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ORIGINAL PAPER

Investigation of the change in physical, mechanical, and microstructural properties of Ahlat ignimbrites under the effect of environment and freeze-thawing

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Abstract

This study aimed to investigate the changes in physical, mechanical, and microstructural properties of Ahlat ignimbrites, which have been widely used in the exterior of buildings in modern architecture from the past to the present, particularly in the Van Lake basin of our country, at room conditions and after freeze–thaw cycles. For this purpose, four different colored Ahlat ignimbrites obtained from the quarries in the region were analyzed for the following properties: changes in unit volume weight, apparent porosity, water absorption rates by weight, ultrasound pulse velocities, uniaxial compressive strengths, and flexural strength, as a result of 10, 30, and 50 freeze–thaw (F-T) cycles compared to room conditions. In addition, the changes in each stone's microstructure properties were examined using SEM analyses performed individually at ambient conditions and after 50 F-T cycles. According to the findings, it was established that as the number of freeze–thaw cycles of these stones increased, their internal structure properties deteriorated significantly, resulting in considerable losses in their physical and mechanical properties.

Keywords Ahlat ignimbrites · Strength · Freeze-thawing effect · Microstructure

Introduction

The utilization of natural stones, which provide aesthetics, durability, and a modern style to buildings, has become increasingly popular in response to rising interest and demand from the past to the present. Natural stones have been used in a wide range of artistic, religious, and residential-style buildings as a decorative outer coating material or as a load-bearing wall element (Çelik and Sert 2021; Kiani et al. 2022; Eslami et al. 2018). Ahlat, a district of Bitlis province and located in the Van Lake basin, is also famous for its Ahlat stone, which plays a significant role in the architecture of the region. Ahlat stone, which has a substantial quantity of reserves in the Ahlat district of Bitlis province, is the pyroclastic rock generated by the volcanic lavas during the eruption of the Nemrut crater in the past, spreading and cooling in the vicinity. Pyroclastic flowing rocks generally contain abundant pumice, volcanic glass, and lithic particles. Ignimbrites, the pyroclastic rocks, are pyroclastic flow units flowing at high temperatures in the laminar flow system and gravity control. Ignimbrites with a high flow rate are less thick when they spread across a vast area. As it advances away from the source location, the thickness of the ignimbrite reduces to 100–10 cm. The ability of ignimbrites generated at high temperatures to undergo plastic deformation and glass fusion is one of their most significant properties (Öner et al. 2006; Altındağ et al. 2004). In the quarries of the Ahlat region, there are ignimbrite levels separated by different colors. Ignimbrites are rocks that originate as a result of the eruption and have unique physical properties. These variances arise from the formation conditions of the pyroclastic rock flows as well as changes in compression-cooling structures and textures. The colors of Ahlat stone include red, black, ash, gray, pale yellow, and white. In the region where many civilizations have ruled throughout history, ignimbrites have been used widely in constructions such as houses, churches, mosques, cupolas, tombstones, fountains, and minarets from past to present (Schaffer 2015; Calcaterra et al. 2004). Examples of the use of Ahlat stone

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and surface deterioration are given in Fig. 1. Several users prefer this stone because of its abundancy in reserves in the region, its easy and inexpensive availability from various quarries, the fact that it does not impose an additional load on the constructions due to its light weight, the fact that it saves energy in buildings by its low heat transmission coefficients (Özvan et al. 2015). However, Ahlat stone, like other natural stones, contains natural defects such as joints, pores, and cracks. As is well known, the quantity and magnitude of these defects, which are present in natural stones, have an impact on the rock's durability (Yang et al. 2021; Alonso and Martinez 2003; Mousavi et al. 2020). The rocks are subjected to repeated freeze–thaw cycles, particularly in locations the winter months are harsh and long. During freeze–thaw cycles, when the temperature drops below zero, the water in the rock pores freezes, increasing the volume of water by 9%. The pressure and microcracks in the pores rise by this repeated event, causing the creation of new cracks in the rock and other damages to the rock (Fener and İnce 2015; Guilbert et al. 2019; Gao et al. 2020; Ruedrich et al. 2011; Bayram 2012; Martínez-Martínez et al. 2013; Seyed et al. 2019). As a result of these cycles recurring for many years, damages become visible in the physical and mechanical properties of natural stones. Due to freezing–thawing cycles of natural stones used for decorative purposes on the exterior of buildings, and deterioration in their internal structures and surface properties, there is a significant decrease in physical, mechanical, and durability properties, particularly in regions the winter months are long and harsh. The physical life of the structure is shortened in consequence of freeze–thaw damage, posing a threat to building safety (Huang et al. 2021, 2020). Therefore, it is critical to decide after analyzing the location and purpose of use in buildings, as well as the amount to which the physical and mechanical performances of natural stones deteriorate with the effects such as freeze–thaw (F-T). In the literature, there are many studies examining the physical and mechanical properties of volcanic rocks at room conditions (Teymen 2018; Aligholi et al. 2019; Yüksek 2019) and the changes in physical, mechanical, and microstructural properties after F-T cycles (Özbek 2014; Koralay and Çelik 2019; Binal and Kasapoglu 2002; Akın et al. 2017; Jamshidi et al. 2013; Erol and Bayram 2020; Zhou et al. 2020; Liu et al. 2018, 2020; Abdolghanizadeh et al. 2020; Khanlari and Sahamieh 2015; Tuğrul 2004). Özbek (Özbek 2014) investigated the mass loss and compressive strength of black, yellow, gray, and red ignimbrite samples after F-T cycles. As a result of the study, it was stated that the mass losses of the black, yellow, gray, and red samples after 50 F-T cycles were 13.61%, 8.75%, 11.59%, and 12.23%, respectively. In addition, it was determined that the compressive strength of black, yellow, gray, and red ignimbrite samples decreased by 41.71%, 35.80%, 37.3%, and 36.73%, respectively, after 50 F-T cycles. Binal and Kasapoğlu (Binal and Kasapoglu 2002) stated that there was a 68.5% decrease in compressive strength of Selime ignimbrite samples after 30 F-T cycles. Akin et al. (Akın et al. 2017) determined the reduction in mass loss and compressive strength of dark gray, light pink cream, dark brown, and brown ignimbrite samples after 40 F-T cycles in their study. According to the results they obtained, they stated that the compressive strength of dark gray, dark brown, and brown ignimbrite samples decreased more than 15%, respectively. Besides, the decrease in compressive strength in light pink cream ignimbrite samples is 43%. Jamshidi et al. (Jamshidi et al. 2013) stated in their study that there was a 19% decrease in the compressive strength of the ignimbrite sample after 30 F-T cycles. Liu et al. (Liu et al. 2018) stated in their study that F-T cycles had a negative effect on the microstructure properties of the rock. They stated that as a result of the transformation of the water entering the rock into ice during the F-T cycles, there is a volume change in

