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Physical and mechanical behavior of granite containing pre-existing holes after high temperature treatment

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ABSTRACT

To understand the high temperature effects on the mechanical and failure behaviors of rock, uniaxial compression tests were carried out on granite specimens containing three pre-existing holes using a rock testing system. Based on the experimental results, the influences of testing temperature on the physical and mechanical parameters of granite were analyzed in detail. An obvious color change of tested granite occurs from gray at room temperature to reddish after 450 °C and to red-brown after 900 °C high temperature treatment. The granite volume increases, mass decreases and density decreases with increasing testing temperature. As the temperature increases, the peak strength first increases and then decreases, while the elastic modulus decreases. However, the peak strain changes slightly before 450 °C, increases dramatically up 450 °C. As the bridge angle increases, the mechanical parameters of granite specimens first decrease and then increase. And then, the crack initiation, propagation and coalescence behavior of granite specimens after high temperature exposure was investigated using an acoustic emission (AE) and photography monitoring technique. The cracking process shows that the propagation of crack from the surface of holes leads to the coalescence between adjacent holes. A large AE count and a stress drop are observed during the crack initiation and propagation. The failure modes can be generally classified into three categories: splitting mode, shear mode and mixed mode and they are closely related to heat treatment temperature and bridge angle. Finally, the mechanism causing the differences in the mechanical parameters observed with increasing temperature was discussed based on the SEM observations.

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1. Introduction

In rock engineering, such as deep mining, underground chambers for nuclear disposal storage and exploration of geothermal resources, meets more and more problems caused by high temperature. To understand the interaction of high temperature and rock, many researchers study the physical and mechanical behavior of rock at or after high temperature. As a typical magmatic rock, granite is an ideal surrounding rock for nuclear disposal storage due to its high strength and low porosity. The mechanical properties of granite at or after high temperature are particularly concerned. Chen et al. [1] conducted uniaxial compression and fatigue loading tests for granite specimens after high temperature treatment and they found that the mechanical properties (peak stress and elastic modulus) decreased, while the peak strain increased with the increase of temperature. Shao et al. [2] investigated the strength, acoustic emission (AE) and failure behavior of granite specimens at high temperature under uniaxial compression. The peak strength and elastic modulus of Australian Strathbogie granite decreased except for 200 °C with the increase of testing temperature [2]. Liu and Xu [3] carried out a series of uniaxial compression tests on heated granite specimens and analyzed the effect of temperature on the apparent form, density, longitudinal wave velocity, stress–strain curve, peak strength, peak strain, and elastic modulus of rocks in detail. The compressive strength in general decreases with increasing temperature, but the strength value at 200 °C is slightly higher than that at 100 °C [3]. Zhao [4] studied the process of thermally induced micro and macro cracks in granite by using particle flow code (PFC). Their numerically simulated results showed that the increasing thermal stresses and the generation of tensile micro cracks were the reasons for reduction of compressive and tensile strength. Liu and Xu [5] and Yin et al. [6] measured the static and dynamic tensile strength of intact granite specimen after high temperature treatment. Both Liu and Xu [5] and Yin et al. [6] experimental results showed that the relationship between static tensile strength and testing temperature was different from that between dynamic tensile strength and testing temperature.

However, all of the above experimental and numerical studies were performed on intact granite specimens, i.e., they did not contain any macroscopic flaws. Holes (pore-like flaws) and fissures (crack-like flaws) are generally existing in engineering rock masses, and influence the mechanical and fracture behavior [7–13]. The crack initiation from pre-existing flaws and crack coalescence between pre-existing flaws lead to the damage of the rock, which have received much attention. To investigate the fracture evolution behavior around a pre-existing hole, Zhao et al. [14] conducted uniaxial compression tests on granite specimens containing a single hole. Their acoustic emission (AE) spatial location results showed that the tensile and compressive stresses had an important influence on the fracture evolution process. Tang et al. [15] studied the influences of hole diameters, specimen widths and geometrical arrangements of the hole locations on the failure behavior of porous solids using material failure process analysis (MFPA), which revealed that specimens containing diagonally arrayed holes are more conducive to interaction than those with horizontally or vertically arranged holes. The numerical simulation by Wong and Lin [16] reproduced the previous experimental observations of granite specimens containing multiple holes under uniaxial compression, and presented the stress distribution around the holes during the crack initiation and coalescence processes. To study the cracking behavior of rock-like material specimen with multiple holes, systematic experiment and simulation were conducted by Haeri et al. [17]. In their study, the effect of the breaking load in Brazilian disk specimens and the effect of distribution of the initial lateral stress on the crack propagation process were analyzed.

Limited laboratory experiments have been carried out on the crack coalescence behavior of real rock specimen containing pre-existing holes after high temperature treatment. For example, Yin et al. [18] investigated the strength and failure mode of sandstone specimen containing a single hole after high-temperature exposure under uniaxial compression. However, crack initiation and coalescence behavior in specimen with multiple holes that has been exposed to high temperatures has not been fully investigated. Therefore, in this study, a series of uniaxial compression tests on granite specimens containing three pre-existing holes with different arrangements after exposure to varying high temperatures was carried out to investigate the strength, deformation properties and crack coalescence behavior. First, physical properties (e.g., color, apparent form, volume, mass and density) of granite after high temperature treatment in the range of room temperature to 900 °C were analyzed. And then, the thermally damaged granite specimens were loaded uniaxially using a rock testing system. The acoustic emission (AE) and crack evolution process were recorded by an AE monitoring and photography technique. Based on the experimental results, the influences of high temperature and bridge angle on the stress–strain curves and mechanical parameters were analyzed in details. Finally, the mechanism causing the differences in the mechanical parameters with increasing temperature was discussed.

2. Material and testing procedure

2.1. Granite material and specimen preparation

Granite taken from Quanzhou city, Fujian province of China was used as the tested rock material in this study. Fig. 1 shows the microscopic structure of the tested granite obtained from thin section and scanning electron microscopic (SEM). The granite has an average unit weight of approximately 2730 kg/m^3. According to the X-ray diffraction (XRD) analysis, the mineral components of the tested granite material were primarily feldspar, quartz, dolomite, and other minerals.

To investigate the influence of pre-existing holes on the strength failure behavior of granite specimen, holes were cut in the rectangular specimens shown in Fig. 2. In this experiment, all specimens were machined from the same block of granite material at the same direction. The prepared intact specimen had a height-to-width ratio of 2.0, to minimize the end friction effect on the test results [19]. Furthermore, to neglect boundary effects on crack propagation, the width of the granite sample was designed to be 80 mm, which was