The effects of freeze-thaw cycles on pyroclastic rocks used in Gümüşler Monastery, Niğde, Turkey

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Abstract: - Stones used in the construction of cultural buildings are exposed to various direct or indirect atmospheric effects depending on the climatic and seasonal conditions. Stones deteriorate partially or fully as a result of these effects and these buildings of historical value cannot survive long. Therefore, understanding and predicting the effect of freeze–thaw cycles is important in environmental science, the built environment and cultural heritage preservation. In this study, fresh pyroclastic rocks obtained from the stone quarry were exposed to different numbers of F-T cycles in the laboratory medium. The effects of the number of F-T cycles on basic physical and mechanical properties of the "Gümüşler stone" were investigated.

Key-Words: Gümüşler Monastery, pyroclastic rocks, freeze-thaw cycles, weathering, cultural buildings

1 Introduction

Owing to their ease of workability and transport, pyroclastic rocks have extensively been used as natural building materials down the ages. Initially, havens and sanctuaries were carved into pyroclastic rocks in order to avoid seasonal temperature differences and enemy attacks such as Cappadocia Region, Turkey; Kandovan, Iran; Vardzia Monastery Complex, Georgia etc. The most distinctive examples of these kind of buildings in Turkey are located in the Cappadocia region. Of these, the most famous and important one is the Gümüşler Monastery a structure which was built by carving a single piece of rock, during the Byzantine period.

From past to the present, stones were used as main building materials in most of the buildings. On the other hand, physical and mechanical characteristics of stones alter depending on the climatic conditions. One of the major reasons of alterations in cold regions is the process of freeze and thaw. As a result of this process, stones deteriorate partially or in total. Buildings having characteristics of cultural heritage lose their qualitative features due to freeze-thaw processes if necessary precautions are not taken.

That the cycles of freeze-thaw processes affected the index and strength parameters of pyroclastic rocks was proved by [1-4]. That freeze-thaw cycles were effective on the abrasion strengths was proved by [3]. Similarly, that possible alterations in rocks as a result of freeze-thaw cycles could be modelled was proved by [5] and that historic buildings were affected by freeze-thaw process was proven by [6-11].

Pyroclastic rocks exhibit a wide distribution on the volcanic belts on the earth. Due to the ease of workability, a great number of havens and sanctuaries were carved into these rocks.

Determination of the behaviour of pyroclastic rocks, which were used as building stones in historic buildings in cold regions, against freeze-thaw cycles is quite important. Within this context, pyroclastic samples obtained from Gümüşler region were systematically exposed to various number of freeze-thaw cycles. Then, the main index properties, strength parameters, abrasion parameters and ultrasonic velocity changes of the samples were modelled.

2 Materials and Methods

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2.1 Sampling area and geology

The rock samples used in this study were taken from Gümüşler town (Niğde) located in Cappadocian Volcanic Province (CVP). CVP is a Neogene-Quaternary volcanic field that extends 300 km in length and 20-50 km in width in NE–SW direction in the central Anatolia of Turkey [12].

The basement rocks in the region are composed of pre-Miocene units. The Yeşilhisar Formation unconformably overlies the basement rocks. The age of the Yeşilhisar Formation is Early Miocene. The Yeşilhisar formation is a coarsely bedded fluvial deposit composed of red mudstone, sandstone and conglomerate alternations [13]. The Ürgüp formation, unconformably overlying the Yeşilhisar formation, has widespread in the area. Ürgüp formation is composed of 8 ignimbrite members (Kavak, Zelve, Sarımaden Tepe, Cemilköy, Tahar, Gördeles, Kızılkaya and Valibaba), 2 volcanic flows (Damsa and Topuzdağ) and fluvial and lacustrine sediments intercalated with them. The age of the unit is Late Miocene-Pliocene [14]. Quaternary-aged Kumtepe formation unconformably overlies the Ürgüp formation. Alluvium unconformably overlies all these units.

The pyroclastic rocks used in the study belong to the Kızılkaya ignimbrite of the Ürgüp formation.

The samples used in the region are light pink in colour. Thin sections were prepared from the rock samples and were analyzed by polarization microscopy. Gümüşler stone microscopically includes % 72 volcanic glass, % 12 plagioclase, % 6 quartzite, % 5 rock fragment, % 4 biotite and 1% opaque minerals. The stone was named as “vitric tuff” according to [15].

2.2 Index properties

Index properties of Gümüşler stone are as follows: Dry unit weight is 12.80 kN/m^3, saturated unit weight is 16.41 kN/m^3, water absorption by weight is 28,23%, void ratio is 58.31% and porosity is 36.83%.

