

3. Experimental results and discussions

3.1. Mechanical properties

3.1.1. Peak strength and strain

The relationships of the peak strength and peak strain versus the heating temperature were shown in Fig. 4, and it shows that

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