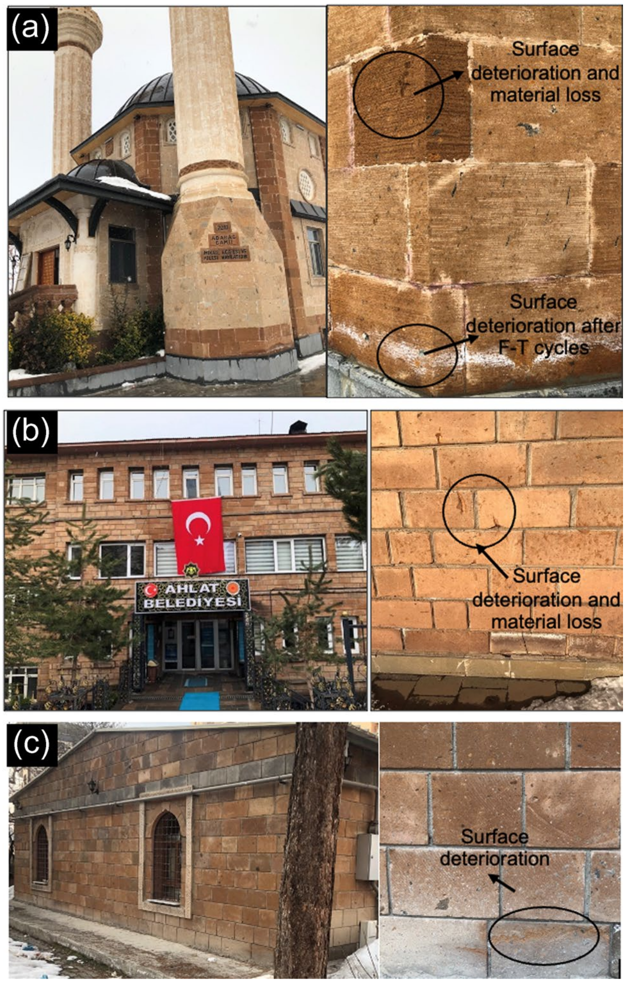


Fig. 1 Examples of the use of Ahlat stone and surface deterioration: **a** Adabağ Mosque (built in 2010), **b** town hall (built in 1985), **c** public building (built in 2011)

the rock, resulting in expansion and macroscopic cracking in the microstructure. In addition, Liu et al. (Liu et al. 2020), in another study investigating the effects of F-T cycles on the deterioration process of natural stones, stated that the pore size distribution and pore geometry were highly effective in the deterioration process. (Abdolghanizadeh et al. 2020; Khanlari and Sahamieh 2015; Tuğrul 2004).

Research significance

With its abundant reserves, Ahlat ignimbrite is considerably frequent and favorite, especially in the provinces, districts, and villages in the surroundings of the Van Lake Basin. With natural stone mining, Ahlat ignimbrites are extracted from the quaries on the foothills of Mount Nemrut, processed and used in buildings, thus adding value to the regional economy. It is well known that Ahlat stone has a poor heat transmission coefficient due to its porous nature, resulting in significant energy savings in homes. Nevertheless, due to its porous structure, one of the most notable disadvantages of this stone is its low endurance to water and sulfate impacts. It is a predictable result that the recurrence of snow and rain waters in the region for prolonged periods may cause damage to the internal structure of the material through enhancing ion exchange. From this point of view, in this study, the changes in the physical, mechanical, and microstructural properties of four distinct Ahlat stones sourced from the quarries in the region were studied and compared at room conditions and with the cycles of 10, 30, and 50 freeze–thaw (F-T).

