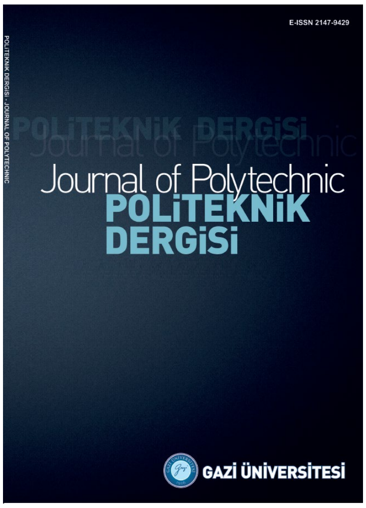

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Investigation of the effect of using epoxy coatings on salt crystallization in ignimbrite (Nevsehir-Turkiye) stones

İgnimbirit (Nevşehir-Türkiye) taşlarında epoksi kaplamaların kullanılmasının tuz kristalleşmesine etkisinin araştırılması

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Investigation of the Effect of Using Epoxy Coatings on Salt Crystallization in Ignimbrite (Nevsehir-Turkiye) Stones

Highlights

- *Epoxy coated ignimbrites showed a lower water uptake percentage than untreated ignimbrites.*
- *The decrease in open porosity of epoxy coated samples increased their apparent density compared to untreated samples.*
- *Epoxy coating forms a protective thin layer that prevents water from entering the pores of the stones.*
- *Epoxy resin fills the pores of the stone and accumulates salt crystals on the surface.*
- *Epoxy coatings show that ignimbrite can potentially be used in the restoration of historic buildings due to their surface resistance to salt crystallization.*

Graphical Abstract

In this study, the effectiveness of using epoxy coatings on the surface of ignimbrite, a type of pyroclastic rock extracted from the Nevsehir region, in preventing damage caused by salt crystallization was discussed. It was determined that there was a 6.20% increase in the dry weight of the epoxy coated samples, while there was a 0.82% decrease in the untreated ignimbrite samples, when subjected to the same salt crystallization test.

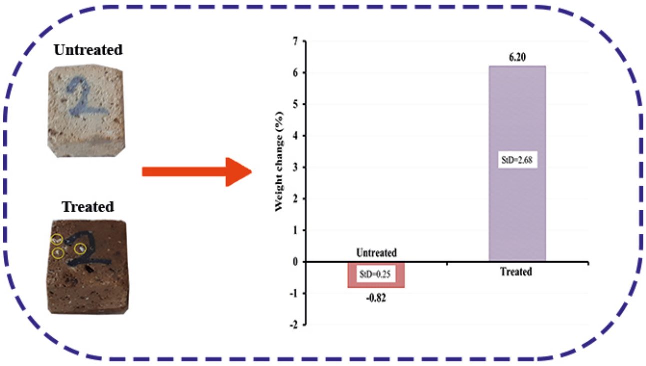

Figure. Dry weight change of untreated and epoxy coated (treated) ignimbrite samples at the end of the salt crystallization test

Aim

In this study, it is aimed to use epoxy coatings on the surface of ignimbrites found in Nevsehir (Turkiye) and to prevent damage caused by salt crystallization.

Design & Methodology

Epoxy coated (treated) and untreated samples; their resistance to salt was examined by performing water absorption, apparent density, open porosity and salt crystallization experiments with sodium chloride solutions.

Originality

In the literature, the deteriorations occurring in ignimbrite stones and their physical, chemical and mineralogical properties were investigated. However, no study has been found in the literature regarding the effectiveness of using surface protective epoxy coatings to prevent damage to these stones due to salt crystallization.

Findings

Experimental results show that epoxy coatings have surface resistance to salt crystallization and water of ignimbrite.

Conclusion

It was observed that the epoxy coating fills the pores in the stones and is more resistant to salt crystallization damage than untreated stones.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation of the Effect of Using Epoxy Coatings on Salt Crystallization in Ignimbrite (Nevsehir-Turkiye) Stones

Research Article / Araştırma Makalesi

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ABSTRACT

Salt crystallization caused by water absorption in ignimbrites used as building stones is one of the most important factors that cause the deterioration of historical buildings. Salt crystals accumulated in the pores of the stones cause deterioration such as cracks and efflorescence during drying due to the effect of internal pressure. In this study, it is aimed to use epoxy coatings on the surface of ignimbrites found in Nevsehir (Turkiye) and to prevent damage caused by salt crystallization. Epoxy coated (treated) and untreated samples; their resistance to salt was examined by performing water absorption, apparent density, open porosity and salt crystallization experiments with sodium chloride solutions. At the end of the salt crystallization test, it was determined that there was a 6.20% increase in the dry weight of the epoxy coated samples, while there was a 0.82% decrease in the untreated ignimbrite samples. It was observed that the epoxy coating fills the pores in the stones and is more resistant to salt crystallization damage than untreated stones. Since epoxy coatings are effective in protecting the surface of ignimbrites, it has been concluded that they can be used to prevent deterioration of historical buildings caused by salt crystallization.

