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Static and dynamic mechanical properties of sedimentary rock after freeze-thaw or thermal shock weathering

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A B S T R A C T

Rocks in engineering works and as building materials are always suffering freeze-thaw (F-T) and thermal shock (TS) weathering, and engineering rocks usually involve responses to impact loads from blasting operation, mechanized construction and seismic oscillation. Sedimentary rock distributes extensively and is important for engineering geological and hydrogeological works. For a deeper understanding of the F-T and TS effects on the rock behaviors, physical tests, static compressions and dynamic impacts were carried out on red-sandstone free from and after artificial F-T or TS cycles in this work. Laboratory tests show the significant physic-mechanical deterioration of red-sandstone after F-T or TS weathering. Compared to fresh specimens, red-sandstone after 10 F-T or TS cycles performs poorly in both the static compression and SHPB impact tests, and F-T/TS induced decreases of UCS and modulus are more remarkable under dynamic impacts than under static loads. Dynamic mechanical behaviors of both fresh and F-T/TS weathered red-sandstone have distinguishable strain rate effects, and water content significantly affects the strain rate effects on mechanical behaviors. Water and temperature variation play important roles in the rock weathering process. In this work, water effects during the rock weathering process were summarized as solvent effect and medium effect, while temperature variation damaged red-sandstone meanly in two ways, non-uniform thermal deformation of mineral grains and phase-transition of water.

1. Introduction

Exposed to the atmosphere and water, as well as artificial disturbances during engineering construction, rocks are always suffering various kinds of weathering (Alavi Nezhad Khalil Abad et al., 2014; Ercoli et al., 2014; Alavi Nezhad Khalil Abad et al., 2015a,b). Due to the significant effects on engineering properties of rock mass, rock weathering is crucial in the whole design, construction and maintenance stages of geotechnical works (Shen, 2004; Alavi Nezhad Khalil Abad et al., 2016).

Cycling freeze-thaw (F-T) and thermal shock (TS) are typical weathering processes and have strong impacts on the physico-mechanical behaviors of rock. Repeated F-T is common and damaging in cold region (Fatih, 2012), where the environment temperature floats up and down the freezing point of water. The frequent freezing and thawing of pore water inside rock expands the cracks and pores and promotes the development of new micro-fractures and thus does great damage to rock engineering (Sousa et al., 2005; Park et al., 2015). Generated by sudden changes in temperature, TS is 'catastrophic fracture under most conditions of high heat transfer and/or rapid environmental temperature variations' (Hasselman, 1969). Rock is naturally a three phase system of air-water-solid, and water behavior is affected by temperature variation during the F-T or TS process, which in turn affects the heat transmission and rock properties. Thus, the F-T and TS weathering of rock are typical coupled hydro-thermal-rock interaction processes.

Besides, because of the widely existed blasting operation, mechanized construction and seismic oscillation, rock engineering disasters often involve rock responses to stress pulses or impact loads, and the corresponding prevention and cure researches come down to the analyses on dynamic mechanical properties of rock-like materials (Zhang and Zhao, 2014; Huang and Xia, 2015;). Due to the rate sensitivity, mechanical responses of rocks after F-T/TS weathering to dynamic loads differ from those to static loads. Literature reviews show that investigations about the F-T/TS weathering are concentrated on physical and static mechanical properties of rock (Tuğrul, 2004; Yavuz et al., 2006; Basu et al., 2009; Basu et al., 2012; Ghobadi and Babazadeh, 2015), while only a few published works studies on the dynamic mechanical behaviors of F-T/TS weathered rock. Wen et al. (2015) obtained

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the relationship between the dynamic strength with the freeze-thaw cycles according to numerical simulations and experiments. Zhou et al. (2015) obtained the microscopic damage characteristics and dynamic mechanical parameters of sandstone after freeze-thaw from the nuclear magnetic resonance (NMR) tests and impact loading tests. Investigations about the effects of water and temperature on rock dynamic mechanical properties during the weathering process are far from enough.

Sedimentary rock distributes extensively in the superficial lithosphere, of which the distribution area is the main provider of minerals and the main place for engineering geological and hydrogeological works. For a deeper understanding of the F-T and TS weathering effects on the static and dynamic mechanical properties, static and dynamic compressive tests on sedimentary rock free from and after cycling F-T or TS were carried out and the results were analyzed in this work. Red-sandstone, a common sedimentary rock, was selected as the test object in this paper. Totally four groups of specimens were prepared for static compressive tests and dynamic impact tests respectively, of which one group was free from weathering treatments and tested in dried state, one group was also free from weathering treatments but tested in water-saturated state, one group was saturated and weathered by 10 F-T cycles and tested in saturated state, the last group was saturated and weathered by 10 TS cycles and then dried before loading tests. Impact loading tests were carried out using the split Hopkinson pressure bar (SHPB) system (Xia and Yao, 2015), with the impact condition set at three incident pulse intensity grades.

