Experimental study of the effect of saline water on weathering of rocks in Robat Namaki region of Khorramabad

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Abstract

The salty running water from Gachsaran Formation in Robat Namaki region, north of Khorramabad city, has caused salt weathering of some rocks in the region. Salt weathering due to the salty running waters of the region is one of the reasons for changing the geomechanical properties of rocks, and as a result reducing their durability. In current research, the effect of salty running waters on the geomechanical properties of outcropping rocks in Robat Namki region has been studied by conducting salt weathering tests. For this purpose, two samples of limestone and sandstone have been prepared and salt weathering tests have been performed on them for 30 cycles in salty running water, spring water and saturated salt solution. After every 5 cycles, the point load index and porosity of the samples were determined. Fitting curves between salt weathering test cycles with point load index and porosity were developed for all three test solutions, and parameters of decay constant and half-life were obtained from them. The effect of the three test solutions on the samples has been evaluated using these parameters, as well as the percentage of changes of the point load index and porosity. The results show that saturated salt solution, spring water and salty running water had the greatest to least effect on the changes of point load index and porosity of the samples, respectively. Also, data analyses shows that sandstone is more affected by salt weathering due to its higher porosity and layered than limestone.

Keywords: Robat Namaki region, Salt weathering, Limestone, Sandstone

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1. Introduction

Weathering by crystallization of salt solutions causes chemical and physical deterioration, changes in appearance (color, beauty and scaling) and geomechanical properties of rock materials used in engineering structures. These changes, in turn, cause a change in the durability of the rock. Durability is defined as the rock's ability to maintain its characteristic features, such as strength, resistance to environmental factors, and its appearance. Therefore, evaluation the durability and deterioration of rocks to select them for use in areas where there is possibility of salt weathering is necessary and unavoidable. So far, various aspects of the effects of salt weathering on the geomechanical properties and durability of various rocks have been studied [1-11]. In addition, a number of researchers have investigated the crystallization pattern, thermo-dynamic conditions of crystallization of various salts, and also their crystallization method [12-16].

Yavuz [3] investigated the abrasion strength of tuff rock samples after salt weathering. The results of this researcher showed that after salt weathering, the weight loss of the samples due to abrasion increased by 60% of the initial value (before salt weathering). The effect of salt weathering on samples of igneous rocks was investigated by Ulusoy [17]. This researcher conducted the salt weathering test in sodium sulfate up to 15 cycles and in order to evaluate the durability of the samples, he measured the uniaxial compressive strength before and after the test, as well as the weight loss of the samples. Zedef et al [18] investigated the effect of salt weathering on dacite, andesite and tuff rocks. The results of their work showed that the durability of rocks against salt weathering depends on their chemical, mineralogical and physical properties.

The effect of salt weathering on the deterioration of six marble samples was investigated by Yavuz and Topal [19]. Their results showed that water absorption, effective porosity, uniaxial compressive strength, abrasion strength and compression wave velocity are more suitable parameters for evaluating the durability and quality of marbles than weight loss, density, Brazilian tensile strength and impact strength. Cultrone et al. [8] performed a series of petrophysical tests and salt weathering in order to evaluate the quality of sedimentary rocks as building materials. Their results showed that the salt weathering test caused the color changes of the rock samples, as well as their weight loss. These researchers the main reason for the weight loss of the samples attributed to the mineralogical difference between the constituent particles and the matrix, as well as the presence of strong anisotropy due to the presence of layering surfaces in the samples. Zalooli et al. [20] evaluated the deterioration of travertine samples against salt weathering using two parameters of alteration index and alteration velocity proposed by Angeli et al. [15].These researchers showed that porosity and strength are important factors controlling the durability of rocks against salt weathering. Jamshidi et al [9] investigated the durability of building stone samples by measuring their weight loss against salt weathering due to sodium sulfate. Zalooli et al. [10] investigated the durability of 15 different travertine samples against magnesium sulfate salt weathering. They showed that the durability of samples has a direct relationship with Brazilian tensile strength and an inverse relationship with effective porosity. Jamshidi et al. [28] introduced a physico-mechanical parameter to evaluate the durability of rocks against salt weathering. This parameter is based on water absorption, average diameter of pores and rock strength. Benavente et al. [16] investigated the effect of sodium sulfate salt weathering on the physical properties and durability of two samples of travertine and carbonate tuff. The results of these researchers showed that travertine is more durable against salt weathering compared to carbonate tuff. Torabi Kaveh et al [11] investigated the role of petrographic characteristics in the durability of limestones used in the historical monument of Persepolis (Marvdasht city, Fars province) against salt weathering caused by sodium sulfate. They founded that porosity is one of the most important parameters affecting the durability of rocks against salt weathering.

