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Physical and mechanical behaviors of a thermal-damaged coarse marble under uniaxial compression

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ABSTRACT

Temperature is an important factor that influences physical and mechanical properties of rocks. This paper studies the physical and mechanical behaviors of a thermal-damaged coarse marble in uniaxial compression tests. Specimens are heated to 200, 400, and 600 °C and then cooled down to room temperature (25 °C) for testing. When the specimens are exposed to high temperatures, their color changes significantly and many microcracks are generated in the specimens. As the applied temperature increases, the longitudinal wave velocity, uniaxial compressive strength, and Young's modulus decrease gradually and the peak strain that corresponds to the peak strength increases. With the increase of temperature, the non-linearity in the initial deformation stage is enhanced and the stress–strain behavior changes from brittle to ductile. The complete stress–strain curves of the thermal-damaged coarse marble are then simulated using a phenomenological model. It is found that the simulated stress–strain curves are in good agreement with the test results.

1. Introduction

The study of physical and mechanical properties of rocks is an important subject in rock mechanics. It is found from numerous studies that many factors influence the physical and mechanical properties of rocks, among which temperature is one of the most significant ones. With increasing geotechnical engineering structures concerning with high temperature problems such as boreholes for oil or gas production, underground caverns for storage of radioactive waste, and deep wells for injection of carbon dioxides, etc., it is important to study the influence of temperature on the physical and mechanical properties of rocks.

The temperature effect on the physical and mechanical properties of rocks under an "in-time" high temperature condition has been studied by many researchers (Dwivedi et al., 2008; Liang et al., 2006; Ranjith et al., 2012; Tullis and Yund, 1977; Wong, 1982; Zhao et al., 2012). Under this "in-time" high temperature condition, a compression test is conducted under a real time high temperature. However, due to inconvenience of this type of test and the strict requirements for test machines, it is much easier to study the physical and mechanical properties of rocks under a post-high temperature condition. Rock specimens are first subjected to a heating–cooling cycle, which can produce thermal damage to the tested specimen. Compression tests are then conducted under room temperature.

Recently, some researchers have studied the influence of thermal damage on the physical and mechanical properties of rocks under a post-high temperature condition by laboratory testing. For example, Keshavarz et al. (2010) conducted uniaxial compression tests on a hard gabbro after thermally heating the rocks to high temperatures up to 1000 °C to study the influence of thermal damage on the mechanical properties of rocks. Yavuz et al. (2010) investigated the effect of thermal damage on the physical properties of five carbonate rocks through examination of microstructure, bulk density, effective porosity, and P-wave velocity of the tested rocks. Chen et al. (2012) studied the influence of temperature on the mechanical properties of a granite under uniaxial compression and fatigue loading. Brotóns et al. (2013) carried out several uniaxial compression tests to research the effect of high temperatures on the physical and mechanical properties of San Julian calcarenite. The influence of thermal damage on linear and nonlinear acoustic properties of the Westerly granite was studied by Inserra et al. (2013). The physical and mechanical behaviors of a claystone exposed to temperatures up to 1000 °C were investigated by Tian et al. (2014) by conducting uniaxial and triaxial compression tests. Liu and Xu (2014) performed uniaxial compression and split tension tests on the Qinling biotite granite after a high temperature treatment of the specimens; they also investigated the physical and mechanical properties of the granite and a sandstone using a hydraulic servo pressure testing machine (Liu and Xu, 2015). Gónzalez-Gómez et al. (2015) studied

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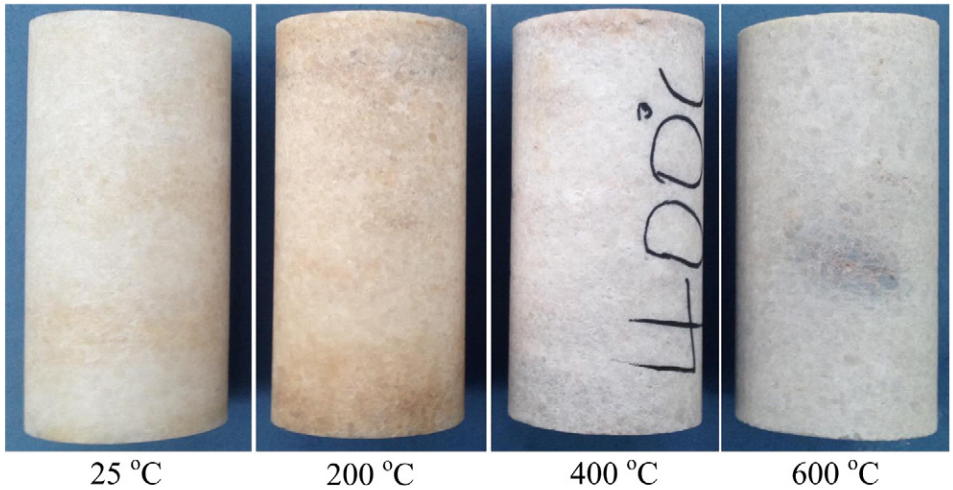

Fig. 1. Photographs of coarse marble specimens after heating to different temperatures.

the effect of thermal damage on the compressive strength, ultimate compressive strain, color and mass loss of four limestones extracted from the Yucatan Peninsula.

