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Improving the slake durability index values of tuff with a water-based copolymer treatment

Su bazlı kopolimer uygulaması ile tüflerin suda dağılmaya karşı duraylılık indeksi değerlerinin iyileştirilmesi

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Abstract

Tuff has been used as a natural building stone in the construction industry since the earliest times. Tuff is slight, simple to manufacture, and has good isolation qualities, which is why it is used so frequently despite its low strength characteristics and high porosity. In this study, samples of white and pink tuff from the regions of Derbent and Gümele districts of Eskisehir province were treated with a water-based (water-soluble) copolymer bath to evaluate their endurance to atmospheric conditions. Spherical samples were subjected to 30-minute slake durability index testing in a water-based copolymer bath. The index values of the initial spherical samples were contrasted with the index values from the fourth cycle of the spherical samples that had received the copolymer bath treatment. Although the index values of the original spherical samples were determined to be 92.22% and 95.32%, respectively, the index values of the spherical sample sets treated with a water-based copolymer bath were determined to be 98.29% and 98.83%, respectively. The study results indicate that spherical samples with a water-based copolymer bath treatment had a greater impact on improving the slake durability index values compared to spherical samples without treatment.

Keywords: Copolymer bath, Pink tuff, Slake durability index, White tuff

Öz

Tüf, antik çağlardan beri inşaat sektöründe doğal yapı taşı olarak kullanılan bir malzeme biçimi olmuştur. Düşük mukavemet özelliklerine ve yüksek gözenekliliğine rağmen; hafif olması, üretiminin kolay olması ve iyi izolasyon özelliklerine sahip olması nedeniyle bu kadar sık kullanılır. Bu çalışmada, Eskişehir ili Derbent ve Gümele bölgelerinden alınan beyaz ve pembe tüf numunelerinin atmosferik şartlara dayanıklılıklarını değerlendirmek için su bazlı kopolimer banyosuna tabi tutulmuştur. Küresel tüf numunelerine, su bazlı bir kopolimer banyosunda 30 dakika bekletilmiş, sonra suda dağılmaya karşı duraylılık indeksi testi uygulanmıştır. Orijinal numunelerin indeks değerleri, kopolimer banyosuna tabi tutulan küresel numunelerin dördüncü çevrim indeks değerleri ile karşılaştırılmıştır. Orijinal numunelerin indeks değerleri sırasıyla %92,22 ve %95,32 olarak belirlenirken, su bazlı kopolimer banyosu ile işlem görmüş küresel numune setlerinin indeks değerleri sırasıyla %98,29 ve %98,83 olarak belirlenmiştir. Çalışma sonuçları, su bazlı kopolimer banyo işlemine tutulan tüf numunelerinin, işlem görmemiş numunelere kıyasla, suda dağılmaya karşı duraylılık indeksi değerlerini iyileştirmede daha büyük bir etkiye sahip olduğunu göstermektedir.

Anahtar kelimeler: *Kopolimer banyosu, Pembe tüf, Suda dağılmaya karşı duraylılık indeksi, Beyaz tüf*

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1.Introduction

Tuff, a form of volcanic rock, is frequently used in the building sector because of its accessibility and somewhat good engineering characteristics. It is made from compacted volcanic ash and is utilized in a variety of construction projects, including building foundations for buildings and embankments and road bases. Tuff's susceptibility to slaking, a process in which the rock disintegrates when exposed to water, is a serious problem, though. The structural stability and long-term durability of structures using tuff as a fundamental material are compromised by this susceptibility, demanding creative methods to deal with the problem. When two or more distinct monomers are polymerized together, they form a class of materials called copolymers, which combine the desired features of each monomer. Water-based copolymers can add a protective layer to tuff that raises the rock's slake durability index, boosting its functionality and lengthening its lifespan.