In the previous studies, fully saturated solutions of various salts, especially sodium and magnesium sulfates, have been used to perform salt weathering tests, and no attention has been paid to the real conditions of salt solutions in nature, which have a lower degree of saturation than laboratory conditions. In addition, much attention has not been paid to point load index and porosity tests, which are known as quick, index and low-cost tests, in the evaluating the rock durability against salt weathering.

In this research, two samples of limestone and sandstone were collected from Robat Namaki region in the north of Khorramabad city, and the effect of salty water and salt saturated solution on their geo-mechanical properties was investigated using salt weathering tests. This investigation has been done by using parameters of decay constant and half-life, as well as the percentage of changes in the point load index and porosity of the samples.

2. Materials and Methods

To perform the current study, a number limestone and sandstone blocks were selected from various locations of the Robat Namaki region in the north of Khorramabad city (Fig. 1). Then, the collected blocks were cored in the laboratory to prepare core samples with NX size (54.1mm diameter) in order to perform point load index and, porosity tests, as well as preparation of microscopic thin sections and chemical analyzes (XRD). On the other hand, the water samples were taken from the running water and spring water and salts existing in the region to simulate the salt weathering tests. The extracted salt of the region was used to prepare a salt saturated solution. The salt weathering tests was performed on limestone and sandstone samples using running water, spring water and salt saturated solution, and the point load index and porosity of the samples were measured. Using the obtained data, the results were analyzed and the effects of running water, spring water, and salt saturated solution on the samples have been investigated using parameters of decay constant and half-life, as well as percentage of changes in point load index and porosity of the samples.

3. Geological setting of the study region

The study region with coordinates $33^\circ 30'$ to $33^\circ 37'$ north latitude and $48^\circ 15'$ to $48^\circ 22'$ east longitude is located in the north of Khorramabad city, in the folded belt of Zagros. This region is known as Rabat Nakami, which is named due to abundance of salt and its extraction. The region of Rabat Namaki is located along Khorramabad-Alshatar road and after traveling a distance of 15 km. Fig. 1 shows the geological map of the region and sampling points. The rock outcrops of the region are mainly Cretaceous-Tertiary rock units, and in order from old to new, they include thick layered conglomerate of Amiran formation, thick layered to massive dolomitic limestone of Asmari-Shahbazan and marl formation, thin to medium layered sandstone, and gypsums belong to

Gachsaran formation. In addition to these formations, Quaternary sediments also cover parts of the region. Rabat Namaki region is one of the rainy and pleasant regions in Khorramabad, which has many running waters, springs and water wells. On the way back to the surface of the earth, the groundwater passes through the Gachsaran formation and dissolves part of the rocks of this formation and reaches the surface of the earth through springs and wells. These waters contain dissolved ions, which partially settle as salt when the water evaporates in the summer season. The native people of the region extract salt by creating ponds and use it for their livelihood. Fig. 2 shows one of salt extraction ponds in the Rabat Namaki region.

