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Degradation of physical and mechanical properties of sandstone subjected to freeze-thaw cycles and chemical erosion

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ABSTRACT

Rocks are often exposed to chemical erosion and extreme temperature changes in cold regions. In this study, the deterioration of sandstone is investigated under rapid freeze-thaw (F-T) cycles. To do so, physical and mechanical properties of sandstone specimens immersed in different chemical solutions were studied after 10, 20 and 30 freeze-thaw cycles. It was found that after applying freeze-thaw cycle specimens' mass, tensile strength and point load strength decrease at different extent while porosity increases. Coupled effects of chemical erosion and freeze-thaw cycles were observed to have a destructive damage on physical and mechanical properties. In this regard, the samples experienced deterioration at different extend when immersed in different chemical solutions. The maximum deterioration was observed for samples being immersed in NaOH solution, followed by that of NaCl solution, H_2SO_4 solution and pure water. Finally, a decay function model is used to further investigate the variations of splitting tensile strength and point load index with freeze-thaw cycles and predict deterioration of rock integrity.

1. Introduction

The mechanical properties of rocks depend on the structure of pore spaces as well as on properties of the constituent minerals. The porosity of typical rocks may be defined by size of pores and micro-cracks. These types of porosity are scattered randomly inside the rock. Distribution and size of both micro-cracks and pores has a significant effect on the mechanical and physical properties of rock such as uniaxial compression strength, tensile strength, Young's modulus and shear wave velocity.

Several scholars have studied the relation of porosity and mechanical properties. Bell (1978) observed an inverse relationship between uniaxial compression strength and porosity and found that the absolute porosity is somehow more important than the effective porosity. Vernik et al. (1993) found a semi-logarithmic relation between uniaxial compression strength and rock porosity. Sousa et al. (2005) derived an empirical formula to relate rock strength to porosity for a set of granite rocks. Baud et al. (2014) proposed an analytical model in which uniaxial compression strength, initial porosity and crack density in a rock sample was related. Mineralogical composition, texture and characteristics of the voids are the main factors involved in controlling the intensity of the physical and chemical damages suffered by rocks when subjected to new environmental conditions (Hudec, 1998).

Rocks in nature often contain water, which is one of the most active elements in geologic activities, contributes to the failure process of rocks. The effects of water and temperature on physical and mechanical properties of rocks have always been an important problem in engineering projects especially in cold regions. A number of studies focused on the relation of freeze-thaw cycles and physical and mechanical properties of rocks. Yavuz et al. (2006) studied the index properties of deteriorated carbonate rocks due to freeze-thaw cycles and found that the index properties of rocks decrease in different extend when subjected to freeze-thaw cycles. Similar studies were others as well (Altindag et al., 2004; Diamantis et al., 2009; Fener and Ince, 2015; Ghobadi and Babazadeh, 2015; Liu et al., 2012; Momeni et al., 2016; Özbek, 2014; Takarli et al., 2008).

Rocks often exist in complicated environmental condition, in some instances, at the same time may be subjected to freeze-thaw cycles and chemical erosion. There are very few studies available in the literature investigated this combination. In this study, splitting tensile strength, point load strength and porosity of sandstone under the combined effects of chemical erosion and freeze-thaw cycles are investigated. Deterioration of mechanical properties such degradation of tensile strength and point load strength were studied using a decay function

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Table 1
Water-physical properties of specimens.

Specimen	Dry weight	Wet weight	Saturation weight	Water absorption	Saturation ratio	Saturation coefficient
1	139.54 g	141.76 g	141.98 g	1.59%	1.75%	0.91
2	139.21 g	141.47 g	141.52 g	1.62%	1.66%	0.98
3	138.23 g	140.63 g	140.73 g	1.74%	1.81%	0.96
Average	138.99 g	141.29 g	141.41 g	1.65%	1.74%	0.95

model.

2. Materials and methods

2.1. Specimen preparation

Porous sandstone formed underneath the seabeds or lands contain a large amount of intergranular pore spaces. Mechanical behaviour of sandstone rocks have been investigated previously (Munoz et al., 2016a; Munoz et al., 2016b; Taheri et al., 2016). To carry out this research, cylindrical sandstone samples were cored from a rock block. In total 36 samples were prepared and placed in four groups (i.e. C_1–C_9, D_1–D_9, E_1–E_9 and F_1–F_9). The diameter of specimens was 50 mm and their aspect ratio (i.e. sample height to diameter) was maintained at 0.6 for tensile strength test. The diameter of sample was more than 20 times bigger than the grain size satisfying the specimen size recommended by the International Society for Rock Mechanics (ISRM). Surface of specimens was prepared smooth and straight. The rock samples correspond to fine grain-size rock having a dry density of 2.37 g/cm^3. Table 1 shows water-physical properties of three identical sandstone samples under room condition and natural water content.