Keywords: Salt crystallization, nevsehir stone, epoxy coatings, stone protection, stone surface protection.

İgnimbirit (Nevşehir-Türkiye) Taşlarında Epoksi Kaplamaların Kullanılmasının Tuz Kristalleşmesine Etkisinin Araştırılması

ÖZ

Yapı taşı olarak kullanılan ignimbiritlerde su emilimiyle oluşan tuz kristalleşmesi tarihi yapıların bozulmasına neden olan en önemli faktörlerdendir. Taşların gözeneklerinde biriken tuz kristalleri, iç basınç etkisiyle çatlaklar ve kuruma esnasında çiçeklenme gibi bozulmaları oluşturmaktadır. Bu çalışmada Nevşehir (Türkiye) ilinde bulunan ignimbiritlerin yüzeyinde epoksi kaplamaların kullanılması, tuz kristalleşmesine bağlı oluşan hasarların önlenmesi amaçlanmaktadır. Epoksi kaplama işlemi görmüş ve işlem görmemiş numunelerin; su emme, görünür yoğunluk, açık gözeneklilik ve sodyum klorür çözeltileriyle tuz kristalleşmesi deneyleri yapılarak tuza karşı gösterdiği dirençleri incelenmiştir. Epoksi kaplama işlemi görmüş numunelerin tuz kristalizasyon testi sonunda kuru ağırlıklarında % 6.20 artış olurken, işlem görmemiş ignimbirit numunelerde ise % 0.82 azalma olduğu belirlenmiştir. Epoksi kaplama, taşlardaki gözenekleri doldurarak işlem görmemiş taşlara göre tuz kristalleşmesi tahribatına karşı daha dirençli olduğu gözlemlenmiştir. Epoksi kaplamalar ignimbiritlerin yüzeyinin korunmasında etkili olduğundan, tarihi yapıların tuz kristalizasyonuyla oluşan bozulmalarını önlemek için kullanılabileceği sonucuna varılmıştır.

Anahtar Kelimeler: Tuz kristalizasyonu, nevşehir taşı, epoksi kaplamalar, taş koruma, taş yüzey koruyucular.

1. INTRODUCTION

Among the main factors that cause damage to stones used in historical buildings, the growth of salt crystals in the pores is one of the most harmful [1]. When water penetrates the stone due to atmospheric factors, the chemical dissolution of the carbonate component of the stone initiates harmful effects on the stone. Salt crystals form as a result of the evaporation of dissolved carbonate components due to changes in air temperature. The stresses caused by salt crystals create cracks in the stone. In cold climates, it causes physical and biological deterioration by increasing the width and number of cracks in stone through freeze-thaw cycles. Therefore, in order to protect historical structures built of stone against decay caused by atmospheric factors, the water absorption of the stone must be reduced. Application of a hydrophobic polymer protective coating applied to the surface of the stone is the most effective way to protect against decay [2].

Polymer protective coatings used on stone surfaces must have features such as reducing water absorption of the stone, good adhesion, resistance to mechanical and physical weathering, transparency and no color reflection change [3]. Nowadays, polymers such as acrylics and copolymers, epoxies and polyurethanes are used to protect the stone surfaces of historical buildings [4]. It

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can be seen in the literature that studies have been conducted on the resistance of polymer protective coatings against salt crystallization that can be used on the surfaces of stones in historical buildings. For instance in the study conducted by da Fonseca, Pinto, Rucha, Alves and Montemor [5], it was determined that alkoxysilanes and phosphate-based consolidants were resistant to salt crystallization damage by reducing the pore rates of limestone in historical buildings. In the study conducted by Andreotti, Franzoni, Ruiz-Agudo, Scherer, Fabbri, Sassoni and Rodriguez-Navarro [6], it was determined that polyacrylic-based polymeric coatings of limestones reduced capillary water absorption and increased the salt resistance of the stones. Vázquez, Luque, Alonso and Grossi [7], it was showed that the damage to the salt crystals of marbles was not caused by the pressure within the pore system, but by the dissolution of carbonate and calcite minerals. In the research conducted by Khallaf, El-Midany and El-Mofty [8], it was stated that in the protection of historical buildings made of sandstone and limestone, the water absorption rate of acrylic polymer decreased as it penetrated into the gaps and pores, and it could be suitable for protection against water problems affecting stones and salt corrosion. In another study conducted by Pinna, Salvadori and Porcinai [9], it was determined that the stones were resistant to damage caused by salt, as the superficial saline growth of epoxy, polydimethylsiloxane and ammonium oxalate monohydrate polymer coatings on the surfaces of limestones was prevented. As can be seen, surface protection coatings penetrate the pores of the stones on which they are applied, reducing water absorption rates and increasing their resistance to salt crystallization damage. However, the differences in the pore structures and porosity levels of stone types also change the amount of salts that the stone can take in along with water. This causes stones with more pores to be more likely to be damaged by salt crystallization. Moreover, the polymers used as surface protectors show different structural behavior for each stone, causing them not to give the same results in applications. Therefore, before applying surface protective coatings on stones, their resistance to salt must be determined through laboratory experiments.