Preparation and testing of samples

Four different colors of Ahlat ignimbrite, beige (BE), black (BL), brown (BR), and red (RE), were used in this study. The pictures of Ahlat ignimbrites are given in Fig. 2. Unit volume weight, apparent porosity, water absorption rate by weight, ultrasound transmission velocity, uniaxial compressive strength (UCS), and flexural strength tests were performed to determine the physical, mechanical, and microstructural properties of Ahlat ignimbrites after 50 F-T cycle compared to room conditions. TS EN 1936 (1936) and TS EN 13755 (2014) standards were used to specify the properties of Ahlat ignimbrite such as unit volume weight, water absorption, and apparent porosity. The ultrasound transmission velocity (Vp) measurements of the Ahlat stones were performed in accordance with the TS EN 14579 (2015) standard, using a Proceq Pundit Lab brand ultrasound test device (P wave). Vp measurements were performed on dry samples utilizing transducers with a frequency of 54 kHz. The UCS tests were carried out in a pressure test with a capacity of 3000 kN and a loading speed of 1 MPa/s (TS EN 1926 2007). The flexural strength tests were conducted using a 1500 kN capacity flexural test device. While 100 × 50 × 400 mm prism samples were utilized in the flexural strength tests, cube samples with 100 × 100 × 100 mm dimensions were used in all other tests. For each of these measurements, five samples were tested and their average values were taken. The F-T cycles were performed in a freeze–thaw test cabinet capable of performing a freeze–thaw program with an automatic control system. Before the F-T cycle, the samples were saturated with water by keeping them in water at + 20 °C for 48 h. Each cycle consists of 12 h of freezing at – 20 °C and 12 h of thawing at + 20 °C (TS EN 12371 2011). Freeze–thaw diagram is shown in Fig. 3. The physical and mechanical properties of all stones were also measured before and after the F-T cycles. In addition, SEM analysis was performed to determine the changes in the microstructure of the samples at room condition and 50 F-T cycles.

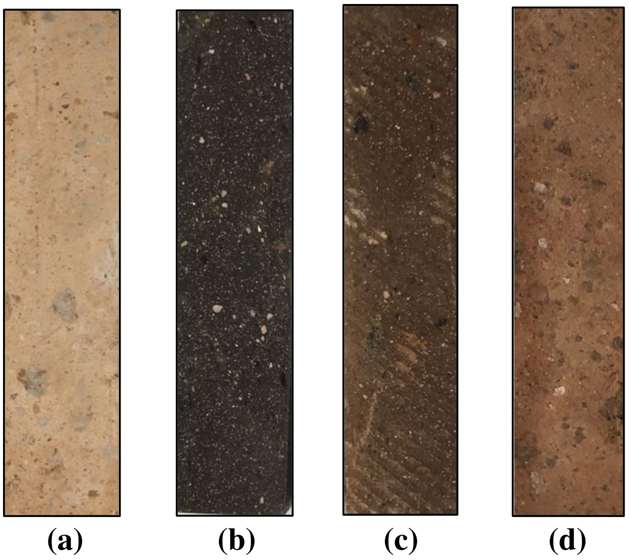


Fig. 2 Ahlat stones in this work. **a** BE, **b** BL, **c** BR, **d** RE

Experimental results

Chemical and mineralogical analyses

X-Ray fluorescence (XRF) and X-Ray diffraction (XRD) analyses were performed to identify the chemical composition and mineralogical constituents of Ahlat ignimbrites. Rigaku XRD machine was used to detect present phases in all Ahlat ignimbrite samples. The chemical composition of the samples was determined using a Panalytical brand XRF device. Analyses were carried out on samples that were kept in room condition. The chemical analysis results of Ahlat

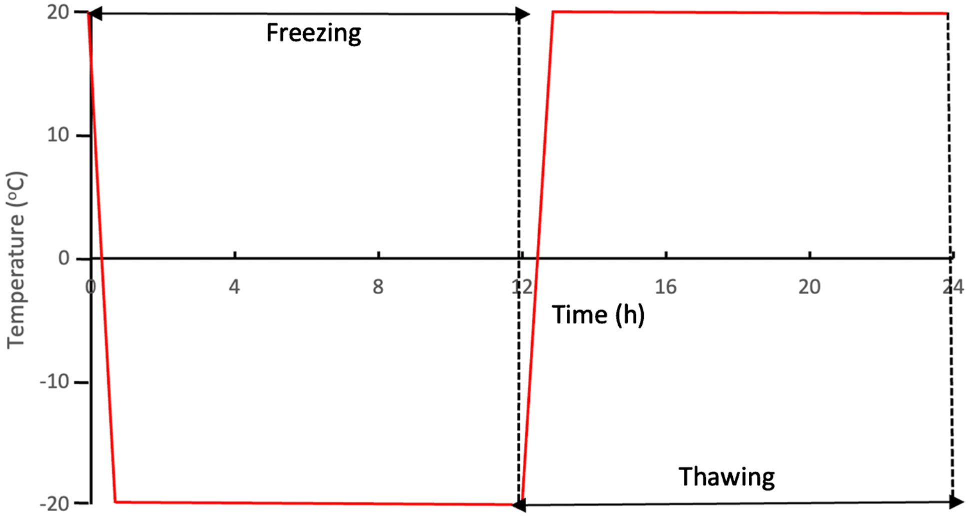


Fig. 3 Temperature variation in freeze–thaw cycle

Table 1 Chemical composition of Ahlat ignimbrites

	BE	BL	BR	RE
SiO_2	66.02	63.02	63.00	61.06
Al_2O_3	14.04	17.01	17.03	19.01
Fe_2O_3	6.27	6.58	6.44	6.89
MgO	0.39	0.25	0.72	0.32
CaO	0.55	1.38	1.58	1.51
Na_2O	4.51	5.48	5.13	4.81
K_2O	5.58	5.40	5.25	6.00
P_2O_5	0.03	0.06	0.07	0.02
TiO_2	0.48	0.59	0.56	0.69
MnO	0.22	0.23	0.21	0.19

