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Dynamic tensile properties of sandstone subjected to wetting and drying cycles

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ABSTRACT

Rocks are commonly used as building stone and construction materials in many engineering applications. They usually undergo cyclic wetting and drying processes due to the periodical variations in moist conditions. In this paper, to understand the deterioration on the tensile strength of sandstone induced by wetting and drying cycles, dynamic Brazilian disc tests were conducted on sandstone specimens after every 10 cycles (for a total of 50 cycles) under a wide range of loading rates using a modified split Hopkinson pressure bar (SHPB) technique. Test results revealed that at the same loading rate, the dynamic tensile strength of specimens decreased with the number of wetting and drying cycles. Microscopic morphological structure on the sandstone surface were also obtained by scanning electron microscope (SEM), the characteristics and fractal analysis indicated that cyclic wetting-drying treatments would result in accumulative crack damage in rock, which was considered as the primary reason for the reduction in strength. Moreover, a decay model considering the effects of loading rate and cyclic wetting and drying deterioration was established to predict the dynamic tensile strength of sandstone after wetting and drying cycles. The forecast data via the decay model matched the trends of the experimental results well, meaning that the decay model was valid and applicable for the strength prediction.

1. Introduction

Due to the long-term exposure to the hydrosphere and atmosphere, rock materials are always suffering various kinds of weathering [1–3]. The cyclic wetting-drying phenomenon, as a part of weathering processes, plays a vitally important role in controlling the properties of rock materials. On account of the periodical changes in moisture conditions (e.g. rain, tide and ebb, groundwater level floating up and down or other reasons), many rock engineering applications, such as slopes, dams, mines and building foundations, may be subjected to cyclic wetting and drying during their construction and operation. Rock and rock mass would be deteriorated in these engineering and responsible for numerous geological hazards [4–6], e.g., landslides, karst collapse, pillar degradation and deformation of foundation. Therefore, the physical and mechanical properties of rock subjected to wetting and drying cycles become the focus of attention increasingly.

In recent years, the influence of cyclic wetting and drying on the physical and mechanical properties of rock materials has been investigated extensively. The rock deterioration to different degrees after cyclic wetting and drying treatments was assessed by changes in physical properties, such as bulk density, weight loss, water absorption, effective porosity and P-wave velocity [1–3,7–13]. For example, Pardini et al. [7] reported that the bulk density of mudrock has a little reduction and the porosity increases with the increase of number of wetting and drying cycles. Gökceoğlu et al. [1] investigated the factors affecting the slake durability index (SDI) of 17 kinds of clay-bearing rocks and emphasized the influence of wetting and drying cycles on the SDI values. Özbek [10] found that by increasing the number of wetting and drying cycles, the bulk density and P-wave velocity of ignimbrite decrease, whereas the water absorption and effective porosity show increasing trends. Khanlari and Abdilor [12] and Zhou et al. [3] showed the similar results after studying physical properties of sandstone subjected to wetting and drying treatments.

A substantial effort has been made towards investigating the mechanical properties of rock materials affected by cyclic wetting and drying. Hale and Shakoor [14] studied the uniaxial compres-

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sive strength (UCS) of six kinds of sandstones after 50 wetting-drying cycles. Their experimental data stated that there was no significant correlation between UCS and wetting-drying treatments. Lin et al. [8] investigated the UCS of two Taiwan sandstones and found that the UCS of TK sandstone with 1% chlorite was not affected by wetting-drying cycles, whereas that of MS1 sandstone with 11% chlorite reduced by about 20%. They deduced that the mineralogy, especially the content of chlorite, account for the discrepancy in the effects of wetting-drying on the UCS of sandstone. However, recent studies suggested that the UCS of rock materials would decrease significantly due to cyclic wetting and drying deteriorations [10,12,15,16]. Except for UCS, other mechanical properties of rock, including tensile strength [13,17,18], rebound value [13], shear behavior [19], triaxial properties [11,16,20] as well as fracture toughness [18,21,22], have also been investigated. For example, Zhao et al. [17] carried out Brazilian disc (BD) tests on sandstone subjected 15 wetting and drying cycles. They found that the tensile strength of sandstone is not sensitive to wetting and drying cycles. Zhang et al. [19] reported that the shear strength of argillaceous siltstone decreases under the same vertical stress after cyclic wetting and drying treatments. Hua et al. [18,21] examined the mode I and II fracture toughness of sandstone subjected to wetting and drying cycles using the central cracked Brazilian disc (CCBD) method, and discovered that there exists 52.4 and 56.2% reductions in mode I and II fracture toughness of sandstone after seven cyclic wetting and drying treatments, respectively. Fig. 1 graphically illustrates the variation tendencies for mechanical properties of rock with the number of wetting and drying cycles which reported in some literature. It can be seen that the mechanical properties for various rock materials have different degrees of deterioration after wetting and drying treatments. More detailed information on the works concerning the effect of cyclic wetting and drying on physical and mechanical properties is summarized in Table 1.