2.3 Experimental procedure

Homogenous blocks of sizes of 20×30×30 cm were cut from Gümüşler quarry for experimental studies. Test samples compatible to the related tests were prepared to determine physical and mechanical properties of the rock. Prepared samples were grouped into six. The first group was not exposed to freeze-thaw cycle and defined as witness samples. The remaining 5 were exposed to different numbers (5, 10, 15, 20 and 30) of cycles.

The summaries of standard procedures used in the study were given in Table 1.

Table 1 List of standard procedures (physical, strength, abrasion and durability properties) of rocks

Subject	Test procedure
Dry unit weight	ISRM [16]
Saturated unit weight	ISRM [16]
Total porosity	ISRM [16]
Water absorption	ISRM [16]
Freeze-Thaw test	ASTM [17]
Uniaxial compressive strength	ASTM, [18]
Point load test	ASTM, [19]
Böhme abrasion test	EN 14157 [20]

3 Results and Discussion

Main physical, mechanical and abrasion properties of the witness and the freeze-thaw processed samples were given in Table 2. In addition, the changes in between these values due to the cycle numbers were statistically investigated and related graphics were presented in Fig. 1.

According to the data obtained, porosity determined as 36.83% in the witness sample raised to 44.67% in the last group. There is an increase of 20% in the porosity of the 5th group with respect to that of the witness group. Porosity values of all the samples exposed to freeze-thaw cycles increased (Table 2). When the graphic showing the relevance between freeze-thaw cycles and porosity is studied, it is seen that there is a polynomial relationship with a high correlation coefficient (R^2: 0.90) (Fig. 1).

Table 2 Main physical, mechanical and abrasion parameters of Gümüşler stone before and after freeze-thaw.

Geo-mechanical properties	Witness	After Freeze-Thaw				
	0	**5**	**10**	**15**	**20**	**30**
	Mean	Mean	Mean	Mean	Mean	Mean
n (%)	36.83	38.85	42.24	42.77	42.11	44.67
σ_u(MPa)	7.56	7.82	6.96	7.08	5.73	5.90
$Is_{(50)}$ (MPa)	1.03	0.91	0.94	0.78	0.61	0.75
σ_t (MPa)	1.68	0.97	1.13	0.98	0.91	0.92
BA (cm^3/50 cm^2)	25.95	31.33	33.64	36.42	36.03	41.35
Vp(km/s)	2.02	1.99	1.99	2.02	1.95	1.93

When the results for uniaxial compressive strengths of the witness samples and those exposed to freeze-thaw cycles are reviewed, it is understood that compressive strengths decrease with the increasing number of freeze-thaw cycles. The values of uniaxial compressive strength stepped down to 5.90 MPa while it was 7.56 MPa for the witness sample.

It is observed that there is a relation of high correlation coefficient (R^2: 0.78) when the relationship between freeze-thaw cycles and the values of uniaxial compressive strength is studied (Fig. 2). A similar relationship is noticed between freeze-thaw cycles and point load and Brazilian tensile strengths as well. In the stone, all values of strengths decreased as the freeze-thaw cycles increased.