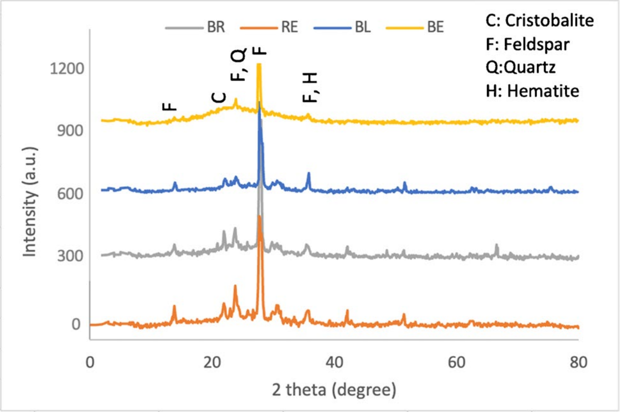


Fig. 4 XRD patterns of Ahlat stones samples

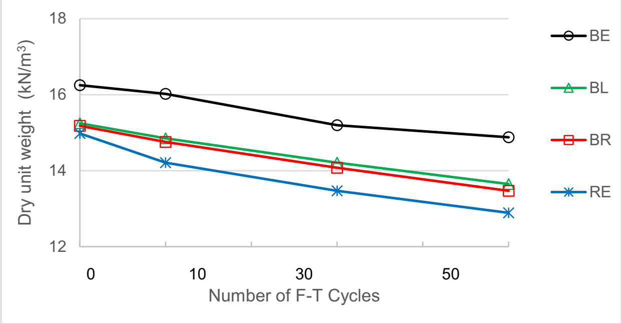


Fig. 5 Values for dry unit weight of Ahlat stones after F-T cycles

ignimbrites are given in Table 1. When the chemical compositions of Ahlat ignimbrites are analyzed, while the SiO_2 content varied between 61.06 and 66.02% in general, the content of Al_2O_3 varied between 14.04 and 19.01% as well as Fe_2O_3 6.39 and 7.78%, K_2O 5.25 and 6.00%, Na_2O 4.51 and 5.48%, CaO 0.55 and 1.58%, MgO 0.25 and 0.72%, TiO_2 0.48 and 0.69%, P_2O_5 0.02 and 0.07%, and MnO 0.19 and 0.23%, respectively. XRD patterns of Ahlat stones samples are given in Fig. 4. Yet, it was concluded that all of the Ahlat stones had crystalline properties when the XRD results were examined. As a result of XRD analysis, the following results were attained: the primary minerals in BE ignimbrite contained feldspar and quartz. BL, BR, and RE ignimbrites contained cristobalite, quartz, feldspar, and hematite.

Dry unit weight, water absorption, and apparent porosity

The dry unit weights of ignimbrite samples at room conditions ranged from 14.98 to 16.25 kN/m^3, which was comparably consistent with previous report findings for similar rocks. As shown in Fig. 5, while the number of freeze–thaw cycles increased, the dry unit weights of the Ahlat stone samples decreased. The KBA value of ignimbrite samples after 50 F-T cycles decreased by 8.43 to 13.95%. After 50 F-T cycles, the BE sample had the lowest change in KBA value with 8.43%, whereas the RE sample had the highest

Table 2 Values of dry unit weight, water absorption, apparent porosity of Ahlat ignimbrites

Code	Number of freeze–thaw cycles	Dry unit weight (kN/m^3)		Water absorption (%)		Apparent porosity (%)	
		Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
BE	0	16.25	0.07	15.85	0.99	20.72	1.79
	10	16.02	0.08	16.01	1.08	21.28	1.20
	30	15.20	0.18	16.43	1.42	23.04	3.09
	50	14.88	0.39	16.96	2.77	25.22	2.59
BL	0	15.25	0.24	18.82	4.27	26.87	1.39
	10	14.85	0.45	19.21	4.29	27.65	1.59
	30	14.21	0.52	19.92	4.74	30.28	4.62
	50	13.65	0.35	20.28	7.03	33.77	3.73
BR	0	15.18	0.10	22.88	1.97	29.27	3.33
	10	14.76	0.28	23.64	4.02	30.16	4.67
	30	14.08	0.16	24.53	4.08	33.18	2.34
	50	13.47	0.35	24.98	3.05	37.25	4.91
RE	0	14.98	0.21	24.57	3.80	32.01	5.90
	10	14.21	0.28	25.67	2.76	33.64	4.40
	30	13.47	0.25	26.93	5.80	38.41	5.15
	50	12.89	0.55	27.42	5.99	41.83	5.83