Ignimbrite stone, mined in and around Nevsehir province (Turkiye), is a material used both in the construction of modern buildings and in the restoration of historical buildings. Ignimbrite stone is one of the stones preferred as facing stone in historical buildings due to its lightness, aesthetic appearance, economy, workability and shaping properties [10]. However, in historical buildings where these stones are used, damage occurs due to environmental and atmospheric factors such as humidity, salt crystallization and capillary water absorption [11]. Precautions are being taken by preparing restorations to repair these damages in historical buildings. In the literature, the decrease in strength of ignimbrite stone due to moisture [12], salt crystallization damages [13], deterioration processes due to wind erosion [14] and capillary water absorption properties [15] were examined. Additionally, the physico-mechanical properties of ignimbrite stone [12, 16-18], its effects in terms of geoengineering [19] and degradation processes due to lichen growth [20] were also examined. In all these studies conducted in the literature, the deteriorations occurring in ignimbrite stones and their physical, chemical and mineralogical properties were investigated. However, no study has been found in the literature regarding the effectiveness of using surface protective epoxy coatings to prevent damage to these stones due to salt crystallization.

Within the scope of this study, the effectiveness of using epoxy coatings on the surface of ignimbrite, a type of pyroclastic rock extracted from the Nevsehir region, in preventing damage caused by salt crystallization was discussed. Water absorption, apparent density, open porosity and salt crystallization with sodium chloride solutions of ignimbrite stones with and without epoxy coating were examined through experiments. With these experiments, the effects of epoxy coating on preventing salt crystallization damage of ignimbrite stones were determined.

2. MATERIALS AND METHODS

2.1. Materials

Ignimbrite is a stone with the structure and texture characteristics of the pyroclastic rocks class. Among the ignimbrites in and around Nevsehir region, the Kavak group represents the oldest pyroclastic deposits (Figure 1) [21]. Kavak ignimbrites consist of pumice, volcanic glass, plagioclase, quartz, biotite and opaque minerals (Figure 2) [12]. This stone is yellow and veined, and its chemical composition contains 78.44% SiO_2 and 13.90% Al_2O_3 element oxides (Table 1) [22].

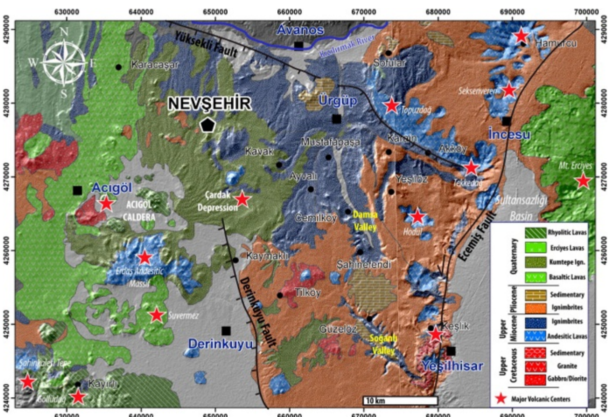

Figure 1. Geological map of Nevsehir region and distribution of pyroclastic deposits [21]

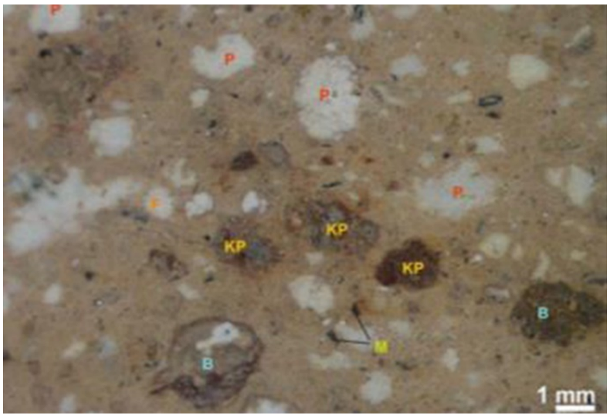

Figure 2. Microscopic image of ignimbrites (KP: rock fragments, P: pumice, M: mica, B: void) [11]

Table 1. Chemical composition of ignimbrites [22]

Oxide	Weight (%)
SiO_2	78.44
Al_2O_3	13.90
Fe_2O_3	0.78
MgO	0.02
CaO	0.05
Na_2O	0.03
K_2O	0.13
TiO_2	0.23
P_2O_5	0.04
LOI (Loss on ignition) (1000°C)	6.40
Total	100.05

The ignimbrite samples used in this study were obtained from Oz Kapadokya stone quarry company, which produces stone around Nevsehir. The resin used for the production of epoxy coatings was purchased from BRTR Kimya A.Ş. (Turkiye) company. Epoxy coatings are formed as a result of the chemical reaction and hardening of epoxy resin. The epoxy purchased from the company has two components, A and B. The A component of the epoxy contains bisphenol-A type resin, while the B component contains the cycloaliphatic polyamine chemical substance that enables the hardening of this resin. Some properties of the epoxy resin used in the experiments are shown in Table 2.