A crucial factor in determining the durability of rocks, particularly in terms of their resistance to slaking, is the slake durability index (SDI). It gauges a rock's resistance to the deterioration brought on by water absorption. Better slake durability is indicated by a higher SDI, which suggests that the rock is less likely to crumble when exposed to moisture. In the fields of geotechnical engineering and material science, it is crucial to increase the slake durability index values of tuff using a water-based copolymer treatment. Tuff, a volcanic rock made of condensed volcanic ash, is frequently used in infrastructure and construction projects because of its availability and generally positive engineering characteristics. Tuff's sensitivity to slaking, in which material breaks down when exposed to water, is a serious obstacle in its use. The structural integrity and long-term viability of constructions using tuff as a foundational material may be jeopardized by this susceptibility. In various studies, researchers have applied SDI tests to different materials. The highest SDI value was obtained on the spherical specimens in the SDI test conducted on 7 different shaped experiment samples prepared from limestone (Danaei & Fereidooni, 2023). A multiple variable regression analysis was conducted to establish the relationship between the SDI values obtained from the SDI test on limestone and the physico-mechanical properties. This analysis was used to predict the SDI index value (Shahid, 2022). In the SDI test conducted on red sandstone, the disintegration behavior of the rock was examined. Based on the particle size distribution, prediction of disintegration breakage was carried out using the Weibull distribution (Fan et al., 2021). SDI tests were conducted on sandstone, limestone, and travertine rocks at different pH levels. Multiple Regression Analysis (MRA), Artificial Neural Network (ANN), and Adaptive Neuro-Fuzzy Inference System (ANFIS) analyses were employed for predicting the SDI values of the rocks using the SDI values within the pH range of 4-7 (Khajevad, 2022). SDI tests were conducted on round and spherical experiment samples prepared from 8 different rocks, and it was determined that the spherical samples had higher SDI values (Aksoy et al., 2019). The soil material improved with cement admixture was subjected to the SDI test. Considering the SDI values, an appropriate cement admixture ratio of 7% is recommended (Hartono, 2019). SDI tests consisting of 25 cycles were conducted on spherical samples prepared from three types of marbles. Mass losses in each cycle were plotted on statistical control charts, and lower and upper SDI values were determined for these rocks (Ankara & Çiçek, 2019).

According to the depth at which they formed, igneous rocks are divided into three categories: depth rocks, semi-depth rocks, and surface rocks. Tuffs are pyroclastic rocks that are part of the group of surface rocks and were created during the eruption phase of volcanic activity. Türkiye has a significant number of extinct volcanoes despite the absence of any active volcanoes there. In numerous locations, there are also young volcanic cones. Tuff formations are common as a result. Since ancient times, tuffs, which are often white and pink in color and are found in Türkiye, have been employed in the construction of homes. The ability to maintain heat is its most crucial quality, and because of this, it is frequently utilized as a food storage facility. It has also been used historically and currently as a raw material for cement (Bella et al., 1997). Tuff that develops as a result of a light-fused ash flow is known as pink tuff. It has columnar joints with vertical branches. Thus, the region's steep slopes are created by pink tuff deposits. The middle and top portions of the pink tuff exhibit honeycomb weathering characteristics. Phenocrysts, which are tiny fragments of metamorphic rock embedded inside the tuff structure, constitute the majority of the material in white tuffs. Phenocrysts of quartz, K-feldspar, biotite, and opaque minerals can be found in white tuff (Sözmen, 2000).

The purpose of this study is to investigate the impact of water-based copolymer treatment on the slake durability index (SDI) values of white and pink tuffs collected from Eskisehir Derbent and Gümele regions. When rocks are put through two normal cycles of drying and wetting, the SDI, a widely used index, determines how resistant they are to deterioration. The test was initially developed by Chandra in 1970, and it was improved upon by Franklin and Chandra in 1972. Since 1972, the test has been widely applied in rock mechanics. The International Society for Rock Mechanics proposed the test as a standard test for rocks as a result of its acceptance and use (Hawkins, 2009). The test was standardized as ASTM D4644 and approved by the American Society for Testing and Materials (ASTM D4644, 1990). SDI has been widely utilized in literature to assess the durability of rocks, particularly brittle and clay-bearing rocks, and has thus become a crucial engineering parameter (Bella et al., 1997; Cetin et al., 2000; Gemici, 2001; Dhakal et al., 2002; Viterbo et al., 2007; Erguler & Ulusay, 2009; Ankara, 2017). Water-based copolymers are used in a variety of industries, such as food, pharmaceuticals, paint, textiles, paper, coating, construction, adhesives, and water treatment (Halake et al., 2014). They can be used to change the features of rock materials, such as altering their wettability and enhancing sand consolidation (Gheraghian et al., 2014). The improvement of the slake durability index values for spherical samples was the main goal of the current investigation. For this purpose, white and pink tuffs collected from Derbent and Gümele districts of Eskisehir province were used. In a water-based copolymer (acrylic) bath, spherical samples were tested for slake durability index for 30 minutes. The fourth cycle of the spherical samples treated with the copolymer bath were compared to the fourth cycle SDI values of the original spherical samples.