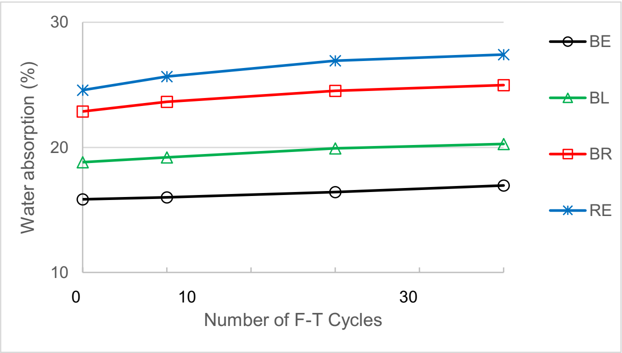


Fig. 6 Values for water absorption of Ahlat stones after F-T cycles

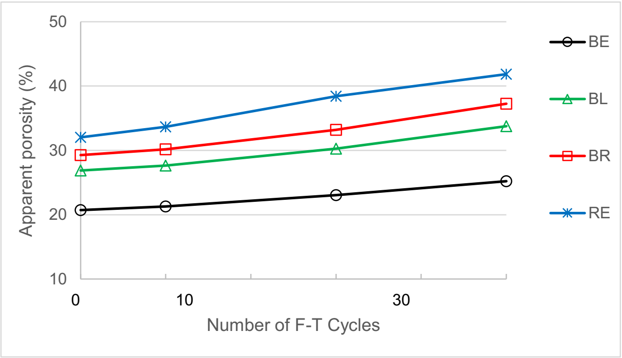


Fig. 7 Values for apparent porosity of Ahlat Stones after F-T cycles

change with 13.95%. When natural stones are exposed to the freeze–thaw cycles, the water infiltrating their bodies freezes and applies pressure on the stone wall, creating cracks and pore size expansion. Especially rocks with high porosity such as ignimbrite are highly affected by this process. As presented in Table 2 and Fig. 6, the water absorption values of BE, BL, BR, and RE ignimbrites measured at room conditions were 15.85%, 18.82%, 22.88%, and 24.57%, respectively. At the end of 10 F-T cycles, there was little change in the water absorption values of all samples. After 50 F-T cycles, however, the water absorption values of BE, BL, BR, and RE ignimbrites were measured as 16.96%, 20.28%, 24.98%, and 27.42%, respectively. The apparent porosity values of ignimbrites are shown in Table 2 and Fig. 7. Accordingly, after 50 F-T cycles, the apparent porosity values measured in BE, BL, BR, and RE samples were 25.22%, 33.77%, 37.25%, and 41.83%, respectively. Yet, after 50 F-T cycles among the Ahlat stones, while the minimum water absorption rate and apparent porosity value were determined in the BE sample, the maximum water absorption rate and apparent porosity value were measured in the RE sample. The expansion of the pores in the rock and the increase in the number of microcracks may explain the increase in water absorption and porosity after F-T tests [24, 9, 11, 41 and 45].

Ultrasonic measurement

Several parameters influence the sound wave propagation speed of natural stones, including rock texture, grain size, porosity, density, water content, and anisotropy. The increase in porosity and microcracks in a natural stone causes the sound wave velocity to be transmitted more slowly. In ignimbrites, ultrasonic measurements were made before and after the cycle to define the P wave velocity variation caused by the F-T cycle. As shown in Table 3 and Fig. 8, it was determined that the values for the ultrasound transmission rate of Ahlat stones decrease with the increase of F-T cycles. The Vp values of BE, BL, BR, and RE stones measured at room conditions were 2470, 2280, 2100, and 1940 m/sn respectively. The RE stone had higher porosity compared to the BE stone. Therefore, depending on the porosity, the P wave velocity of the RE stone had the lowest value compared to other stones. Correspondingly, the Vp values of Ahlat stones were found to decline as the F-T cycle increased. At the end of 50 F-T cycles, the Vp values measured were 2250, 2000, 1880, and 1630 m/sn respectively. According to the findings mentioned above, an increase in the number of F-T cycles had a significant impact on the Vp velocities of ignimbrite rocks, which had a porous structure. When the research results in the literature were examined, it was discovered that as the number of Freeze–thaw cycles increased, the porosity of the rocks also increased; however, the P wave velocities decreased (Bayram 2012; Martínez-Martínez et al. 2013). The decrease in Vp wave velocity might be explained by the fact that freeze–thaw cycling induces the growth of existing cracks in the stone by increasing the occurrence of microcracks.

Table 3 Values of P wave velocity of Ahlat ignimbrites after F-T cycles

Code	Number of freeze–thaw cycles	P wave velocity (m/sn)	
		Mean	Std. Dev
BE	0	2470	283
	10	2418	229
	30	2350	191
	50	2250	238
BL	0	2280	269
	10	2155	247
	30	2085	148
	50	2000	168
BR	0	2100	127
	10	2010	93
	30	1950	78
	50	1880	184
RE	0	1940	158
	10	1820	146
	30	1710	117
	50	1630	140

Mass loss

As demonstrated in Table 4 and Fig. 9, the mass loss values of Ahlat stones increase in parallel to the increase of F-T cycles. In 10 F-T cycles, it was measured that the RE sample had the highest mass loss of 4.15%, and the BE sample had the lowest mass loss of 1.32% when compared to room conditions. Similarly, after 50 F-T cycles, it was observed that while the maximum mass loss was recorded in the RE sample with 8.76%, the minimum mass loss was observed in the BE sample with 4.21%, when compared to room conditions. Koralay and Çelik (Koralay and Çelik 2019) stated in their study that the mass loss in ignimbrites after 25 freeze–thaw cycles ranged from 0.65 to 1.32%. Furthermore, Binal (Binal 2009) indicated in his study that Ankara ignimbrite had a mass loss of 0.44% after 40 F-T cycles.

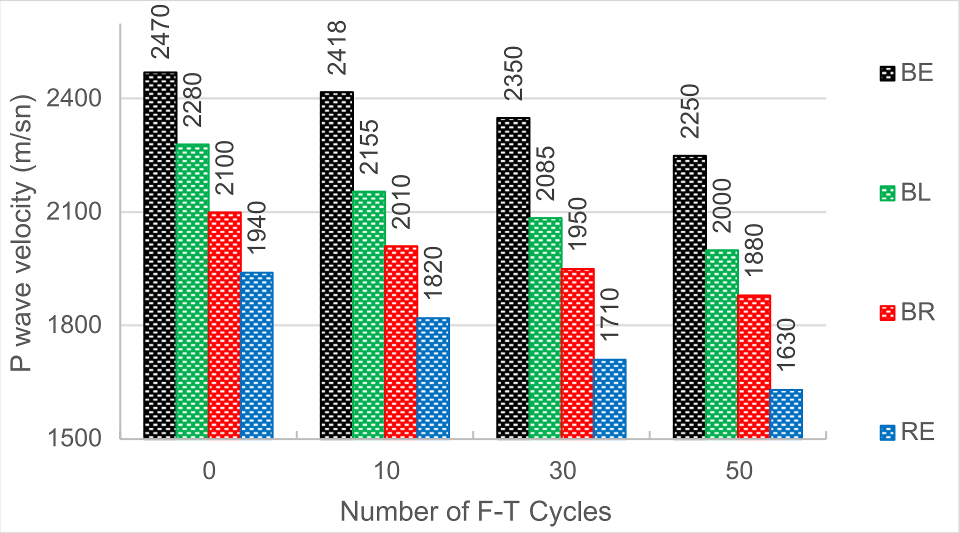


Fig. 8 Values for P wave velocity of Ahlat stones after F-T cycles

Table 4 Values of mass loss of Ahlat ignimbrites after F-T cycles

	Number of freeze–thaw cycles	Mass loss change (%)
BE	10	1.32
	30	2.15
	50	4.21
BL	10	2.63
	30	4.55
	50	5.15
BR	10	3.82
	30	4.85
	50	6.82
RE	10	4.15
	30	6.85
	50	8.76