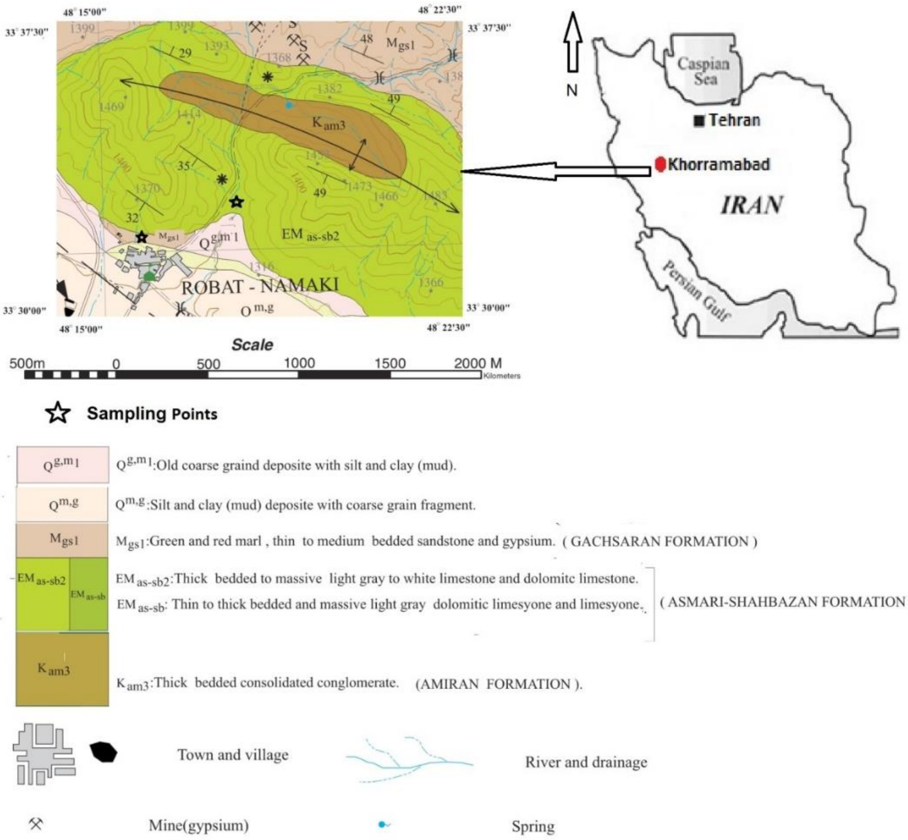


Figure 1. Geological map of the study region and sampling points [21]

Figure 2. A picture of the salt extraction ponds in Robat Namaki region, north of Khorramabad city

4. Laboratory tests

4.1. Petrographical characteristics

In order to investigate the petrographic characteristics including the mineralogical composition of the samples, microscopic thin sections were prepared from each rock sample. Fig. 3 shows the microscopic thin sections of the samples. The mineralogical composition of limestone is mainly fossil fragments (bioclasts) placed in a micrite (limestone) matrix. On the other hand, sandstone is a lithic arenite that contains chert, limestone, igneous and some quartz fragments.

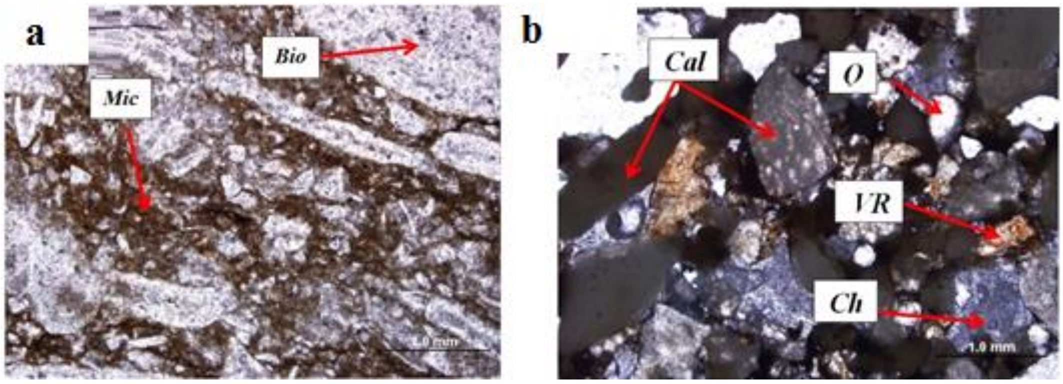


Figure 3. Microscopic image of microscopic thin sections a) Limestone, and b) Sandstone Micrite (Mic), fossil (Bio), chert (Ch), limestone (Cal), and igneous (VR fragments), quartz (Q)

4.2. Porosity and Point Load Index of the samples

To determine the porosity of limestone and sandstone, 5 samples for each type of rock were tested according to the ISRM [22] and their average values were determined. The following equation is used to determine the porosity:

$$n = \frac{(M_{sat} - M_s)/\rho_w}{V} \times 100 \qquad (1)$$

where n is the porosity in term %percent, M_s and M_{sat} are the dry and saturated mass in term g, respectively, ρ_W is the water density in term gr/cm^3, and V is the sample volume in term cm^3.

