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Short Communication

Comparison of mechanical properties of undamaged and thermal-damaged coarse marbles under triaxial compression

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1. Introduction

With increasing demands of underground resource exploitations, many large geotechnical engineering structures such as deep tunnels, boreholes for oil or gas production, underground caverns for storage of radioactive waste, and wells for injection of carbon dioxides, etc., are constructed in a ground with very complex geological conditions. Among these geological conditions, the temperature is one of the key factors that influence the strength and deformation behaviors of rocks. Experimental and numerical characterizations of the effect of temperature on the mechanical properties of rocks are, therefore, of vital importance for proper engineering design and long-term stability maintainence of these structures.

In the last two decades, many researchers have studied the mechanical characteristics of rocks under high temperature environments from laboratory testing.[1–18] Most of the tests are conducted in uniaxial compression and the results from these tests show that the mechanical properties are significantly affected by thermal heating of the rock specimen. However, due to differences in mineral composition, grain size, and microstructures, etc., the observed strength and deformation behaviors are quite complex. Different types of rocks under high temperature treatment exhibit different mechanical characteristics, even for rocks with the same type. For example, the Young's modulus and the compressive strength of granite specimens[5,10,14,17] and marble specimens[3,13] generally decrease with increase of the heating temperature, while a threshold temperature exists for these properties of some sandstone specimens.[6,11] Below this threshold temperature, the Young's modulus and the compressive strength show an increasing trend to some extent. When the treatment temperature exceeds this threshold temperature, the Young's modulus and the compressive strength gradually decrease.

Although numerous experiments have been conducted to study the mechanical behavior of thermal-damaged rocks, the mechanism of thermal treatment influencing the mechanical properties of rocks is still not completely understood. Furthermore, most of the existing researches focused on the mechanical properties of thermal-damaged rocks in uniaxial compression. The study of strength and deformation behaviors of thermal-damaged rocks in triaxial compression is still limited. In the present study, a coarse marble is heated to 600 °C and then slowly cooled down to the room temperature to generate sufficient thermal damage in the specimen. Mechanical properties of undamaged and thermal-damaged specimens under triaxial compression are investigated and compared.

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2. Experimental design

2.1. Description of rock samples

The tested rock specimens were collected from a copper mine in Zhenping City, which is located in Henan Province, China. In order to ensure homogeneity of the tested rock specimen, a massive intact marble block with a rough dimension of $60 \times 50 \times 15\ cm^3$ was collected. The rock block was coarse-grained and was relatively isotropic in texture and composition. The grain size is about 3–4 mm. Cylindrical specimens were then drilled out of the large block, with the diameter of 50 mm and the length of 100 mm. The ends of all specimens were finely grinded and polished to meet the specifications recommended by ISRM.[19] From a thin section of the rock specimen, it was found that the rock was mainly composed of dolomite and calcite, with slight biotite. Physical properties of the rock specimen were measured prior to testing. The uniaxial compressive strength (UCS) of the rock was about 70.1 MPa and the average density was $2700\ kg/m^3$. The longitudinal wave velocity of the specimen was measured through an ultrasonic pulse transmission technique and the average longitudinal wave velocity was 4478 m/s.

2.2. Testing equipment and procedure

The heating device used in this study is a SX3-10-12 box-type resistance furnace, which is composed of the control box and the furnace. The maximum operating temperature is 1200 °C and the rated power is 10 kW. Half of the prepared rock specimens were put into the furnace and heated to a predetermined temperature with a heating rate of 10 °C/min. The predetermined temperature, once reached, was kept constant for 4 h. After that the specimens were left in the furnace to cool down to the room temperature. By referring to a previous work conducted by Rosengren and Jaeger,[20] the predetermined temperature used herein was 600 °C in order to generate sufficient thermal damage to the marble specimens.

The triaxial compression tests for the undamaged and thermal-damaged specimens were performed using a hydraulic servo-controlled compression system with a maximum load capacity of 2000 kN. The measurement ranges for the axial and lateral extensometers were 8 mm and 4 mm, respectively. The non-linearity of the two extensometers was less than 0.01% of the full scale measuring range. The extensometers were carefully calibrated before testing. The rock specimens were sealed in a rubber sleeve to ensure that the oil in the triaxial cell would not permeate into the specimens. A prescribed confining pressure was firstly applied on the specimen and the axial-displacement controlled loading was used with a loading rate of 0.075 mm/min till the recorded stress–strain curve entered into a stable residual stage. The axial strain, lateral strain, and axial stress were recorded during the loading process. In this study, the maximum confining pressure applied on the specimen was 40 MPa.