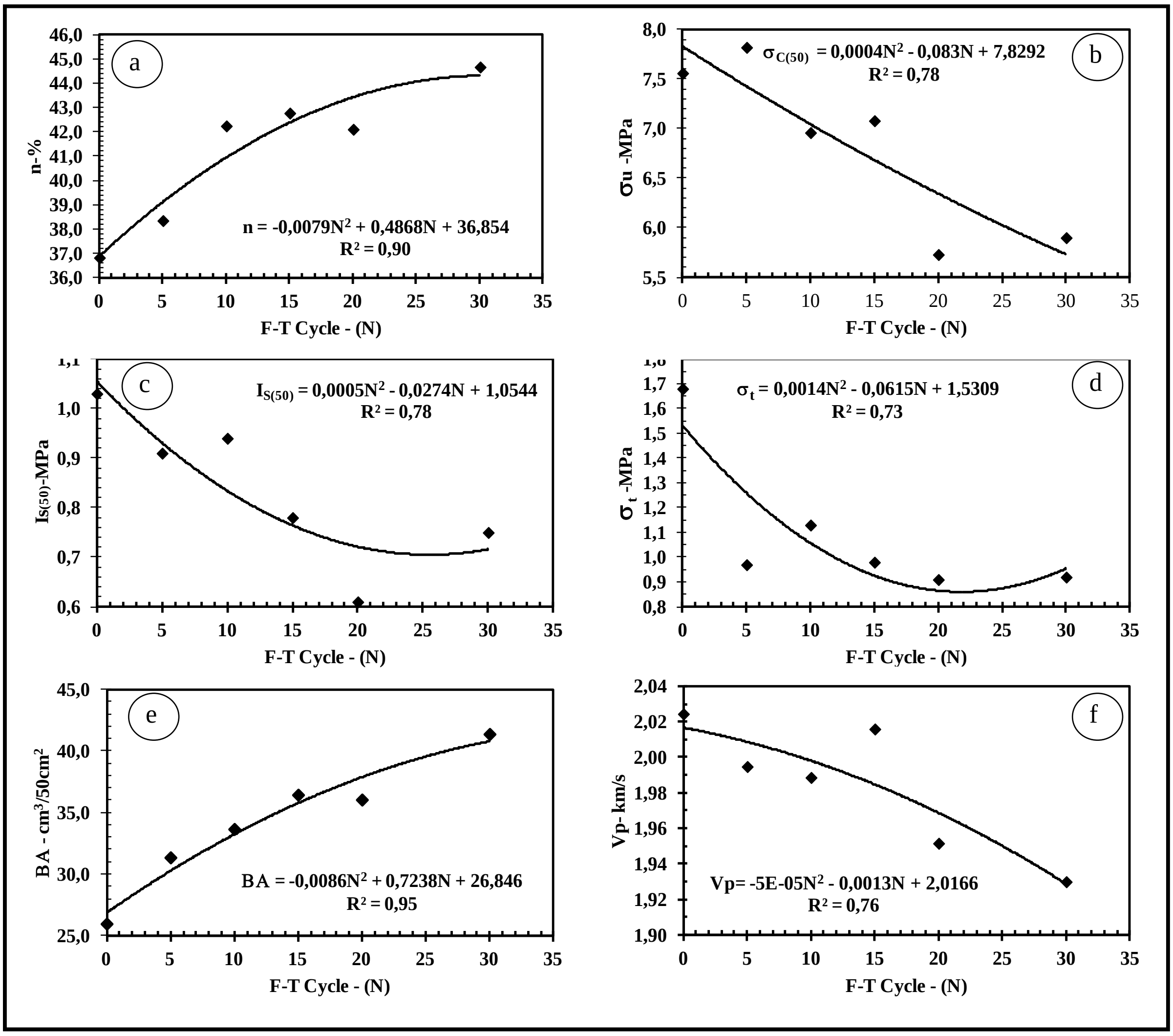

Fig. 1 Graphics of changes of basic physical, mechanical and abrasion parameters of Gümüşler stone, with respect to the numbers of cycles, before and after F-T; a) porosity (n), b) Uniaxial compressive strength, c) Point load strength, d) Brazilian tensile strength, e) Böhme abrasion loss (BA), f) P Wave velocity (Vp).

The value of abrasion loss of witness sample was found as 25.95 $cm^3/50cm^2$. This value increased with the increasing number of freeze-thaw cycles and stepped up to 41.35 $cm^3/50cm^2$ in the 5^{th} group. The change of the loss of abrasion strength in the 5^{th} group is approximately 60% with respect to that of the witness sample.

It was determined that an inverse relationship existed between the freeze-thaw cycles and the P wave velocities. The observations showed that P wave velocities decreased as the number of freeze-thaw cycles increased. The velocity stepped down to 1.93 km/s while it was 2.02 km/s for the witness sample (Table 2). This decrease is due to the increases in porosities following freeze-thaw cycles. The correlation coefficient of the relationship between P wave velocities and number of freeze-thaw cycles is 0.76.

4 Conclusion

There are historic buildings which have been carved into pyroclastic rocks and are located in different locations of the World in different historic periods. Pyroclastic rocks are commonly used at the present as well as centuries before due to their ease of workability and resistance to thermal conductivity. Modelling the buildings and the changes in pyroclastic stones used in buildings in cold regions where freeze-thaw effects are intensively experienced are of real importance. Within this context, pyroclastic samples obtained from Gümüşler were systematically exposed to different numbers of freeze-thaw cycles, and their basic index properties, strength parameters, abrasion parameters and changes in ultrasonic velocities were modeled.

Based on the analyses, the following main conclusions were drawn.

a. There is a linear relationship between freeze-thaw cycles and porosity of Gümüşler pyroclastic stone (R^2:0,90). Porosity increases with the increasing number of cycles.

b. There is an inverse relation of high correlation coefficient between the number of freeze-thaw cycles and the uniaxial compressive, point load and Brazilian tensile strengths of Gümüşler pyroclastic. Correlation coefficients are 0.78, 0.78 and 0.73 respectively.

c. The most important factor in the freeze-thaw process is the existence of water. Necessary precautions to prevent surface and ground water from penetrating into stones should be taken to let buildings get affected by freeze-thaw cycles at the minimum possible level.

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