2. Material and method

2.1. Material

Due to their softness and ease of processing, tuffs and ignimbrites-type rocks were employed to construct historical structures and are still used as decorative materials in Türkiye today. For instance, these kinds of rocks were used to create some significant natural and historical landmarks in Türkiye, including the Phrygian Valley, the Phrygian Monument, and the Cappadocian chimneys. The tuffs in other regions are produced as decorative materials. Derbent and Gümele districts in Eskisehir province are two locations where tuff is produced. Tuff blocks gathered in this location are known as Gümele pink tuff and Derbent white tuff. Quartz, K-Feldspar, biotite, and unusual crystals of opaque minerals make up the tuffs' mineral composition. White pumice and different metamorphic rock fragments can also be seen. White pumice, rock fragments, and phenomenon crystals are buried in the structure of the slightly decomposing tuff. The presence of volcanic glass fragments in tuffs is fairly common. Pink tuff is considerably more durable than white tuff (Binal et al., 1997; Sözmen, 2000). The results of the elemental analysis conducted on tuff samples are presented in Table 1. The images of pink and white tuffs were given in Figure 1.

Table 1. Element contents of the tuff samples

Tuff	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	LOI (%)
Pink	69.35	13.52	1.51	0.74	1.32	2.35	5.28	5.5
White (Ankara, 2017)	69.62	13.30	1.08	0.93	1.06	1.93	5.09	7.7

Figure 1. The images of pink and white tuffs. (a) Pink tuff (b) White tuff

2.2. Experimental analysis

There are three steps involved in creating equivalent size and weight spherical test samples. The first step is to cut cubes from the gathered rock samples that match the final spherical sample diameter in size. The cube edge length is determined with the goal of having a final sample weight standard of 50 gr. As a result, the rock's volume and dry density are used to calculate the sample's diameter. Following the measurement of the diameter, the cube's edge length is set to be the diameter plus 2 mm. The second step involves cutting cubes into a pre-spherical shape known as the Pasha Cut. Pasha cuts are made in two steps: (a) cutting the cub's edges, (b) cutting the samples' corners following the first step. The final stage is to use a customized apparatus to gather equidistant spherical samples from Pasha Cut. Samples are put into the spherical preparation machine after the pasha cut step (Covington brand). Special cutter cups with a 35 and 40 mm diameter were created and produced. Diamond is the abrasive material utilized in these cups. The entire sample preparation procedure is known as the Pasha Method (Ankara et al., 2013).

For the water-based copolymer (acrylic) bath and slake durability test, a total of 20 spherical samples were prepared. First, 20 spherical samples were placed in a water-based copolymer bath for 30 minutes. Two sets of oven-dried samples were placed in drums positioned in their respective water-filled troughs after waiting for 4 hours at room temperature. The drums were rotated at 20 rpm for a period of 10 min. Every sample that had been kept in the drums was carefully taken out, placed in the oven for the time recommended by international society for rock mechanics (ISRM) standards, and then the oven-dried weight was calculated. The samples were once more placed within the drums, and the process was then repeated four times. A 12-cycle SDI test was applied to each experimental set for statistical analysis.

This experiment has been developed to simulate the wetting and drying cycles of rocks in natural conditions. Standards and literature recommend the test to have 2 (ASTM D4644 , 1998; ISRM, 2007) or 4 cycles (Ulusay et al., 1995; Gökçeoğlu et al., 2000; Ulusay et al., 2011). Based on the index value against disintegration for these cycle numbers, rock strength is qualitatively determined. A flowchart of the study was given in Figure 2.