2.2. Freeze-thaw tests

Freeze-thaw tests were conducted by a cyclic freeze-thaw testing machine (type TDS-300) shown in Fig. 1. The sandstone rock block is from a civil engineering project located in the Qinghai-Tibet Plateau, north-west of China. According to the China Meteorological Administration, the highest and lowest average temperatures are about 20°C and − 20°C respectively. So in this study for freezing and thawing, temperatures of − 20 °C and 20 °C were adopted respectively. The freeze-thaw cycles were repeated for 10, 20 and 30 times. Each freeze-thaw cycle lasts for 8 h (i.e. 4 h freezing and 4 h thawing). Fig. 2 shows the variations of temperature versus time for each test.

For freeze-thaw (F-T) tests four different solution were used; H_2SO_4 solution (initial pH = 1.5), NaOH solution (initial pH = 12.5), NaCl solution (initial pH = 7) and pure water (initial pH = 7). Four different groups of samples, 9 samples in each group, were immersed in H_2SO_4 solution (i.e. C_1–C_9), NaOH solution (i.e. D_1–D_9), NaCl solution (i.e. E_1–E_9) and pure water (i.e. F_1–F_9). Specimens with subscript numbers of 1–3, 4–6 and 7–9 were, respectively, experienced freeze-thaw cycles of 10, 20 and 30.

Fig. 1. Cyclic freeze-thaw testing machine.

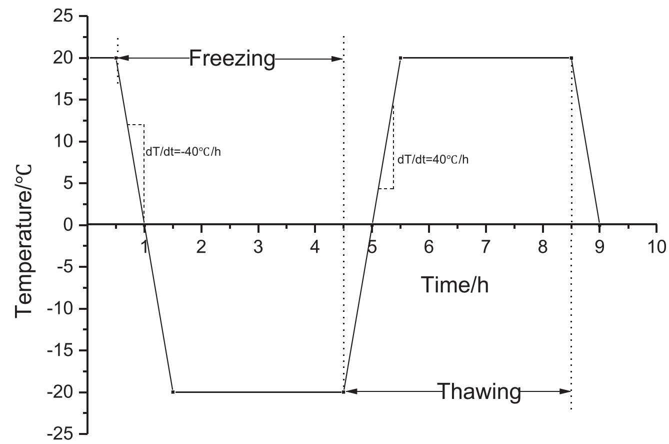

Fig. 2. Temperature change program.

Before each test, specimens were saturated in the corresponding chemical solution for 48 h. In order to have consistent and repeatable results, pH value in each test should be kept constant. Due to the chemical reactions between sandstone and solutions, the pH changed during the F-T cycles. Therefore, pH variation during the test were monitored and if necessary additional solution were added to maintain the initial amount of pH. The procedure is presented in Fig. 3.

2.3. Tensile strength testing

Brazilian test was used to measure the tensile strength of specimens. A SHT4206 loading machine (see Fig. 4a) with maximum loading capacity of is 200 kN (with a ± 1% precision) was used to conduct the test. A small steel bar was tied to the specimens as auxiliary means adopted by The Professional Standard Compilation Group of People's Republic of China (2007).

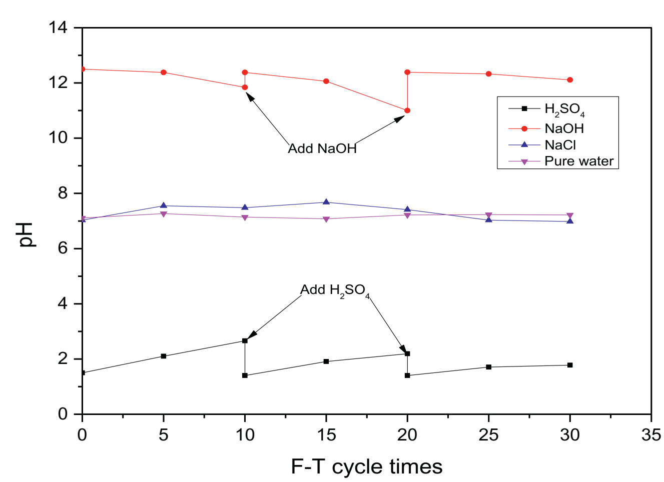

Fig. 3. Monitoring scheme of pH during the test.