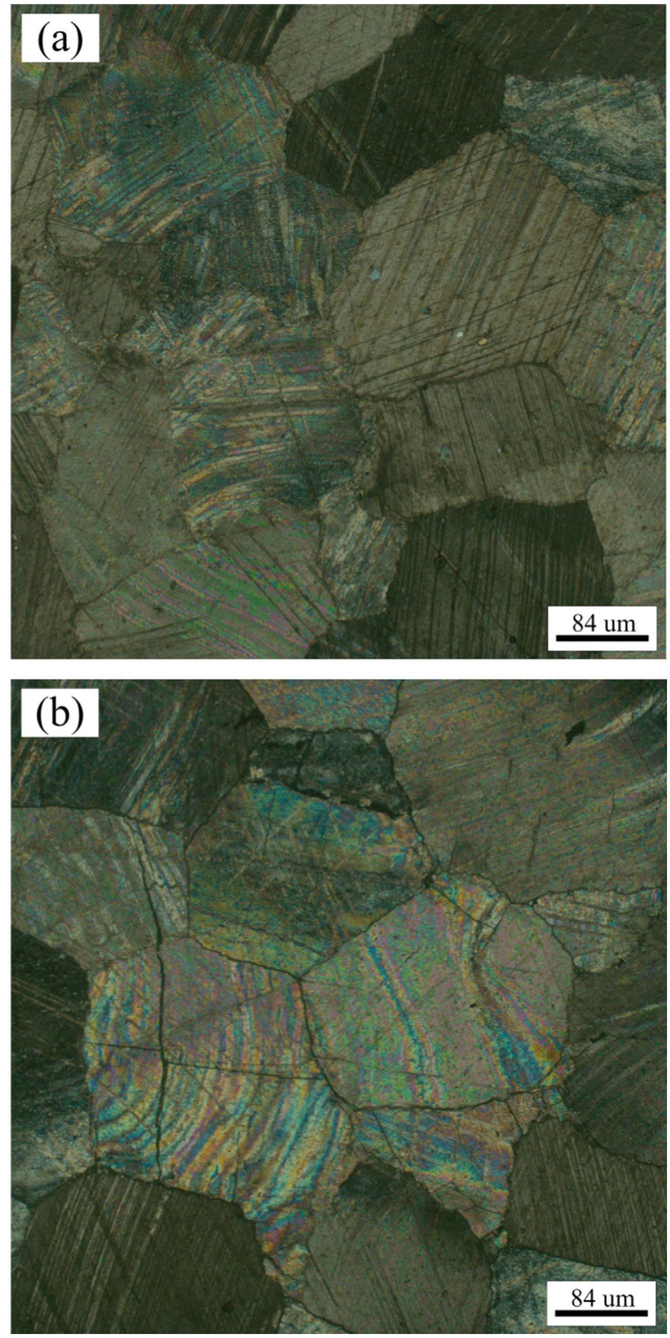

Fig. 1. Optical microscope observations of coarse marbles: (a) Undamaged specimen and (b) thermal-treated specimen under the temperature of 600 °C. The microstructures are enlarged by 25.

3. Experimental results

3.1. Physical properties and microstructures of rock specimens

Due to the thermal treatment, the physical properties of the thermal-damaged specimens were quite different with that of undamaged specimens. The color of the undamaged specimen was milk white, with pearly luster. After thermal treatment under the temperature of 600 °C, the color changed to dark gray. By measuring the longitudinal wave velocity of thermal-treated specimens using an ultrasonic pulse transmission technique, it was found that the average value was 746 m/s, which was quite lower than that of undamaged specimen. The result showed that a large amount of microcracks were developed inside the specimen after thermal treatment. However, there was no obvious difference in the volume and the weight between the thermal-damaged and undamaged specimens.

Thin sections of both damaged and undamaged specimens were observed using an optical microscope. The microstructures inside the specimen were enlarged by 25 and the results are shown in Fig. 1. It is seen that there is basically no microcracks inside the specimen and the grains are well cemented with each other. However, after thermal treatment, the heat expansion caused separation of the grains at the grain boundaries and a large amount of microcracks, especially the grain boundary microcracks, could be detected. The thermal induced microcrack damage will