The porosity of limestone and sandstone are equal to 1.50 and 10.71%, respectively. Based on the classification of Matula et al. [23], limestone and sandstone are classified as low (1-5%) and medium (5-15%) porosity rocks, respectively.

Point load index test is one of the simple, quick and low-cost methods to determine the strength of rocks. In this research, the point load index test was performed on cylindrical samples for 5 specimens of each type of rock according to the ISRM [22]. Fig. 4 shows the point load testing device and some of specimens before testing. The results obtained from the point load index test were corrected for the diameter of 50 mm. The results show that the point load index of limestone and sandstone is equal to 6.7 and 5.2 MPa, respectively. According to the Franklin and Chandra [24], the samples are in the class of rocks with very good strength (point load index equal to 3-1o MPa).

a b

Figure 4. a) Point load test device, and b) Some of specimens before testing

4.3. Salt weathering test

To conduct the salt weathering test, water samples was collected from running water and spring water in the region. Running water with geographical coordinates of 33° 30′ north latitude and 48° 19.5′ east longitude and spring water with geographical coordinates of 33° 5.5′ north latitude and 48° 18′ east longitude were collected. In addition, some salt was prepared from the extracted salts in the region to prepare a fully saturated solution. The chemical composition of the prepared salt was investigated by XRD analysis. Fig. 5 shows the results of this analysis. As can see, the chemical composition of salt includes sodium chloride, calcium chloride and sodium sulfate.

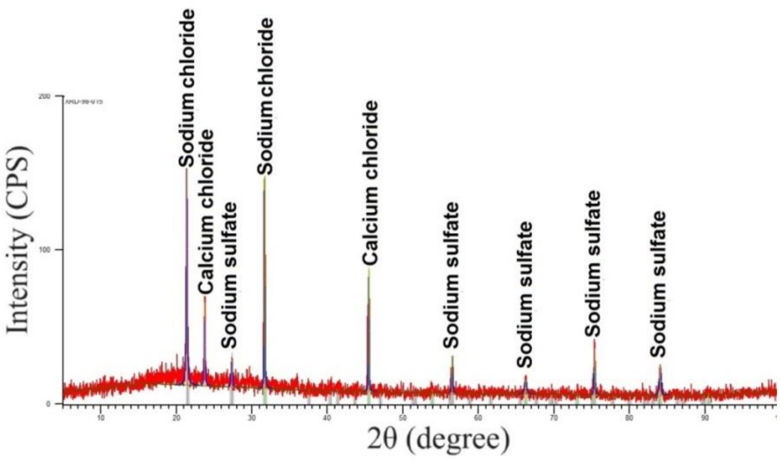


Figure 5. Result of XRD analysis of the studied salt sample

In the fallowing, the salt weathering test up to 30 cycles in running water, spring water and salt saturated solution was performed according to the European standard [25] and after every 5 cycles the porosity and point load index of limestone and sandstone were determined. For each cycle of salt weathering test, first the samples were placed in the pool of each of the solutions for 6 hours (immersion stage), then the samples were placed in the oven at a temperature of 100 ± 5 ℃ for 18 hours (drying stage). In Fig. 6, various solutions prepared for the salt weathering tests are shown. The results of determinations of porosity and point load index of the samples after salt weathering tests are presented in Tables 1 and 2.

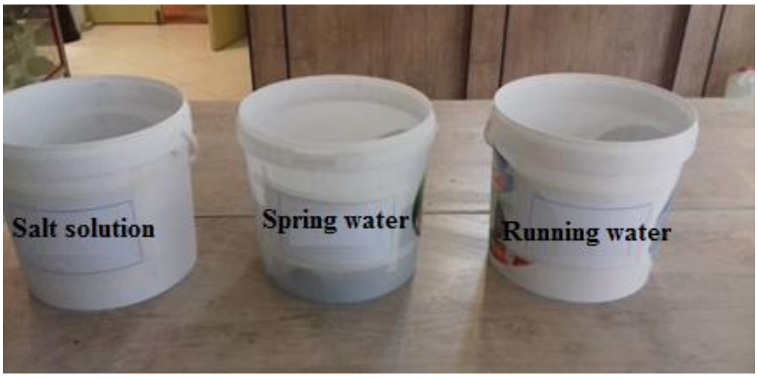


Figure 6. Solutions prepared for salt weathering tests

Table 1. Values of point load index (MPa) of limestone and sandstone during the salt weathering tests

