Effect of number of freeze-thaw cycles on physical and mechanical properties of Lushan sandstone and cement mortar

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Abstract

Various natural factors, known as weathering factors, physically and chemically affect natural and artificial materials such as rocks and cement-based material like concrete and cement mortar. Freeze-thaw process is one of these factors which extensively affects rocks and concrete properties. Thus, taking its impact on physical and mechanical properties of materials into account is required in the regions susceptible to the process. In most of the previous studies, the freezing and thawing periods' temperatures and their duration were chosen regardless of the weather conditions of the regions susceptible to the freeze-thaw process and regarding cement-based materials, the investigations were focused on concrete and there are a few studies on freeze-thaw effect on cement mortar. This study addressed the effect of number of freeze-thaw cycles on porosity, uniaxial compressive strength and Brazilian tensile strength of sandstone and cement mortar specimens considering the climatic data of Ardebil province in which the occurrence of freeze-thaw process is possible. Furthermore, the computerized scan (CT) was carried out on the sandstone specimen to examine the damage resulting from freeze-thaw. The results indicated that the increase in the number of freeze-thaw cycles caused in linear increase in the porosity of the specimens, while reducing their uniaxial and tensile strength. The study of the CT images also showed that the damage factor was increased by increasing the number of cycles.

Keywords: *physical and mechanical properties, Freeze-thaw cycle, sandstone, cement mortar*

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Extended Abstract:

1. Introduction

The freeze-thaw cycle represents an influential and strong process of physical weathering that results in a reduction in the stone's durability and stability, by affecting the rock's physical and mechanical properties (Zappia et al., 1998). The effect of freeze-thaw cycles on multiple stones and cement-based materials has been investigated by many researchers. Topal and Sözmen (2003), by studying tuff specimens, found that increase in the number of cycles leads to a decrease in the speed of longitudinal waves and the uniaxial compressive strength (UCS), and an increase in the porosity level. A decay function model for predicting the effect of freeze-thaw cycles was presented by Mutlutürk et al. in 2004. By increasing the number of freeze-thaw cycles, the speed of longitudinal waves, the elastic modulus, adhesion, angle of internal friction and the UCS of the red sandstone specimens are decreased (Yu et al., 2015). Saito et al. (1994) examined chloride permeability of concrete subjected to freeze-thaw damage and found that the freeze-thaw process enhances the permeability of the specimens. Siline et al. (2017) studied the effect of freeze–Thaw cycles on the physicomechanical properties of a pozzolanic mortar and found that increasing the number of freeze-thaw cycles reduced UCS and thermal conductivity of the specimens, whereas porosity level and water absorption increased. They suggested that silicate-based materials (Pozzolans) can promote the concrete strength against the freeze-thaw cycles. The temperature of the freeze-thaw period has been extensively studied in recent years, excluding the effect of climate interactions; however, little research has been conducted on cement mortar. In this study, the freezing and thawing temperatures were -16 and 20 °C, respectively, regarding the most critical conditions in the climate data of Ardebil province over the past ten years. The purpose of this investigation was to evaluate the effect of the number of freeze-thaw cycles on physical and mechanical properties of Lushan sandstone and cement mortar. A computed tomography (CT) scan method was adopted to allow magnification of the damages occurred in sandstone specimens by the freeze-thaw cycle.

2. Materials and methods

In our study, we applied sandstone specimens because of their abundance in most formations of Iran, and cement mortar because of its application in concrete-placing operations. The concrete mortar applied contains Portland cement, fine-grained sandstone, and water, with a water to cement ratio of 0.5 and cement to sandstone ratio of 1.

Specimens were first submerged in water for 48 hours under saturated atmospheric pressure. Then specimens submerged in water for 18 hours at -16 °C and 6 hours at 20 °C, for freezing and thawing, respectively. Effective porosity, UCS, and Brazilian tensile strength of the specimens were determined before applying freeze-thaw cycles, and after 5, 10, 20 and 30 freeze-thaw cycles.

