Journal of African Earth Sciences 120 (2016) 134–140

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

A prediction model for uniaxial compressive strength of deteriorated pyroclastic rocks due to freeze–thaw cycle

İsmail İnce [a,*], Mustafa Fener [b]

[a] Department of Geology, Selçuk University, Konya, 42250, Turkey
[b] Department of Geology, Ankara University, Ankara, 06100, Turkey

ARTICLE INFO

Article history:
Received 21 March 2016
Received in revised form
2 May 2016
Accepted 4 May 2016
Available online 8 May 2016

Keywords:
Pyroclastic
Freeze-thaw cycle
Loss of uniaxial compressive strength
Statistical model
Building stone

ABSTRACT

Either directly or indirectly, building stone is exposed to diverse atmospheric interactions depending on the seasonal conditions. Due to those interactions, objects of historic and cultural heritage, as well as modern buildings, partially or completely deteriorate. Among processes involved in rock deterioration, the freeze–thaw (F–T) cycle is one of the most important. Even though pyroclastic rocks have been used as building stone worldwide due to their easy workability, they are the building stone most affected by the F-T cycle. A historical region in Central Anatolia, Turkey, Cappadoia encompasses exceptional natural wonders characterized by fairy chimneys and unique historical and cultural heritage. Human-created caves, places of worship and houses have been dug into the pyroclastic rocks, which have in turn been used in architectural construction as building stone.

Using 10 pyroclastic rock samples collected from Cappadocia, we determined the rock's index-mechanical properties to develop a statistical model for estimating percentage loss of uniaxial compressive strength a critical parameter of F-T cycle's important value. We used dry density (ρ_d), ultrasonic velocity (V_p), point load strengths ($I_{S(50)}$), and slake-durability test indexes (I_{d4}) values of unweathered rocks in our model, which is highly reliable ($R^2 = 0.84$) for predetermination of percentage loss of uniaxial compressive strengths of pyroclastic rocks without requiring any F-T tests.

1. Introduction

Due to their easy workability and transport, pyroclastic rocks have been widely used as natural building stone. Even though these rocks are hard enough to be used in construction, they are nevertheless soft enough to be cut and excavated. In historical time, houses and temples carved into pyroclastic rocks and they were used as building stone in many architectural work. Today, such rocks are widely used as building stone and facing stone in modern architecture, largely due to their decorative features.

The Cappadocia region in Turkey exhibits a great deal of pyroclastic rocks, used both in prehistoric and more recent times. In Central Anatolia and home to cities of Nevşehir, Kayseri, Niğde and Aksaray (Fig. 1), Cappadocia is an exceptional natural wonder characterized by fairy chimneys and unique historical and cultural heritage carved into pyroclastic rocks (Fig. 2). In fact, for its incredible rocky landscape and ancient underground settlement, Cappadocia was named a UNESCO Word Heritage Site; among important underground cities excavated in pyroclastic rocks there are Kaymaklı, Derinkuyu and Özkonak in Nevşehir; Gözyaşı, Saraltı and Ozancık in Aksaray; Ali Dağı in Kayseri and GümüşlerMonastery in Niğde.

Physical and mechanical properties of building stones change depending on climatic circumstances. In cold region, a primary cause of such changes is the freeze-thaw (F-T) cycle. The effectiveness of F-T cycles in rocks changes depending on the rock-s'mineralogical composition, texture, structural and physicomechanical properties. In pyroclastic rocks, high capillarity and porosity accelerate the process. Whereas their high capillarity ensures that pore spaces are quickly saturated with water, their high porosity allows the amount of water to increase in those spaces, which is crucial for the F-T cycle. When the temperature drops below 0 °C in cold regions, the volume of water, now freezing, increases by about 9%, thereby putting pressure on the pores and cracks of the surrounding rocks. Increased pressure enlarges the pores and fractures, and causes new micro cracks to develop (Chen et al., 2004). As this cycle recurs, building stone becomes subject to unwanted weathering.

* Corresponding author.
E-mail addresses: iince@selcuk.edu.tr (İnce), mfener@ankara.edu.tr (M. Fener).

http://dx.doi.org/10.1016/j.jafrearsci.2016.05.001
1464-343X/

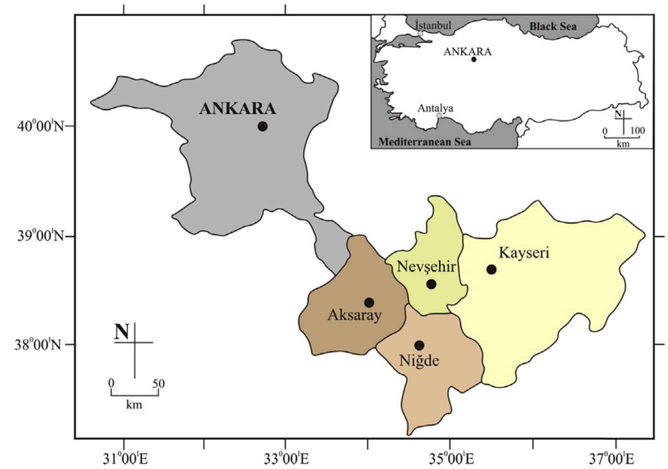

Fig. 1. Location map of the Cappadocia region.