It is found from the above studies that the physical and mechanical properties of rocks are significantly affected by thermal treatment of the rock specimens. However, due to differences in mineral composition, grain size, and microstructures, etc., the observed physical and mechanical behaviors are quite complex for different types of rocks. For example, the Young's modulus and the uniaxial compressive strength (UCS) of granite and marble specimens show a gradual decreasing trend as the applied temperature increases. On the other hand, a threshold temperature usually exists for these properties of sandstone specimens. Below this threshold temperature, the Young's modulus and the UCS can increase to some extent. When the temperature exceeds the threshold temperature, the Young's modulus and the UCS decrease gradually as temperature increases. This phenomenon is believed to be caused by the difference in the mineral composition and mineral transformation properties of the rock specimens.

Although many experiments have been conducted to study the physical and mechanical behaviors of high temperature heated rocks, the mechanism of how thermal damage influences the physical and mechanical properties of rocks is still not completely understood. Furthermore, the physical and mechanical properties of rocks are mainly studied through laboratory testing at present. There is still limited contribution in developing novel constitutive models which can be used to simulate the complete stress–strain behaviors (i.e., pre-peak initial nonlinearity and post-peak strain-softening response) of thermal-damaged rocks. In the present study, we investigate the physical and mechanical behaviors of a coarse marble subjected to temperatures from room temperature (25 °C) to 600 °C. The variations of color, longitudinal wave velocity, microstructure, UCS, Young's modulus, peak strain, stress–strain relation, and failure mode of the specimens with the change of temperature are analyzed. The complete stress–strain behaviors of the thermal-damaged coarse marble are then simulated using a phenomenological model.

2. Experimental design

2.1. Description of rock specimens

Coarse marble samples for the laboratory test were collected from a copper mine in Zhenping City, located in Henan Province, China. To ensure homogeneity of the rock specimens used for testing, a large rock block with a rough dimension of $60 \times 50 \times 15$ cm^3 was collected from the mine. The rock block was then shipped to Wuhan University, China, and a total of 24 cylindrical specimens with a diameter of 50 mm and a length of 100 mm were drilled from the rock block. The ends of all specimens were grinded and polished carefully to meet the specifications recommended by ISRM (Fairhurst and Hudson, 1999).

The rock was relatively homogeneous in texture and composition and the grain size was about 3 to 4 mm. From a thin section of the rock specimen, it was found that the rock was mainly composed of dolomite and calcite, with a small amount of biotite. The average UCS, density, and longitudinal wave velocity of the rock were 70 MPa, 2700 kg/m^3, and 4478 m/s, respectively.

2.2. Heating procedure

The heating device used in this study is a SX3-10-12 box-type resistance furnace, which is composed of a control box and a furnace. The maximum operating temperature is 1200 °C and the rated power is 10 kW. The 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 taken out of the furnace to cool down to the room temperature.

The strength of the coarse marble before heating was medium according to the ISRM classification. When a coarse marble specimen

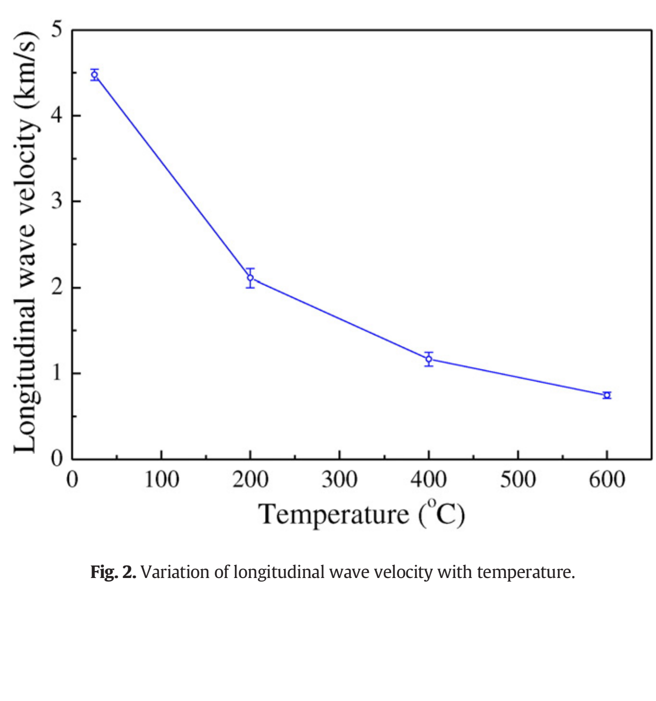

Fig. 2. Variation of longitudinal wave velocity with temperature.