2. Materials and methods

2.1. Red-sandstone specimen preparation

Red-sandstone in this work was gathered from underground construction field in the Hengduan Mountains, located at the southeastern corner of the Tibet plateau. Powder X-ray diffraction analysis was used to determine the mineral composition, with the test environment set at 25 °C and 40% humidity. According to the XRD spectrum (Fig. 1), quartz accounted for 81% and was the main mineral, besides of which the red-sandstone was composed of 10% plagioclase feldspar, 3% potash feldspar and 3% calcite. Small amounts of chlorite, illite and hematite were also detected from the samples.

Red-sandstone were made into standard cylinder specimens, Φ50× 100 mm for static uniaxial compressive tests and Φ96× 48 mm for dynamic impact compression tests, respectively. Specimen sizes and machining accuracies met the requirements of ISRM suggested methods (Fairhurst and Hudson, 1999; ISRM, 2007; Zhou et al., 2012). Attention was paid to prepare samples which were free from visible defects and flaws, and ultrasonic detection was performed to minimize variations among specimens during the selection.

2.2. Water absorption and artificial F-T/TS tests

For static and dynamic compressive tests respectively, four groups of red-sandstone specimens were prepared, free from or after F-T/TS weathering. Water absorption and cycling F-T/TS tests followed the DL/T 5368–2007 (National Development and Reform Commission of the People's Republic of China, 2007).

Two groups of specimens were prepared free from F-T and TS cycles for comparative analyses, named as dried specimens and saturated specimens respectively. The specific preparing process was: 1). Dried specimens were made by drying in an oven at 107 °C for 48-h. 2). Saturated specimens were made by submerging the dried specimens in water at room temperature for 48-h and then submerging in boiling water for 6-h.

Another two groups of specimens were made by artificial weathering tests, one for 10 F-T cycles and one for 10 TS cycles.

An automatic freeze-thaw cycle machine was used for accelerated F-T weathering, with one F-T cycle procedure set as follows: 4-h freezing in air after the test chamber temperature reaching −20 °C, followed by a 4-h thawing in water at 20 °C. In this paper, 10 F-T cycles were carried out on red-sandstone specimens saturated beforehand. An electric thermostat-box and a thermostatic water bath were used for accelerated TS weathering. For one TS cycle, specimens were heated inside the air-ventilated thermostat-box at 200 °C for 4-h (exclusive of the heating up time), then the specimens at 200 °C were taken out of the box and immediately immersed in water at 20 °C for 6-h. In this paper, 10 TS cycles were carried out on saturated red-sandstone specimens as well. Since Newton's Law of Heating and Cooling applied to those F-T or TS cycles, the temperature change followed almost the same path during each cycle for F-T or TS tests respectively (see Fig. 2) (Mutlutürk et al., 2004). Specimens after 10 F-T cycles were kept underwater till loaded in mechanical tests, except for a short time for physical determination. TS weathering tests differed. Samples after 10 TS cycles were dried in an oven at 107 °C for 48-h and then cooled to room temperature. In other words, the F-T weathered specimens remained almost saturated while the TS weathered specimens were dried for the mechanical tests.

Red-sandstone specimens were significantly damaged after 10 cycles of F-T or TS, clear from the visible macro-cracks and mineral loss on the specimen surfaces as shown in Fig. 3.

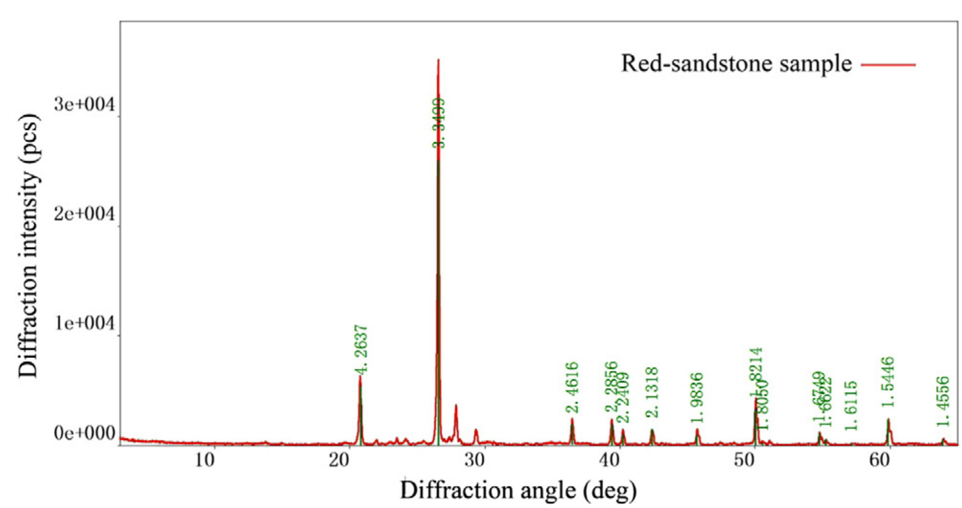

Fig. 1. XRD spectrum of red-sandstone sample (under 25 °C and 40% humidity).