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Effects of thermal treatment on fracture characteristics of granite from Beishan, a possible high-level radioactive waste disposal site in China

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ABSTRACT

In-situ experimental investigations on fracture behavior of Beishan granite under loading after 125–600 °C thermal treatments have been carried out through high temperature Scanning Electron Microscope (SEM) testing system. Thermal microcracks and non-uniform expansion of grains, long and deep thermal cracks along the grain boundary were observed on the surface of Beishan granite with thermal treatments at different temperatures. The initial direction of microcracks and the main crack propagation path are affected by the shape of mineral grains and the distribution of thermal cracks. The effect of the distribution of thermal cracks becomes more dominant with the increasing temperatures. There are multiple mechanisms of thermal effects on strength and fracture toughness of Beishan granite, namely, thermal cracking, water evaporation, hot melting and phase transition of quartz. The main controlling mechanism changes with treatment temperatures. While elastic modulus slightly increases at 275 °C because of hot melting, in general, it decreases with the increasing temperature due to increasing thermal cracks. Stress intensity factor for short-span (the ratio of span to height is 2) three-point bending specimen is determined using boundary collocation method. The relationship between fracture toughness and heat treatment temperature can be approximately described by linear decreasing function.

1. Introduction

Deep geological repository has been widely accepted for high-level radioactive waste disposal. Research on geological disposal of high-level radioactive waste in China has been conducted since 1985. And Beishan area in Gansu Province is considered as the most potential area [1]. Radioactive elements in the high-level radioactive waste release a lot of heat during decay process, which raises the temperature in surrounding rock of repository. Under the combined effects of temperature and stress, extended natural cracks and newly induced ones can be the pathways of nuclide migration.

Taking the effects of temperature into consideration, mechanical properties of various kinds of rocks have been studied in some literatures. Experimental results [2] demonstrate that strength of red sandstone increases with heat treatments from

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Nomenclature

a	length of preset notch
B	thickness of three-point bending specimen
f	the number of collocation points on the lateral boundary
K_I	stress intensity factor of I mode crack
K_{IC}	mode I fracture toughness
M	the bending moment at cross section containing preset notch
m	number of collocation points
P	load applied on three-point bending specimen
S	support span
S'	effective support span
T	pretreat temperature
W	height of specimen
X_1	the coefficient corresponding to the $r^{-1/2}$ stress singularity
Δ	spacing between adjacent collocation points

20 °C to 200 °C, then decreases with heat treatments from 200 to 600 °C, while the permeability of the rock changes in the opposite trend. Yin et al. [3]'s experimental results show that dynamic fracture toughness of Laurentian granite increases with the loading rate but decreases with the treatment temperature. Static mode I fracture toughness of dolerite and two types of sandstone after thermal treatments that range from ambient conditions to 600 °C were measured by Mahanta et al. [4], results indicated that thermally induced micro-cracks are primarily responsible for the decrease in fracture toughness. Zhao [5] demonstrated that heating generally reduces the compressive and tensile strengths of granites, first because of increasing thermal stresses, and second because of the generation of tensile micro cracks. Zuo et al. [6]'s work indicate that thermal-induced or thermal-mechanical-induced cracking mechanisms depend strongly on thermal deformation mismatch between the mineral compositions.

While previous studies have helped us to understand how temperature affects rock mechanical properties, most of them were focused on rock mechanical characteristics at macroscopic scale [3,7,8], or using SEM to investigate fracture mechanism at mesoscopic scale after rock failure [4,9]. In this study, fracture process of Beishan granite is captured by *in-situ* SEM experiments, and the effects of temperature on Beishan granite fracture characteristic are investigated in detail, which is of great importance to understand thoroughly the mechanical properties and to prevent radionuclide underground migration.

2. Sample preparation and experimental procedure

Granite tested in this present study was obtained from Beishan area of Gansu Province, northwest of China, at the depth of 634–636 m. The mineralogical composition obtained by X-ray diffraction techniques is shown in Table 1 [10], and the average grain size of the granite is approximately 1.5–2 mm.

Three-point bending tests were conducted using the SEM with loading system in the State Key Laboratory of Coal Resources and Safe Ming, China University of Mining and Technology. According to the specifications of the loading system, the geometry of the specimen was 25 mm × 10 mm × 5 mm, with a preset single edge-notch at the middle of the specimen, as shown in Fig. 1. Because the mineral particles are relatively large, it is very difficult to make V-shape edge-notch which is widely used in the fracture mechanism tests for metal materials. Therefore, U-shape edge-notch was adopted in this work, and the width of notch was about 0.4 mm. For the purpose of minimizing the errors caused by anisotropy, all specimens were sampled from the same intact rock block, and processed in the same direction. In order to obtain clear SEM images, the observed surface of specimen has been plated with gold using an ion sputtering apparatus.

Thirty-three specimens were prepared and equally divided into eleven groups for different thermal pretreatments before loading. Specimens were heated in a high temperature furnace. The temperature inside the furnace was raised at a rate of 3–4 °C/min and kept for 1 h after it reached the assigned value, namely, 125 °C, 150 °C, 175 °C, 200 °C, 225 °C, 250 °C, 275 °C, 300 °C, 400 °C, 500 °C, 600 °C, then naturally cooled down to the room temperature (25 °C). The fracture behavior of Beishan

Table 1
Mineral composition and content [10].

Quartz	K-feldspar	Plagioclase	Mica, clay minerals
24.05% ± 4.7%	16.95% ± 2.0%	55.65% ± 7.2%	3.35% ± 2.2%

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