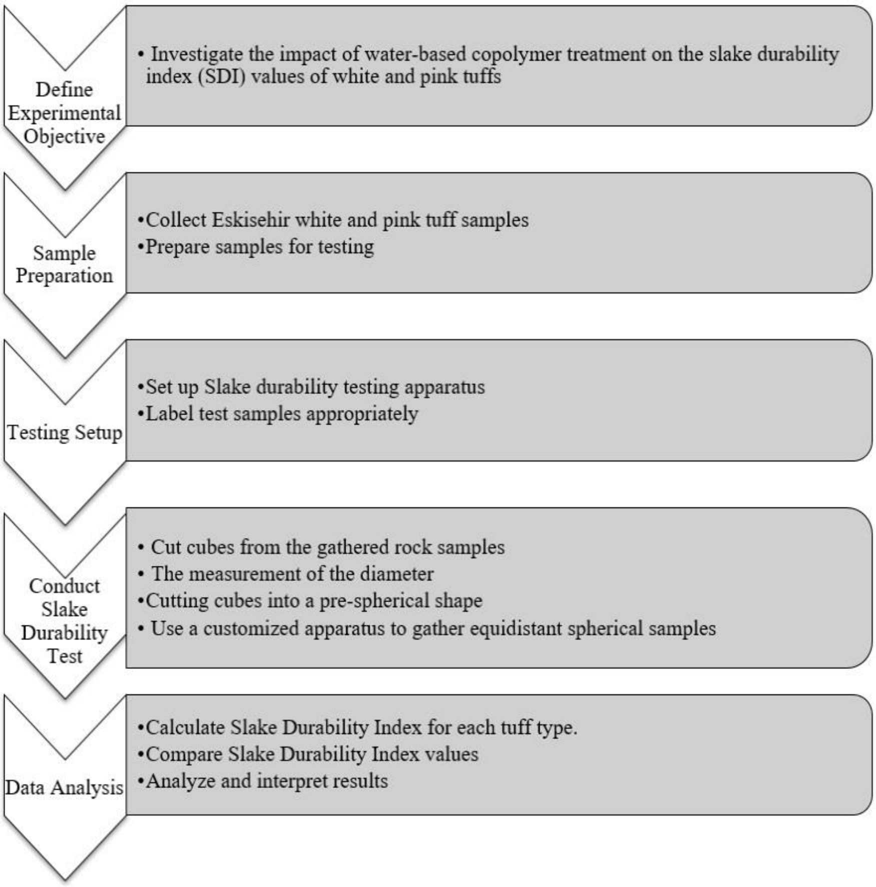

Figure 2. Flowchart of the study

3. Results and discussion

Pink and white tuffs had average water absorption rates of 23.20% and 20.94%, respectively. Pink and white tuffs' average weight acrylic absorption ratios were calculated to be 13.83% and 14.27%, respectively. Long-term exposure to acrylic products will not be cost-effective. Therefore, acrylic absorption tests of tuffs were carried out for 10 and 30 minutes. It was established that soaking the pink and white tuffs in acrylic for 30 minutes would be adequate, and it was found that they absorbed 8.80% and 5.36% of acrylic, respectively. 12-cycle SDI test was performed for untreated tuff samples (Table 2).

Eskisehir Gümele pink tuff and Derbent white tuff quarry equal-sized spherical samples were used in this study's slake durability testing. Fourth cycle for equal sized spherical samples kept for water-based copolymer bath were found to be 98.83% and 98.29%, respectively. Preliminary researches original spherical samples after fourth cycle were determined between 95.32% and 92.22%, respectively. The results of the according to ISRM slake durability test on the identically sized spherical samples were shown in Table 3. The SDI results are illustrated in Figure 3.

Table 2. Test results for the slake durability index on original tuffs

SDI	Pink tuff (%)	White tuff (Ankara, 2017) (%)
I_{d1}	98.97	98.46
I_{d2}	97.81	96.33
I_{d3}	96.50	94.25
I_{d4}	95.32	92.22
I_{d5}	94.07	90.00
I_{d6}	92.91	87.68
I_{d7}	91.50	85.21
I_{d8}	90.32	82.77
I_{d9}	89.05	80.06
I_{d10}	87.89	77.49
I_{d11}	86.70	74.87
I_{d12}	85.38	72.48

Table 3. Results of the copolymer bath treatment

SDI	Pink tuff (%)	White tuff (%)
I_{d1}	99.52	99.29
Id_2	99.36	98.94
I_{d3}	99.22	98.73
I_{d4}	98.83	98.29
I_{d5}	98.10	97.66
I_{d6}	97.17	96.68
I_{d7}	95.93	94.86
I_{d8}	94.48	92.63
I_{d9}	93.17	90.35
I_{d10}	91.99	87.64
I_{d11}	90.68	84.99
I_{d12}	89.46	82.11