Uniaxial compressive strength and flexural strength

Compressive strength and flexural strength are the most critical parameters in determining the mechanical properties of rocks. As demonstrated in Table 5 and Fig. 10, when 50 F-T cycles are compared to room conditions, the maximum compressive strength loss was recorded in the RE sample with 41.43%, while the minimum compressive strength loss was obtained in the BE sample with 22.82%. As a result, as the number of F-T cycles increases, the compressive strength of ignimbrites diminished. The fundamental cause for this can be explained by the formation of new capillary cracks in the internal structures of the rocks by freezing the water in the cavities of the rocks as a result of the F-T cycles; as a result, it leads to acceleration of the deteriorations and deformations. Furthermore, it is under consideration that the porosity value of the ignimbrite samples increased in accordance with the elevating number of F-T cycles, resulting in a decrease in their strength. As demonstrated in Table 5 and Fig. 11, after 50 F-T cycles compared to room conditions, the maximum loss of flexural strength was recorded in the RE sample with 38.18%, while the minimum loss was achieved in the BE sample with 24.41%. These results were also supported by other researchers in the literature (Binal 2009; Pola et al. 2016; Şimşek and Erdal 2004; Koralay et al. 2014). In a study performed on the mechanical properties of ignimbrites following freeze–thaw cycles, it was discovered that there was a loss of 44.87% in compressive strength and 56.80% in flexural strength at the end of 55 F-T cycles. The same researchers indicated that the strength losses were caused by an increase in the porosity of ignimbrites (Liu et al. 2018). In another literature, the compressive strength losses of ignimbrites sourced from different ignimbrite levels were investigated after F-T cycles. Accordingly, they discovered after F-T cycle that the freeze–thaw losses for the bottom-, middle-, and top-level ignimbrites decreased by 32.80%, 20.97%, and 3.59%, respectively. Researchers stated that the decreases could be attributed to variable degrees of welding, porosity, and textural features of the rocks being adversely affected by F-T cycles (Niu et al. 2021).

Scanning electron microscope (SEM) analysis

Many researchers have stated that significant damage occurs in the microstructures of different rock types that have been exposed to F-T cycles (Koralay et al. 2014; Niu et al. 2021; Hou et al. 2021; Wang et al. 2019). The most important reason for this is that the water entering the existing cracks of the rock after repeated F-T cycles causes hydrostatic pressure in the rock cavities. The pressure in the rock causes the existing cracks to expand and increase the pores. In addition, it has been stated that F-T cycles have a destructive effect on

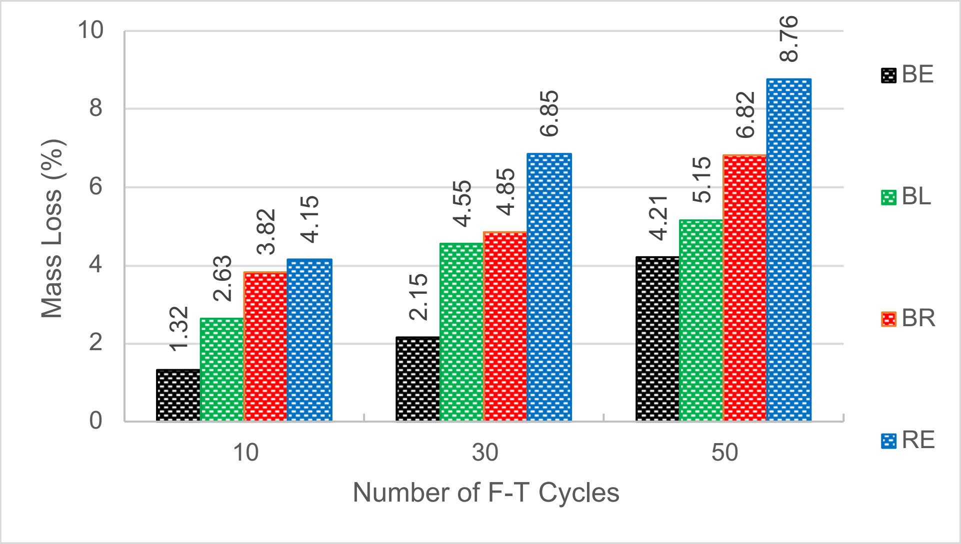


Fig. 9 Values for mass loss of Ahlat stones after F-T cycles

Table 5 Values for uniaxial compressive strength and flexural strength of Ahlat ignimbrites after F-T cycles