Çankırı (Turkiye) rock salt was used for sodium chloride solution in salt crystallization experiments. These experiments were carried out according to the standard of TS EN 12370 [23], and 14% solutions were prepared using 14 g of salt and 86 g of pure water in 100 g of solution. 50x50x50 mm sizes cubic shaped each of the 5 ignimbrite stone samples were cut to size in accordance with the standards for salt crystallization experiments.

2.2. Preparation of Epoxy Coated Samples

The hardening of epoxy resin is exothermic, meaning it produces heat as it hardens [24]. For this reason, it should not be subjected to any drying process. Because high or low temperatures may cause the epoxy not to harden at all. For this reason, it is generally recommended that the epoxy be at the optimum temperature condition (22°–25°C) for hardening [25]. However, humidity in the air can cause the epoxy to harden more slowly or unevenly, leading to a weaker bond [26]. For this reason, the coated stones were kept in a desiccator during the hardening period to protect them from the effect of humidity in the air. For the production of epoxy coatings, first components A and B of the epoxy resin were placed in a container in a ratio of 5:3. A 5:3 ratio means 5 parts of A resin, and 3 part of B hardener are mixed together. Then, this mixture was mixed for 3 min to make it homogeneous. When applying epoxy coatings on building blocks, they are applied with a brush. For this reason, the resulting mixture was applied to the stones in one layer with a brush. After the epoxy coating process was completed, all stones were kept in a desiccator at 25°C for 24 h without absorbing moisture from the air for the polymerization process. After this period, the samples were used in the measurement of experimental studies. The production process of epoxy coated samples is briefly summarized in Figure 3.

Table 2. Some properties of the epoxy resin used in the experiments

Features	Values
Color and Appearance:	Transparent and Glossy
Density (gr/cm^3):	1.10
Mixing Ratio (A/B):	5/3
Viscosity(cps, at 20°C):	520–550
Mixture Life (25°C):	30 min
Drying Time (25°C):	12 h

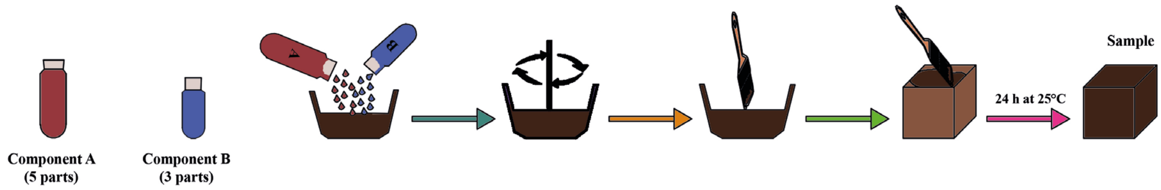

Figure 3. Production stages of epoxy coated samples

2.3. Method

2.3.1. Salt crystallization test

There are many standards for salt crystallization tests of stones carried out in laboratory environments. Standards such as TS EN 12370 [23], RILEM 1980 [27], DIN 5211 [28] and ASTM C-88 [29] are generally used for salt crystallization tests of stones. These standards are distinguished from each other by the different experimental conditions such as salt water solution, temperature, sample size, number of cycles and salt concentration [30]. In this study, the TS EN 12370 [23] standard was preferred in terms of the use of epoxy coated stones, temperature, salt concentration and duration. Additionally, in the literature, TS EN 12370 [23] standard was used in the salt crystallization test of stones uncoated and coated with polymer material [31-33]. Therefore, the salt crystallization test in the study was carried out according to the principles specified in the TS EN 12370 [23] standard. In salt crystallization experiments, samples were prepared by checking the density of the solution in each cycle. The weights of the samples were measured on a precision scale with an accuracy of 0.001 g before the experiment. While the samples were placed in the container, they were placed in such a way that they did not touch each other. In the salt crystallization experiment, the samples were first kept in the solution containers at 20°C for 2 h. After this period, the samples were taken from the containers and dried in an oven at 105°C for 16 h. Then, these samples were allowed to cooling at room temperature for 2 h. These processes were repeated 10 times to determine the resistance of the samples to salt. This test was carried out on 50x50x50 mm sized each of the 5 samples, both epoxy coated and untreated samples. The scheme of the salt crystallization experiment process and the images of the samples taken during the experiment are shown in Figure 4.