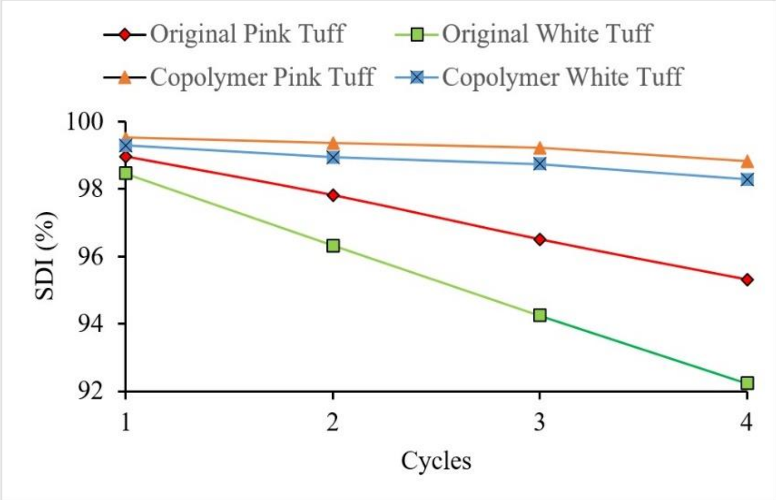

Figure 3. Graphical presentation of SDI values

Pink and white tuffs retained for water-based (water soluble) polymer can be characterized as having a very high tensile strength, according to the results of tests using equal-sized spherical samples. However, they can be classified as strong and moderately strong, respectively, based on the results of the original tuff sample testing. In the second set of the SDI values for the samples preserved for the water-based copolymer bath are comparable to those for the spherical samples that received no treatment. As a result, samples held for a water-based copolymer bath showed improved slake durability index compared to untreated samples. The percentage change values of each index value according to the preceding index value were given in Table 4.

Table 4. Percentage change values of each index

Cycle	Index value		% Change from previous cycle	
	Pink tuff	White tuff	Pink tuff	White tuff
I_{d1}	99.52	99.29	-	-
I_{d2}	99.36	98.94	-0.16%	-0.35%
I_{d3}	99.22	98.73	-0.14%	-0.21%
I_{d4}	98.83	98.29	-0.39%	-0.45%
I_{d5}	98.10	97.66	-0.74%	-0.64%
I_{d6}	97.17	96.68	-0.95%	-1.00%
I_{d7}	95.93	94.86	-1.28%	-1.88%
I_{d8}	94.48	92.63	-1.51%	-2.35%
I_{d9}	93.17	90.35	-1.39%	-2.46%
I_{d10}	91.99	87.64	-1.27%	-3.00%
I_{d11}	90.68	84.99	-1.42%	-3.02%
I_{d12}	89.46	82.11	-1.35%	-3.39%

When opposed to the white tuff, the pink tuff may have a more compact or cohesive physical structure. Higher resistance to disintegration during wetting and drying can result from a structure that is denser and has stronger interparticle linkages. The SDI may be impacted by variations in grain size, grain shape, or microstructure. The better resilience to disintegration of the pink-colored tuff may be attributable to its more advantageous grain shape or size distribution. Compared to the pink-colored tuff, the white tuff may be more worn or changed. A lower SDI may be the result of softer, more easily disintegrating material due to greater weathering. The tuffs' characteristics may have been influenced by the geological past and earlier occurrences to which they have been exposed. The pink-colored tuff may have been more durable than the white-colored tuff due to different geological processes that may have had an impact on it (Binal, 1996). To find out if there was any difference between the original spherical samples and samples treated with a water-based copolymer bath, a test of hypothesis was conducted. In the test of hypothesis:

H_0: There is no significant difference between the two mass means.
H_1: There is a significant difference between the two mass means.

The t-test value was utilized to compare the hypotheses because there were fewer than 30 samples (n<30) used in the tests. Table 5 displays the findings of the t-test used to compare the differences between the means of original white spherical samples-spherical samples subjected to water-based copolymer bath and pink spherical samples-spherical samples subjected to water-based copolymer bath. The test was performed for 95% confidence level (p=0.05). H_1 is accepted if the estimated p value is less than or equal to 0.05, while H_0 is approved if the estimated p value is more than 0.05. The initial spherical samples and samples that were subjected to a water-based copolymer bath differ significantly from one another. The strength of the original spherical samples increases at a 95% confidence level when they are subjected to a water-based copolymer bath.

Table 5. Results of *t*-test

	Std. deviation	Test value (t)	*p* value	Significance of mean differences
White tuff	3.278	-7.955	0.000	Significant (H_1 hypothesis is accepted)
Pink tuff	1.227	-9.761	0.000	Significant (H_1 hypothesis is accepted)

In the literature, apart from the studies conducted by some researchers (Ankara, 2017; Ankara & Çiçek, 2019), there is a study available. Danaei & Fereidooni (2023) conducted SDI tests on spherical samples and found higher index values for spherical samples compared to other shaped samples. Additionally, in ASTM and ISRM standards, it is recommended to prepare test samples as uniformly sized and as close to spherical as possible (ASTM D4644, 1998; ISRM, 2007; Ulusay et al., 2011). The SDI test conducted using test samples treated with a water-based copolymer is not available in the literature. Therefore, the current study is the first of its kind in the literature. Apart from this study, there are studies in the literature conducted using different methods and additives (Bascetin et al., 2020; Bascetin et al., 2022; Eker & Bascetin, 2022). These studies demonstrate that the use of various additives has positive effects on durability.

