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Evaluation of long-term durability of carbonate building stones after freeze and thaw cycles using CART method

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Abstract

The freeze and thaw cycles are one of the most important factors in physical weathering of stones, which substantially can influence the long-term durability and service life of building stones. To evaluate the long-term durability of stones against freeze and thaw cycles, two parameters of decay constant (λ) and half-life index ($N_{1/2}$) can be applied. To determine these two parameters, the freeze and thaw test should be done, which is a difficult, time-consuming and expensive process. Therefore, development of indirect models to estimate these two parameters without performing freeze and thaw test can be useful for fast and low-cost evaluation of stones' long-term durability. In this paper, considering the P-wave velocity (V_P) of stones during the freeze and thaw process for 22 types of Iran's carbonate building stones, two parameters of λ and $N_{1/2}$ were determined. Then, based on obtained data and using regression analysis and classification and regression tree (CART) techniques, models were developed to predict these two parameters. The results indicated that the developed models using CART technique have higher accuracy and precision than the regression models. These models are able to present acceptable prediction of λ and $N_{1/2}$ based on the initial porosity of stone.

Keywords: *Freeze and thaw cycles, Long-term durability, Classification and Regression Tree (CART), Half-life index, Decay constant*

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Extended Abstract:

1. Introduction

One of the most critical issues of building stones for outdoor applications is their resistance to physical weathering. Freeze and thaw effect is the main reason of physical weathering in cold regions and can lead to a high degree of rock deterioration. Freeze and thaw may cause a rapid change in the physical and mechanical properties of building stones and thus reduce their long-term durability and service life (Akin and Özsan, 2011; Jamshidi et al., 2013). Therefore, understanding and evaluating the long-term durability of building stones after freeze and thaw process is critical in selecting the stones for outdoor applications. Researchers have previously studied the effect of freeze and thaw process on different building stones and proposed several decay models to describe the deterioration due to freeze and thaw action. The most applicable decay model has been presented by Mutlutürk et al. (2004). They proposed an exponential decay function model which uses the decay constant (λ) and half-life index ($N_{1/2}$) parameters to express the disintegration rate of rock. The decay constant is the average integrity loss at any cycle of freeze and thaw. Half-life index can be described as the number of cycles necessary to reduce a physical or mechanical property to its half value; rocks that are resistant to deterioration have high half-life values.

Thus, to evaluate the long-term durability of stones against freeze and thaw cycles, two parameters of decay constant (λ) and half-life index ($N_{1/2}$) can be applied. To determine these two parameters, the freeze and thaw test should be done, which is a difficult, time-consuming and expensive process. Therefore, development of indirect models to estimate these two parameters without performing freeze and thaw test can be useful for fast and low-cost evaluation of stones' long-term durability. The main purpose of this study is to develop indirect models for predicting two parameters of λ and $N_{1/2}$ based on initial stone properties.

2. Materials and methods

To do this study, 22 carbonate building stones (including 3 types of limestone, 12 types of travertine and 7 types of marble) were selected from various quarries in Iran. Laboratory investigations in this study were performed in four stages. In the first stage, the physical properties (dry density, saturated density, effective porosity and water absorption) of all stones were determined according to the ISRM standard test method (ISRM, 1979). In the second stage, the uniaxial compressive strength (UCS) of studied stones were determined according to ASTM C170 (2017). In the third stage, all studied stones were subjected to freeze and thaw test in accordance to TSE (TS 699) standard (TSE, 1987). The freeze and thaw test was carried out for 25 cycles and the P-wave velocity (V_P) of stones was determined after every 5 cycle. On the other hand, the V_P values for all stones before freeze and thaw test (cycle 0) and after every 5 cycle (cycles 5, 10, 15, 20, and 25) were determined according to ISRM (ISRM, 1978).

3. Discussion and conclusions

In this paper, based on change in V_P values during the freeze and thaw process for 22 types of carbonate building stones, two parameters of λ and $N_{1/2}$ were determined using decay function model proposed by Mutlutürk et al. (2004). Then, three initial physical-mechanical properties of stones (i.e. UCS, V_P, and porosity of fresh stone before freeze and thaw test) were considered to develop indirect predictive models for λ and $N_{1/2}$. Regression analysis results indicated that among these initial properties, porosity is the most important feature that mainly controls the long-term

durability of stones. So, this property was considered as input parameter to develop the predictive models. Then, using regression analysis and classification and regression tree (CART) techniques, models were developed to predict λ and $N_{1/2}$ parameters. The results indicated that the developed models using CART technique have higher accuracy and precision than the regression models. The coefficient of determination (R^2), the variance account for (VAF) and the normalized root mean square error (NRMSE) were obtained as 0.88, 88.07% and 0.11 for the decay constant tree model, and 0.93, 92.81% and 0.07 for the half-life index tree model. These indices illustrated that the CART technique very effective and robust tool for assessment of long-term durability of building stones.

These tree models should be applied to evaluate the resistance of stones to deterioration before selecting the appropriate building stone. Using these models, the λ and $N_{1/2}$ can be predicted without performing laborious and time consuming test of freeze and thaw. These models present tree structures, which are easy to use and readily interpretable. Finally, it should be mentioned that the suggested models can be improved by accumulation of more data which leads to comprehensive models with better prediction capacities.

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