As a result of the experiment, the weight changes of the samples were calculated according to Equation (1).

$$\Delta M = (\frac{m_f - m_d}{m_d})x100 \quad (1)$$

in which ΔM is the change in weight of the samples before and after salt crystallization test (%), m_f is the weight of the dry test sample after the tenth treatment (g), m_d is the weight of the dry test sample (g)

2.3.2. Water absorption test

Water absorption tests were performed epoxy coated and untreated on each of the 5 samples. This test was applied to 50x50x50 mm sizes cubic samples in accordance with ASTM standard D570-98 [34]. First, the dry weights of the samples were noted on a precision scale with an accuracy of 0.001 g, and then they were placed in containers filled with pure water. The samples were kept in water at 20°C for 24 h. After this period, the samples taken out of the water were weighed on a precision scale with an accuracy of 0.001 g. Then, the change in water absorption rates of the samples was determined by noting the difference between the water absorbed weight and dry weight of the samples. The formula required to calculate the data obtained from the water absorption test of the samples is given in Equation (2).

$$\text{Water absorption } (\%) = (\frac{W_1 - W_2}{W_2})x100 \quad (2)$$

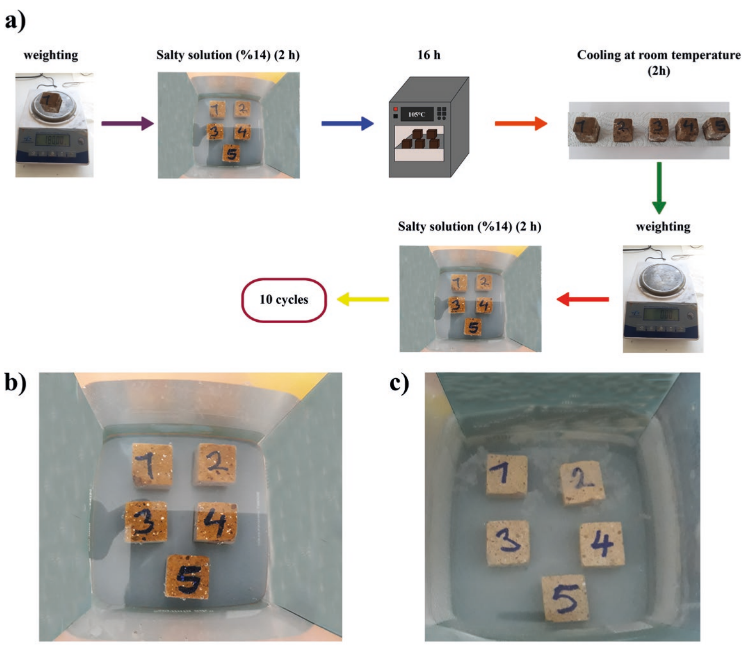

Figure 4. (a) Scheme of the salt crystallization experimental process; (b) image of epoxy coated samples in saline solution; (c) image of untreated samples in saline solution.

in which W_1 is the weight of the water-absorbed sample (g), W_2 is the weight of the dry test sample (g)

2.3.3. Apparent density

The determination of the apparent density values of the samples was carried out in accordance with the standard TS EN 1936 [35]. After the water absorption test, the epoxy coated and untreated samples were dried in a drying oven at 100°C until they reached a constant weight. Then, these samples were left in the desiccator for 2 h to cooling at room temperature. After this period, they were taken out of the desiccator and weighed on a precision scale with an accuracy of 0.001 g. Finally, the difference between the weight of the samples when saturated with water and in water was noted with a precision scale with an accuracy of 0.001 g. The formula required to calculate the apparent density values of the samples is given in Equation (3).

$$\rho_b = \left(\frac{m_d}{m_s - m_h}\right) x \rho_{rh} \quad (3)$$

in which ρ_b is the apparent density (kg/m^3), m_d is the weight of dry test sample (m^3), m_s is the weight of the water absorbed sample (m^3), m_h is the weight of the water-absorbed sample in water (m^3), p_{rh} is the density of water (997.6 kg/m^3)

2.3.4. Open porosity

Open porosity values of epoxy coated and untreated samples were determined according to the standard TS EN 1936 [35]. After the water absorption test of these samples, they were dried in a drying oven at 100°C until they reached a constant weight. Then, these samples were kept in the desiccator for 2 h to cooling at room temperature and their weights were measured on a precision scale with an accuracy of 0.001 g. Finally, the weight of these samples when saturated with water and in water was weighed and noted. The formula required to calculate the open porosity values of the samples is given in Equation (4).

$$\rho_o = \left(\frac{m_s - m_d}{m_s - m_h}\right) x100 \quad (4)$$

in which p_o is the open porosity (%), m_d is the weight of the dry test sample (m^3), m_s is the weight of the water absorbed sample (m^3), m_h is the weight of the water-absorbed sample in water (m^3)

3. RESULTS AND DISCUSSION

3.1. Results of Salt Crystallization Test

In the salt crystallization test, each sample was photographed for visual inspection. The images of the samples after the experiment at the end of each five cycles are given in Figure 5. The behavior of epoxy coated and untreated samples at the end of ten cycles in salt crystallization tests are similar to their behavior in the first cycle. A low level of color change was observed in the salt crystallization tests of untreated samples, while no color change was observed in the salt crystallization tests of samples subjected to epoxy coating. In untreated ignimbrite samples, the chipping at the corners started after the 5th cycle. There was material loss in these samples at the end of the 10th cycle (Figure 5a). No significant material loss was observed at the end of the 10th cycle in the samples subjected to epoxy coating. Epoxy coatings kept salt crystals out of the samples and ensured that no deterioration occurred on the surface of the samples (Figure 5b).