Assigning dispersion resistance classes based on the SDI values involves categorizing the SDI values into predefined ranges and associating a class or category with each range. This can be a qualitative assessment of the durability of the rock samples. Table 6 represents the dispersion resistance class. Durability classification was carried out according to Franklin & Chandra (1972) in Table 7.

Table 6. Dispersion resistance class (Franklin & Chandra 1972)

Slake durability I_d (%)	Classification
0-25	Very low
25-50	Low
50-75	Medium
75-90	High
90-95	Very high
95-100	Extremely high

4. Conclusions

Tuffs are a prevalent type of rock in Anatolian geography. Within this rock type, natural formations such as fairy chimneys have emerged, and subterranean cities and monuments have been constructed in artificial settings. Furthermore, tuffs are currently increasingly employed for decorative purposes as building stones. Tuffs are fragile rocks easily influenced by atmospheric conditions. One of the contributing factors is the wetting and drying cycle.

Table 7. Slake durability index classification

SDI	Pink tuff (%)	Durability classification based on Franklin & Chandra (1972)	White tuff (%)	Durability classification based on Franklin &Chandra (1972)
I_{d1}	99.52	Extremely High	99.29	Extremely High
Id_2	99.36	Extremely High	98.94	Extremely High
I_{d3}	99.22	Extremely High	98.73	Extremely High
I_{d4}	98.83	Extremely High	98.29	Extremely High
I_{d5}	98.10	Extremely High	97.66	Extremely High
I_{d6}	97.17	Extremely High	96.68	Extremely High
I_{d7}	95.93	Extremely High	94.86	Very High
I_{d8}	94.48	Very High	92.63	Very High
I_{d9}	93.17	Very High	90.35	Very High
I_{d10}	91.99	Very High	87.64	High
I_{d11}	90.68	Very High	84.99	High
I_{d12}	89.46	High	82.11	High

The slake durability test enables the exploration of wetting and drying cycles in controlled conditions. The SDI test categorizes the rock based on the index value. According to the classifications by ISRM and Gamble, white and pink tuffs (second cycle index of the original) have been identified as having high slake durability. However, tuffs treated with water-based copolymers fall into a significantly higher category. This suggests that water-based copolymers can be utilized to improve the durability of tuffs under atmospheric conditions.

The present study aimed to investigate whether testing spherical samples for slake durability index in a water-based copolymer bath could enhance the strength properties of tuff. Gümele pink tuff and Derbent white tuff samples were utilized for this purpose. The initial IV values of the spherical samples were compared with the IV values after the fourth cycle of treatment in the copolymer bath. The initial IV values of the spherical samples were 92.22% and 95.32%, respectively. Subsequently, both sets of samples treated with the water-based copolymer bath showed IV values of 98.29% and 98.83%, respectively. Statistical analysis of variance was conducted on the initial spherical samples and those treated with the water-based copolymer bath. The statistical analysis indicated a significant influence of the water-based copolymer bath on the slake durability index.

The study results clearly indicate a significant enhancement in the slake durability index of tuff material following treatment with water-based copolymers. This improvement enhances the material's resistance to physical deterioration and reduces degradation when exposed to water. These findings suggest that water-based copolymer treatment can be an effective approach to enhance the durability of natural materials like tuff. Such applications can be leveraged to bolster the rock's durability and water resistance in the construction and mining sectors. Furthermore, by offering environmentally friendly and sustainable solutions, they can contribute to efficient resource utilization. In the future, conducting similar studies with a broader array of materials and under varying conditions will yield a more comprehensive understanding of the widespread impact of such treatments. Additional research could delve into various rock characteristics, such as porosity, deformation, and insulation properties. Moreover, mineralogical and optical measurements could offer valuable insights into comprehending the strength enhancement.

Author contribution

The first author contributed to the research design, conceptualization, literature review, and drafting of the article. The second author contributed to conceptualization, methodology, investigation, visualization, and supervision stages.

Declaration of ethical code

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

Conflicts of interest

The authors declare that there is no conflict of interest.

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