The effects of F-T cycles on the index and strength parameters of pyroclastic rocks have been investigated by numerous researchers (Binal et al., 1997, 1998; Topal and Doyuran, 1997, 1998; Topal and Sözmen, 2000, 2003; Chen et al., 2004; Török et al., 2007; Ergüler, 2009; Koralay et al., 2011; Ruedrich et al., 2011; Yavuz, 2012; İnce, 2013; Fener and İnce, 2015; Özbek, 2014; Park et al., 2015; İnce et al., 2015). During these cycles, the welding degree (Binal et al., 1997; Koralay et al., 2011), water saturation degree (Chen et al., 2004) and texture and pore size (Török et al., 2007) are important features for pyroclastic rocks. By extension, modeling the F-T cycle for the long-term durability of rocks is important, and various models have been developed to assess changes in rocks following F-T cycles (Mutlutürk et al., 2004; Altındag et al., 2004, 2006; Yavuz et al., 2006; Akin and Özsan, 2011; Bayram, 2012; Jamshidi et al., 2013; Liu et al., 2015). For example, Mutlutürk et al. (2004) developed a decay function model (DFM) for the loss of integrity in rocks after repeated F-T cycles, in which they used variables of decay constant and half-life derived from rocks' Shore hardness of rocks. At the same time, Altındag et al. (2004, 2006) investigated the applicability of DFM on ignimbrite and carbonate rocks, respectively, and determined the decay constant and half-life based on rocks' various index and mechanical properties. In more recent studies involving DFMs, Akin and Özsan (2011) studied long-term performance of yellow travertine, and Jamshidi et al. (2013) examined the long-term effects of F-T cycles on 14 different rock samples used as building stone. Along similar lines, Yavuz et al. (2006) developed a model to predict the index properties of carbonate rocks after F-T cycles.

In related research, Bayram (2012) developed a statistical model to determine the percentage loss of uniaxial compressive strength of limestones after F-T cycle. Liu et al. (2015) improved an empiric equation to determine uniaxial compressive strengths based on rock properties before and after F-T cycles. Indeed, uniaxial compressive strength is an important parameter for building stones in determining a location's suitability for use. In fact, it is compulsory to determine the percentage loss of uniaxial compressive strength of building stones after F-T cycles to determine their usability for outdoor application in cold climate regions. Although determining the percentage loss of uniaxial compressive strength of building stones is relatively simple, it is time consuming and expensive.

As the studies cited above imply, the long-term effects of F-T cycles on different rocks have previously been investigated. However, the long-term effects of F-T cycles on pyroclastic rocks, which are most affected by the process, and their percentage loss of uniaxial compressive strengths have yet to be modelled. In response, we developed a statistical model to predict the percentage loss of uniaxial compressive strength of Cappadocian pyroclastic rocks with intact rock properties after F-T cycles without requiring F-T test.

2. Material and method

2.1. General geology and petrographic properties

Shown in Fig. 3, are the pyroclastic rocks tested that were taken

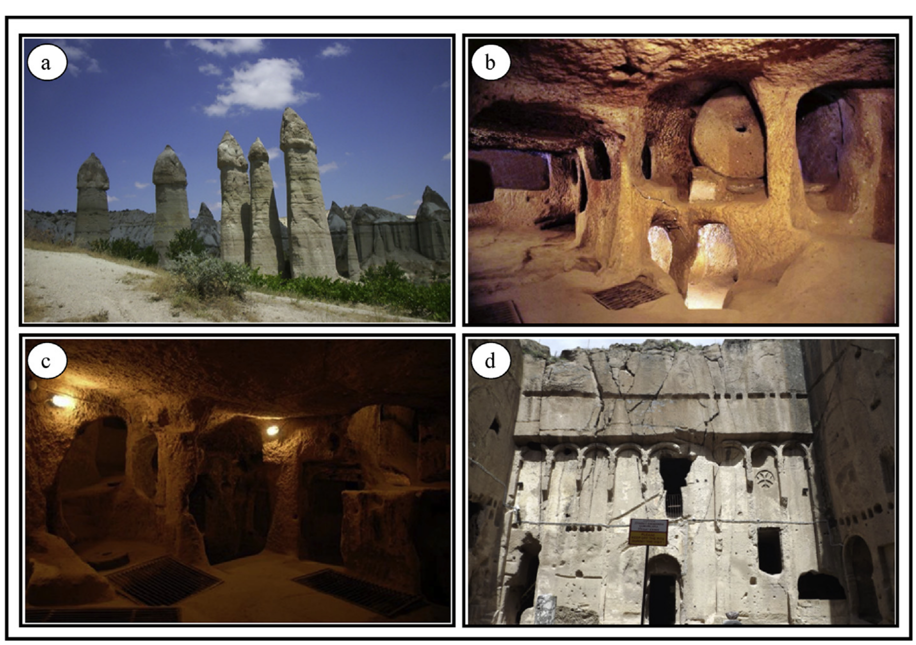

Fig. 2. Cultural heritages in the Cappadocia region a) fairy chimneys, b) Kaymaklı Underground City (Nevşehir), c) Derinkuyu Underground City (Nevşehir), d) Gümüşler Monastery (Niğde).