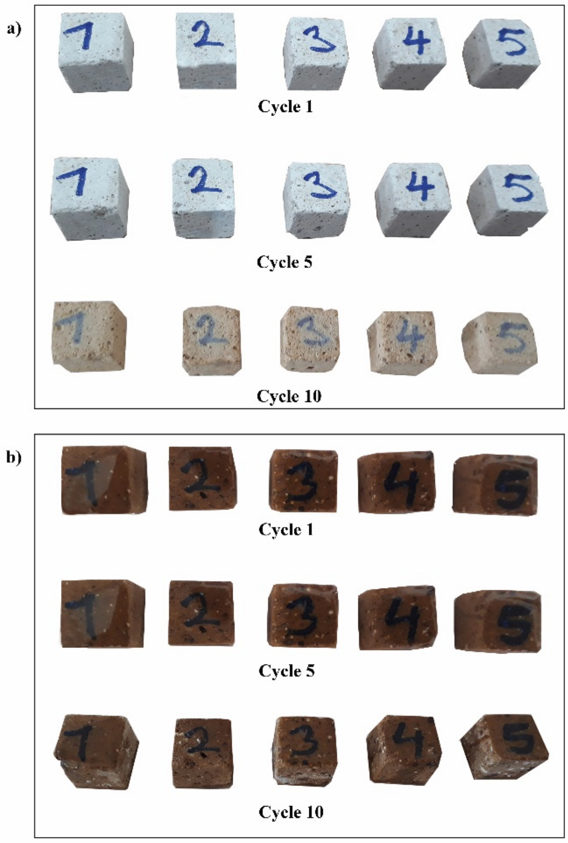

Figure 5. (a) Images of untreated ignimbrite samples at the end of each five cycles in the salt crystallization test; (b) images of epoxy coated ignimbrite samples at the end of each five cycles in the salt crystallization test

The change in dry weight loss due to salt crystallization of epoxy coated (treated) and untreated samples are given in Figure 6. According to the results given in Figure 6, the dry weight loss of untreated samples was 0.82%, while the samples subjected to epoxy coating showed an increase of 6.20%. Epoxy resin reduces the water absorption of the stones by filling the pores of the stones. Increasing the number of cycles applied to the samples increases the salt crystals in the pores, which causes the weight increase of the epoxy coated samples (Figure 7). However, in untreated samples, the salt solution entering the pores causes the internal pressure of the salt crystals to exceed the cohesion limit during evaporation, causing the stones to separate in the form of small crumbs. In this case, a weight decrease was observed in untreated samples. Similar results, in the research conducted by Çelik and Sert [36], were observed in the salt crystallization test of treated and untreated andesite samples. It was determined that in treated andesite samples, the internal pressure exerted by the salt crystals did not exceed the cohesion limit and an increase in weight occurred due to the accumulation of salt crystals on the surface, while in untreated andesite samples, there was a weight loss because the internal pressure exerted by the salt crystals exceeded the cohesion limit. In the study conducted by Vacchiano, Incarnato, Scarfato and Acierno [37], the resistance of untreated and polymer resin-treated tuffs to salt attack damage was investigated. Since the polymer resin in treated tuffs prevents water from entering the pores, they were determined to be more resistant to disintegration caused by salt crystals than untreated samples. In the study by Striani, Corcione, Muia and Frigione [38], it was determined that the treatment of a calcarenitic porous stone from the Apulia Region of Italy with polymer coatings significantly reduced the deterioration of the stone by reducing the ingress of soluble salt.