Code	Number of freeze–thaw cycles	Uniaxial compressive strength (MPa)		Flexural strength (MPa)	
		Mean	Std. Dev	Mean	Std. Dev
BE	0	27,52	1.78	2,13	1.53
	10	26,94	2.83	2,06	2.42
	30	23,47	2.46	1,91	2.31
	50	21,24	3.32	1,61	3.14
BL	0	24.26	2.91	2.08	2.87
	10	23.62	3.13	1.98	3.08
	30	19.24	5.25	1.75	4.16
	50	15.54	3.17	1.44	4.77
BR	0	22.45	2.86	1.93	2.42
	10	21.62	3.68	1.83	2.61
	30	17.03	5.08	1.57	4.14
	50	14.03	3.82	1.26	2.42
RE	0	18.10	4.13	1.65	2.77
	10	17.05	3.49	1.52	3.44
	30	13.12	5.84	1.24	4.12
	50	10.60	4.29	1.02	5.17

the bond strength between rock particles, and the increasing number of F-T cycles causes an increase in cracks and porosity in the rock. In addition to this, various mechanisms such as capillary and crystallization pressure take place in addition to hydrostatic pressure during F-T cycles, and these mechanisms cause significant damage to the rock interior (Hou et al. 2021; Wang et al. 2019). In this study, the microstructures of BE, BL, BR, and RE were investigated with the help of SEM analysis at room conditions and after 10, 30, and 50 F-T cycles. SEM images of BE, BL, BR, and RE ignimbrites are given in Fig. 12a–p at ambient and after F-T cycles. As shown in Fig. 12, the BE ignimbrite (Fig. 12a) demonstrated a more compact and homogeneous microstructure than the RE ignimbrite (Fig. 12d) at room conditions. When the number of F-T cycles increased, microsture deterioration such as pores was much higher in the RE ignimbrite (Fig. 12p) than in the BE ignimbrite (Fig. 12d). These defects were more frequent in the samples subjected to 30 F-T and 50 F-T cycles than in the samples subjected to 10 F-T cycles. It was also observed that the ignimbrites subjected to 50 F-T cycles had deteriorations in their mineral integrity compared to the others, and the porosity increased, generating cracks in the micro structure. Furthermore, it was observed that the RE sample had more pore structure compared to the others. For this reason, it is thought that the RE sample is more affected by the F-T cycles. In addition, it was determined that the microstructure of the BE sample was more homogeneous and coarse crystalline, while the RE sample had a finer grained structure. In addition, it is seen that the void structure of the BE sample is less compared to the others. As the number of F-T cycles increases in the RE sample, it is seen that the damage caused by the volumetric expansion and hydrostatic pressure increase occurs at a higher rate compared to the other samples. In parallel with this, it was determined that more voids were formed in the RE sample internal structure as a result of 50 F-T cycles compared to the other samples, and as a result, the porosity ratio increased more.

Conclusions

Since ancient times, easily processable rocks such as ignimbrite have been utilized in various places. Even today, it has been widely used as an exterior stone in buildings due to its characteristics such as uncomplicated manufacturing and

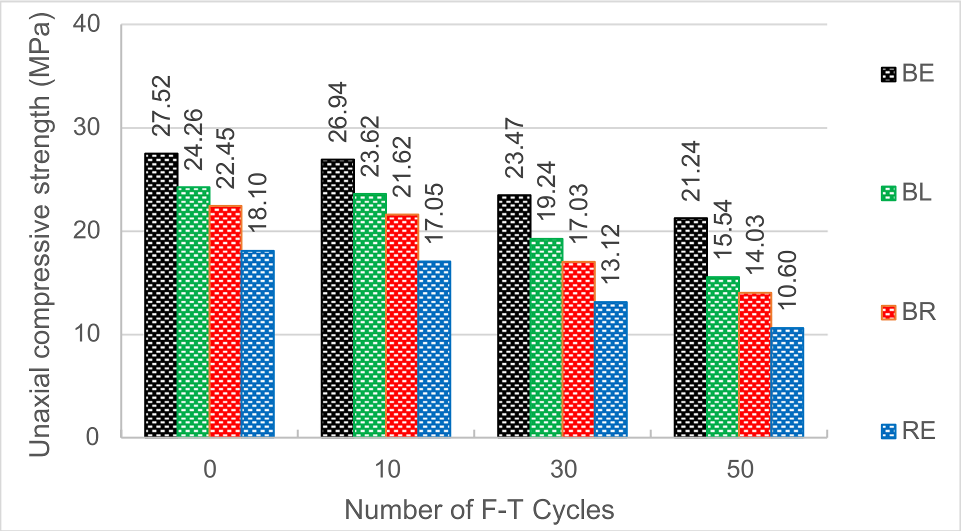
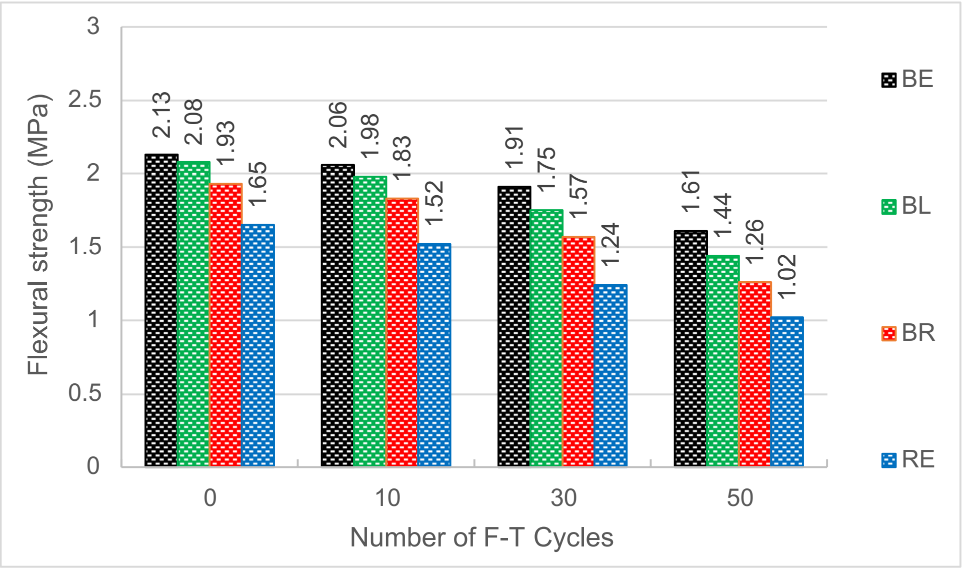