Actually, rock and rock mass are usually broken and failed dynamically in many rock engineering applications because of the widely existed dynamic loads, such as blast, seismicity, shock and vibration. Under dynamic loading condition, the behavior of rock is different with that of rock under static loading condition [23,24]. However, literature review mentioned above have been concentrated on static mechanical properties, only a few published works have been reported on the dynamic behavior of cyclic wetting and drying weathered rock materials. Yuan and Ma [25] performed dynamic compressive tests on sandstone using the split Hopkinson pressure bar (SHPB) setup. They argued that with the wetting and drying cycles increasing, the dynamic compressive strength (DCS) decreased in a power relationship and the size of fragments becomes much smaller. Zhou et al. [3] also investigated the dynamic properties of sandstone after different wetting and drying cycles. Their results showed that the DCS of sandstone subjected to wetting and drying cycles was rate-dependent, and the DCS and elastic modulus at the same strain rate decreased when the number of wetting and drying cycles increases. But the investigations about wetting-drying effects on rock dynamic properties are still insufficient, especially, the dynamic tensile strength after the rock specimens experiencing cyclic wetting and drying treatments have been not determined so far. Therefore, there address a need to investigate the wetting-drying effects on the dynamic tensile strength of rock in order to comprehensively assess the safety and stability of rock structure and control the hazard of rock engineering projects.

The objectives of this research are to understand the deterioration in rocks induced by cyclic wetting and drying treatments and its effect on the dynamic tensile strength of rocks. In this study, the microscopic features of sandstone specimen were observed using the scanning electro microscope (SEM) technique. The fractal dimension was applied to quantitatively evaluate the crack-damage induced by wetting-drying cycles. A series of impact tests were also conducted on sandstone specimens using the Brazilian disc (BD) method with the SHPB setup to determine the dynamic tensile strength of sandstone after different degrees of wetting and drying weathering deterioration (for a total of 50 cycles). In addition, a decay model synthetically considering the cyclic wetting-drying weathering and loading rate effects was established to predict the dynamic tensile strength of sandstone after wetting-drying cycles.

2. Experimental material and methodology

2.1. Material description

In this study, the rock material is a fine-grained homogeneous sandstone widely available in the northwest of Kunming, Yunnan province of China. The mineralogical composition for the sandstone was determined by the Energy Dispersive X-ray spectrometer (EDX MLA 250) technique. The sandstone is mainly composed

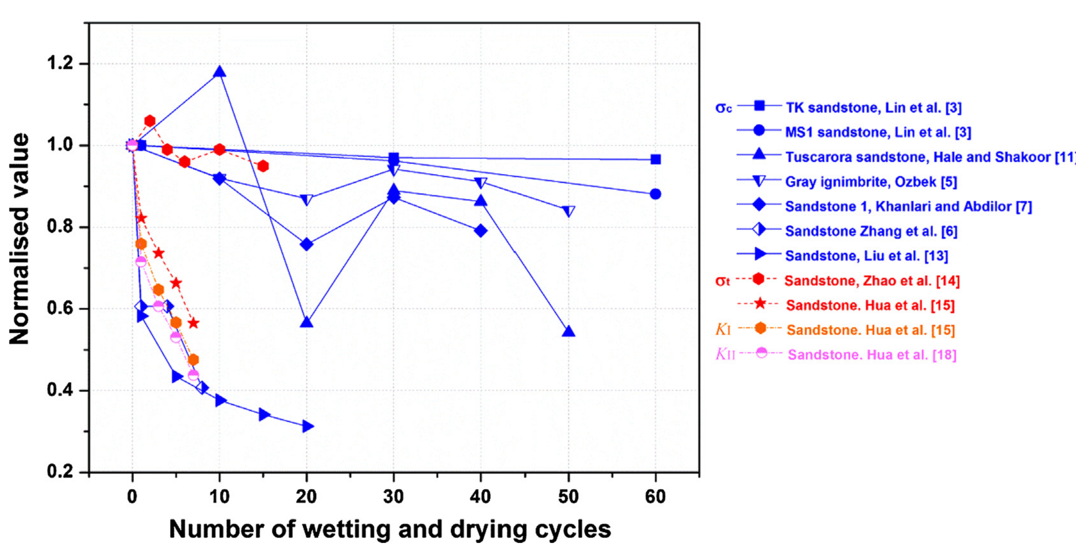

Fig. 1. Normalised value for mechanical properties of rock materials after cyclic wetting and drying treatments reported in literatures.