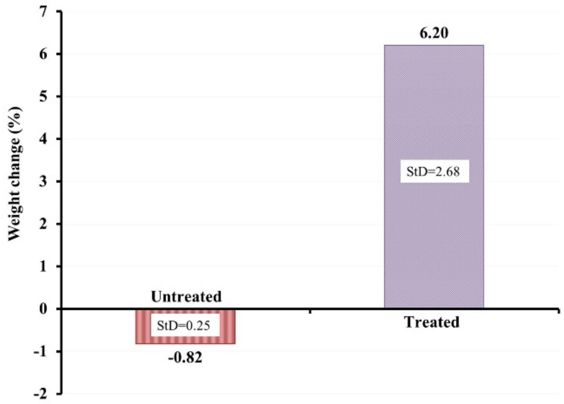

Figure 6. Dry weight change of untreated and epoxy coated (treated) ignimbrite samples at the end of the salt crystallization test (StD: standard deviation)

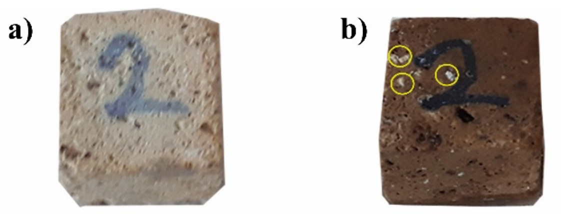

Figure 7. (a) Untreated ignimbrite sample; (b) epoxy coated ignimbrite sample (salt crystals are inside the yellow circles)

It can be seen in the literature that there are many studies on damages caused by salt crystallization in historical buildings [13, 18, 39, 40]. For example, in the research conducted by Topal and Doyuran [18], it was determined that the dry weight loss of Cappadocia ignimbrite stones due to salt crystallization was 1.62%. They concluded that materials resistant to salt action should be used to protect stones with weathered joint walls. Deniz and Topal [40], it was determined that the weight loss values due to salt crystallization of tuff (ignimbrite) stones taken from nine different quarries in the Cappadocia region were between 11.87–18.86%. They stated that it is important to know the resistance of tuffs to salt crystallization for the restoration of ancient monuments. Furthermore, studies in the literature have stated that the use of epoxy coatings on the surface of stones increases their resistance to salt action by reducing water absorption and porosity [41, 42]. Therefore, it is seen that the measured salt crystallization values of epoxy-coated ignimbrite stones are compatible with the results of relevant studies in the literature.

3.2. Results of Open Porosity Values

When the pressure exerted by the salt crystals accumulated on the surfaces of natural stones exceeds the cohesion limit, it causes dry weight losses, whereas if the pressure exerted by the salt crystals accumulated on the surfaces of the stones is below the cohesion limit, there is no dry weight loss. However, it can cause more damage depending on the number of cracks and pores that have previously formed in the stones [39]. The main reason for the weight loss due to salt crystallization in untreated samples is that they have a higher open porosity ratio than the epoxy coated samples. According to the results given in Figure 8, it was determined that the open porosity rate of untreated samples was 15.89%, and the open porosity rate of epoxy coated (treated) samples was 13.91%. Therefore, the fact that untreated samples have a higher open porosity than epoxy coated samples means that ignimbrite stones are not resistant to salt crystals (Figure 6). This result shows that epoxy resin reduces the presence of interconnected pores of the stone. The reason for this is that epoxy resin fills the pores of the stone and accumulates salt crystals on the surface (Figure 7).

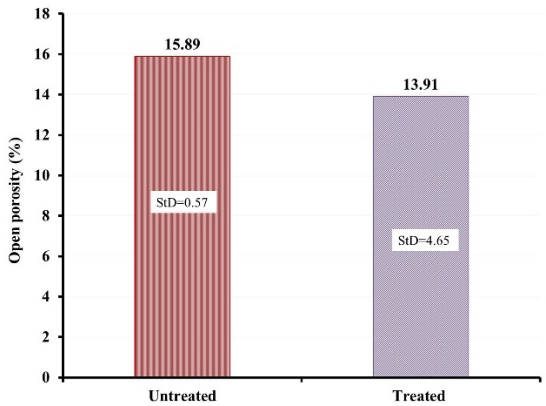

Figure 8. Change in open porosity (%) values of untreated and epoxy coated (treated) ignimbrite samples (StD: standard deviation)

When studies in the literature on the open pores of epoxy coatings for the protection of stone surfaces are examined, it is seen that the open pores of stones with high porosity are reduced by epoxy material providing a strong barrier [43-45]. For instance in the study conducted by Urosevic, Sebastián-Pardo and Cardell [45], it was determined that the open porosity rate of untreated travertines was 8.16%, while the epoxy coated travertine samples were 7.26%. Therefore, within the scope of this research, the observation of a decrease in the open porosity rate of epoxy coated samples compared to untreated samples is compatible with the results of relevant studies in the literature.

3.3. Results of Apparent Density Values

The apparent density values results of untreated and epoxy coated (treated) ignimbrite samples are given in Figure 9. According to the results given in Figure 9, it was determined that the apparent density value of untreated ignimbrite samples was 1848.39 kg/m^3 and the apparent density value of epoxy coated ignimbrite samples was 1941.79 kg/m^3. This result is due to the fact that the open porosity rates of the stones differ from each other in changing density. The decrease in the open porosity of the epoxy coated samples compared to the untreated samples caused a 5% increase in their apparent density. Additionally, as stated in previous studies in the literature, it has been stated that the use of polymer coatings on the stone surface reduces porosity, prevents salt crystals from accumulating on the surface, and this increases the density values [8, 46]. For this reason, it is seen that the density values obtained for epoxy coatings are compatible with the studies in the relevant literature.