3. Tests results

3.1. Effect of the number of freeze-thaw cycles on effective porosity of sandstone and cement mortar specimens

The increase in the number of freeze-thaw cycles was linearly led to an increase in the porosity of sandstone and cement mortar specimens, with coefficients of determination 0.79 and 0.96, respectively. This indicates creating and expanding cracks caused by the freezing-thawing cycle. The values of effective porosity of sandstone and cement mortar specimens are presented in table 1.

Table 1. Effective porosity of sandstone and cement mortar specimens before applying freeze-thaw cycles, and after 5, 10, 20 and 30 freeze-thaw cycles.

Number of Cycle	0	5	10	20	30
Effective porosity of Sandstone	13.18	13.27	13.3	14.6	19.48
Effective porosity of Mortar	12.23	13.25	15.42	17.35	18.67

3.2. Effect of the number of freeze-thaw cycles on UCS and Brazilian tensile strength of sandstone and cement mortar specimens

The UCS and the Brazilian tensile strength of the specimens were decreased exponentially, with increasing the number of freeze-thaw cycles. Correlations and coefficient of determination of these variations are presented in table 2; the reduction in these two parameters and the increase in porosity of the specimens are presented in table 3.

Table 2. Equation and coefficient of determination between UCS and Brazilian tensile strength of sandstone and cement mortar specimens with the number of freeze-thaw cycles

Sample	regression equation for UCS	R^2	regression equation for TS	R^2
Sandstone	$UCS = 54.816e^{-0.011N}$	0.82	$\sigma_t = 4.8589e^{-0.014N}$	0.83
Mortar	$UCS = 26.523e^{-0.011N}$	0.77	$\sigma_t = 4.1601e^{-0.016N}$	0.82

Table 3. Percentage of porosity increase and decrease in UCS and Brazilian tensile strength of specimens after 30 freeze-thaw cycles

Sample	regression equation for UCS	R^2	regression equation for TS	R^2
Sandstone	$UCS = 54.816e^{-0.011N}$	0.82	$\sigma_t = 4.8589e^{-0.014N}$	0.83
Mortar	$UCS = 26.523e^{-0.011N}$	0.77	$\sigma_t = 4.1601e^{-0.016N}$	0.82

As shown, the highest and lowest effect after the 30th cycle is on the porosity of cement mortar (52.65% increase) and the UCS of cement mortar (30.91%), respectively.

3.3. CT scan images obtained from specimens at different cycles

The CT scan method was adopted before applying the freeze-thaw cycle and after 10 and 20 cycles to observe the cracks created. Significant changes were not observed in specimens. The CT value (Raynaud et al., 1989) was calculated to analyze the CT scan images. This parameter determines the level of decrease in X-rays passed through the material as well as the materials' density. After determining this parameter, it was found that increasing the number of cycles caused a linear reduction in the CT valve with a coefficient of determination of 0.99. This indicates the creation and expansion of cracks caused by freeze-thaw cycles.

3.4. Parameters of the decay function model

A decay function model was first presented by Mutlutürk et al. in 2004 for predicting the effect of the number of freeze-thaw cycles on the integrity loss of rock when subjected to recurrent cycles. The values of this model parameters (e.g. half-life and constant degradation) and the results of their comparison with the findings of this study are presented in table 4.

Table 4. Half-life and constant degradation of sandstone and cement mortar specimens for UCS and the Brazilian tensile strength

Sample	Parameter	Decay Constant	Half life
SandStone	UCS	0.011	63
	TS	0.014	50
Mortar	UCS	0.011	63

4. Conclusion

Effect of the number of freeze-thaw cycles on porosity, UCS and tensile strength of sandstone and cement mortar specimens were studied, under the effect of climate interactions. The results showed that increasing the number of cycles leads to a linear increase in the effective porosity and exponential decrease in the UCS and tensile strength of sandstone and cement mortar specimens. These results, besides calculating the CT value of the CT scan images, shows the creation and expansion of cracks caused by freeze-thaw cycles. A decay function model presented by Mutlutürk et al. in 2004 can be applied for long-term prediction of the effect of freeze-thaw cycles on UCS and tensile strength of sandstone and cement mortar specimens.

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