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Effect of Freeze-Thaw Cycles on Fracture Toughness and Strength Parameters of Travertine

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ABSTRACT: The present research investigates the effect of freeze-thaw cycles on mode I and mode II fracture toughness and strength parameters of travertine. In order to investigate the effect of freeze-thaw cycles on mode I and mode II fracture toughness, the samples were exposed to 0, 1, 4, 8, 16 and 32 freeze-thaw cycles and mode I and mode II fracture toughness were studied in different cycles. Confining pressures of 0, 2.5 and 5 MPa were applied to the samples to explore the effect of freeze-thaw cycles on strength parameters of travertine. Furthermore, microscopic studies were conducted to more precisely examine and evaluate the structural changes of the samples due to freeze-thaw cycles. Results show that mode I and mode II fracture toughness decrease exponentially as the number of freeze-thaw cycles increases. Mode I fracture toughness of the white and brown travertine were decreased after 64 cycles compared to 0 cycle as much as 35.48 and 37 percent, respectively and mode II fracture toughness of the white and brown travertine were decreased after 64 cycles compared to 0 cycle as much as 45.75 and 50 percent, respectively. Moreover, as the number of freeze-thaw cycles increases, triaxial compressive strength, uniaxial compressive strength, cohesion and internal friction angle decrease with regard to 0 cycle. Microscopic studies revealed that due to the freeze-thaw cycles, the microcracks of the stones propagate and new cracks are developed.

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1- Introduction

There are various environmental factors that influence the physical and mechanical properties of the stones as weathering. The effects can be physical or chemical. Freeze-thaw process is one of the major and most severe physical weathering factors which influence the physical and mechanical properties of the stones and reduces their durability and stability [1]. With the continued economic development around the world, many rock-related projects including mining and oil/gas exploration are currently undertaken in regions with cold climates. High precipitation and cold weather are the characteristics of the winters of the northwestern and western provinces of Iran which have mild summers and cold winters. Under these conditions, rocks are exposed to long frosts and numerous freeze-thaw cycles. In regions where this process is likely to occur, it is thus necessary to examine its impact on the physical and mechanical properties of the materials. The rock strength against freeze-thaw cycles depends on a complex set of the rock characteristics including mineralogical composition [2], size and distribution of rock pores [3] and consequent hydraulic [4], as well as mechanical characteristics of the rock especially its tensile strength [5]. This research investigates the impact of freeze-thaw cycles on mode I and mode II fracture toughness and strength parameters of travertine.

2- Sample preparation

In the present research, the white and brown travertine blocks were prepared from a stone-cutting workshop situated in shamsabad industrial city (located 40 Km from Tehran on Tehran-Qom freeway). White and brown samples were related to the travertine quarries of Mahallat township in Markazi province and Kashan province in Isfahan province, respectively (Figure 1). XRF analysis indicated that the main components of the studied travertines were calcium oxide along with impurities of silicon oxide as well as oxides of metals including iron, aluminium, sodium and magnesium (Table 1). L.O.I* in table 1 represents the volatiles and H_2O whose weights are calculated as percent through igniting the sample at 1000°C and are situated in the chemical analysis list.

Table 1. XRF chemical analysis results of travertine samples

Sample	Unit	MgO	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	*L.O.I.
Brown	%	0.2	1.2	0.5	0.1	54.7	<0.1	43.1
White	%	0.2	2.3	0.5	0.2	53.8	0.2	42.4

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Table 2. the mean results of mode I and mode II fracture toughness of the white travertine samples during 0, 1, 4, 8,16, 32 and 64 cycles

Number of cycles	mode I (MPa.m$^{1/2}$)	mode II (MPa.m$^{1/2}$)
0	0.62	1.53
1	0.57	1.42
4	0.53	1.24
8	0.52	1.11
16	0.44	0.97
32	0.43	0.86
64	0.4	0.83

Table 3. the mean results of mode I and mode II fracture toughness of the brown travertine samples during 0, 1, 4, 8,16, 32 and 64 cycles

Number of cycles	mode I(MPa.m$^{1/2}$)	mode II (MPa.m$^{1/2}$)
0	0.46	1.32
1	0.41	0.96
4	0.38	0.89
8	0.35	0.87
16	0.33	0.76
32	0.32	0.71
64	0.29	0.66

3- Results and Discussion

Mode I and mode II fracture toughness of the white and brown travertine were determined before exposure to freeze-thaw cycles and after 1, 4, 8, 16, 32 and 64 cycles. Four samples were used in each cycle to assure the reliability of the results. Tables 2 and 3 show the mean results.

As shown in Tables 2 and 3, mode I and mode II fracture toughness of the white and brown travertine decreased with increasing the number of freeze-thaw cycles.

This decreasing tendency is nonlinear and exponential. The initial crack propagation and rise in the present microcracks of the travertine samples can be responsible for the above decrease. To examine the crack propagation, Electron Microscope Images were prepared.

Electron Microscope analysis of the white and brown travertine stones after 64 cycles at a magnification of 500 revealed that due to the loss of the present cementitious materials, the openings between minerals as well as the cracks and the pores of the samples exposed to freeze-thaw cycles increased compared with the samples that were not exposed to those cycles and new cracks were developed in the former.

4- Conclusion

The results of this research are summarized as follows:

mode I and mode II fracture toughness of the white and brown travertine have decreased exponentially as the number of freeze-thaw cycles increases.

The effect of the freeze-thaw cycles on the fracture toughness of the white travertine was less than the brown one.

The uniaxial compressive strength of the travertine samples has decreased exponentially as the number of freeze-thaw cycles increases. The amount of this decrease reached to 38.22 percent at the end of the 64th cycle.

The triaxial compressive strength of the travertine samples has decreased exponentially as the number of freeze-thaw cycles increases. The amount of this decrease at the end of the 64th cycle for the pressures of 2.5 and 5 MPa reached to 54.78 and 39.23 %, respectively.

The cohesion and the internal friction angle of the travertine samples have decreased exponentially as the number of freeze-thaw cycles increases. The amount of this decrease at the end of the 64th cycle for cohesion and the internal friction angle reached 31.57 and 22.92 %, respectively. The cohesion has experienced more decrease than the internal friction angle.

The water absorption rate of the white and brown travertine samples has increased exponentially as the number of freeze-thaw cycles increases. Increase in the water absorption rate is attributed to the propagation of the initial cracks and the development of new cracks.

The longitudinal-wave velocity of the travertine samples has decreased exponentially as the number of the freeze-thaw cycles increases and its reason is the increase of microcracks.

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