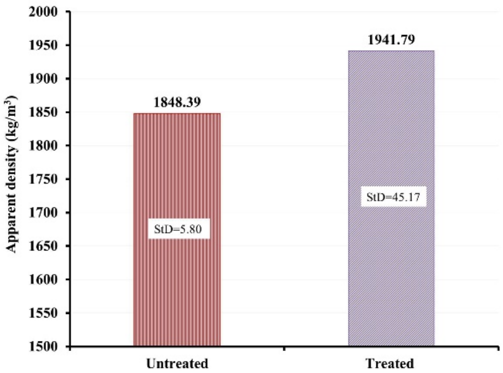

Figure 9. Change in apparent density (kg/m^3) values of untreated and epoxy coated (treated) ignimbrite samples (StD: standard deviation)

3.4. Results of Water Absorption Test

The transport, crystallization and hydration of salts by the absorption of water formed by rain or moisture in the pores of the stones are the main reasons for the deterioration of historical buildings [38, 47]. Depending on the weather conditions, in environmental conditions where the temperature is below 0°C, water absorbed in the pores of the stones causes the volume of ice crystals to increase and reduces the strength of the stone [48]. For this reason, one of the important parameters investigating the resistance of stones against salt crystals is the determination of the water absorption amount of stones treated with polymer coating [37, 38]. Water absorption values of untreated and epoxy coated (treated) ignimbrite samples are given in Figure 10. According to the results given in Figure 10, it was determined that the water absorption value of untreated ignimbrite samples was 24.69% and the water absorption value of epoxy coated ignimbrite samples was 19.51%. This result, consistent with the results of open porosity values, shows that the water absorption of epoxy coated stones is reduced compared to untreated stones. The decrease in the absorption of water in stones can be attributed to the fact that the epoxy coating creates a protective thin layer that prevents water entry into the pores of the stones.

It can be seen in the literature that there are many studies investigating the use of polymer coatings to protect stones in historical buildings from water damage [49, 50]. For example, in the study conducted by La Russa, Ruffolo, de Buergo, Ricca, Belfiore, Pezzino and Crisci [49], it was determined that Neapolitan yellow tuff (Italy) was treated with polymer coating and water absorption was reduced compared to untreated tuffs because these samples created a smooth surface. They stated that as the amount of water absorbed from the polymer coating surface decreased, the amount of salt precipitated near the surface decreased. In the research conducted by Salazar-Hernández, Cervantes, Puy-Alquiza and Miranda [50], investigated the protective properties of TEOS/colloidal silica/PDMS-OH polymer coatings used in the restoration of various historical buildings in the city of Guanajuato, Mexico. They stated that these polymer coatings slow down the decay process by preventing water from entering the stones. For this reason, as stated in previous studies in the literature [37, 38, 49, 50], the use of epoxy coatings can be recommended to protect historical buildings built with ignimbrite stones against deterioration caused by moisture.

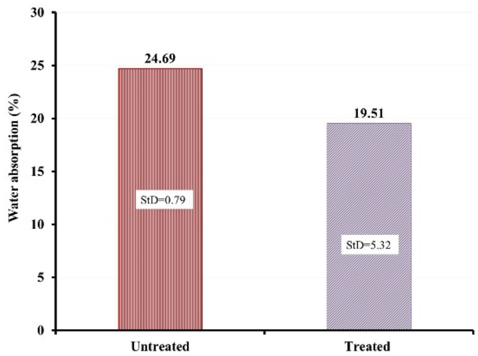

Figure 10. Change in water absorption (%) values of untreated and epoxy coated ignimbrite samples (StD: standard deviation)

4. CONCLUSIONS

This article focuses on examining the resistance to salt crystallization destruction of the use of epoxy coatings on ignimbrite stones for the restoration of historical structures. Within the scope of the research, the following results were obtained based on the data obtained from the experiments:

- According to the salt crystallization test results, determined that the dry weight loss of untreated ignimbrites was 0.82%, while the dry weight of epoxy coated ignimbrites increased by 6.20%.
- It was determined that the open porosity rate of untreated samples was 15.89%, and the open porosity rate of epoxy coated samples was 13.91%.

Epoxy resin filled the pores of the stone and reduced the open porosity of the stones.

- The decrease in open porosity of epoxy coated samples increased their apparent density by 5% compared to untreated samples.
- According to the water absorption test results, epoxy coated ignimbrites showed a lower water uptake percentage than untreated ignimbrites. Epoxy coating creates a protective thin layer in the pores of the stones that prevents water entry, making them more resistant to water than untreated ignimbrites.

As a result, epoxy coatings show that ignimbrites can be potentially used for the restoration of historical buildings, due to their surface resistance to salt crystallization and water.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Ahmet Cihat ARI: Performed the experiments and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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