Fig. 10 Values for uniaxial compressive strength of Ahlat stones after F-T cycles

Fig. 11 Values for flexural strength of Ahlat stones after F-T cycles



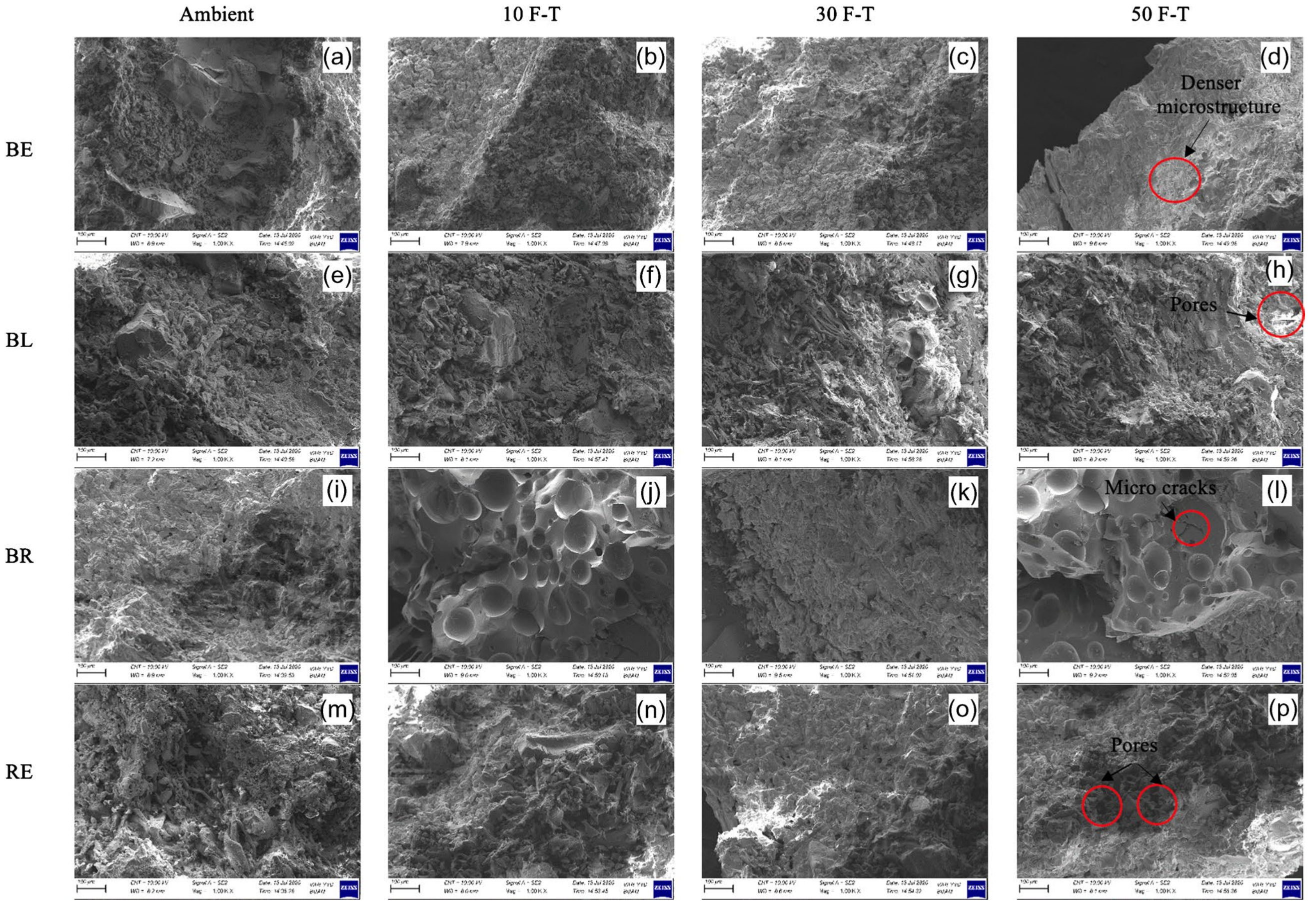


Fig. 12 **a–p** SEM images of BE, BL, BR, and RE stones at ambient and after F-T cycles

workability. Eventually, alterations have been observed in the strength and durability properties of these rocks, which are employed in constructions, due to atmospheric actions. It is extremely critical to reveal the effects of these alterations on the economic life of the buildings, and as well as their place of use. Therefore, after freeze–thaw cycles, changes in the physical and mechanical properties of four different ignimbrite rocks were carried out in this study. According to the study results, it was concluded that the BE ignimbrite is better than other rocks in terms of physical and mechanical properties after F-T cycles. However, the physical and mechanical properties of the RE ignimbrite were shown to downgrade drastically as a result of F-T cycles. Compared to room conditions, it was discovered that the porosity and mass loss values of all rocks increased drastically, and uniaxial compressive strengths and flexural strengths decreased significantly after subjecting to varying F-T cycles. The rise in F-T cycles was accompanied by a progressive drop in Vp velocities in all samples. The RE sample, which contained the highest initial porosity, demonstrated an extreme decrease among all the samples measured. Furthermore, it was determined from the SEM analyses of the rocks that the number and size of fractures, cracks, and pores that occurred in the microstructure of the rocks as a result of F-T cycles increased, and that these deteriorations in the microstructure adversely affected the physical and mechanical properties of the rocks.

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Declarations

Conflict of interest The author declares no competing interests.

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