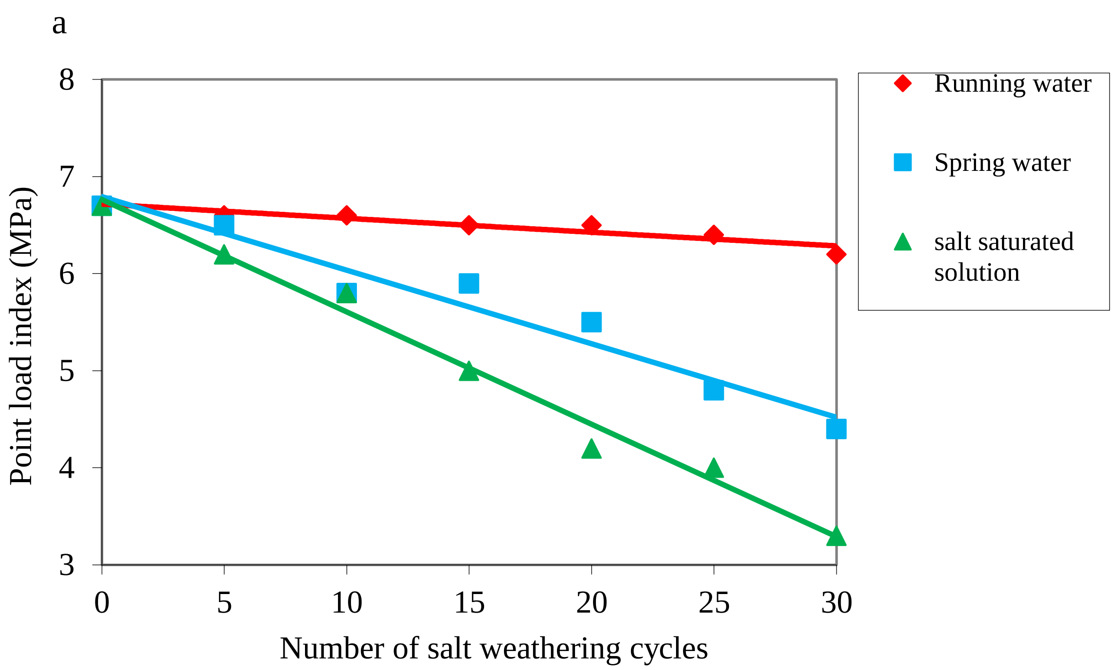
Sandstone			Limestone			
Salt saturated solution	Spring water	Running water	Salt saturated solution	Spring water	Running water	Cycle no.
5.2	5.2	5.2	6.7	6.7	6.7	0
4.4	4.9	5.2	6.2	6.5	6.6	5
3.8	4.7	5.0	5.8	5.8	6.6	10
3.6	4.1	4.9	5.0	5.9	6.5	15
2.7	4.0	4.8	4.2	5.5	6.5	20
2.4	3.6	4.6	4.0	4.8	6.4	25
1.7	3.1	4.3	3.3	4.4	6.2	30
67.3	40.4	17.3	50.7	34.3	7.5	Change (%)

Table 2. Values of porosity (%) of limestone and sandstone during the salt weathering tests

Sandstone			Limestone			
Salt saturated solution	Spring water	Running water	Salt saturated solution	Spring water	Running water	Cycle no.
10.71	10.71	10.71	1.50	1.50	1.50	0
12.12	12.22	11.21	1.94	1.74	1.55	5
13.34	12.88	11.58	2.34	1.85	1.57	10
14.56	13.45	11.99	2.65	2.01	1.62	15
15.22	14.00	12.47	3.06	2.33	1.70	20
16.54	16.00	12.90	3.67	2.65	1.73	25
18.00	16.70	13.55	4.06	3.01	1.78	30
68.1	55.9	26.5	170.7	100.7	18.7	Change (%)

5. Results and Discussion

In order to investigate the relationship between the changes of point load index and porosity with salt weathering cycles, bivariate regression analyzes were established. These analyzes are shown in Figs. 7 and 8. It should be noted that these Figs. are obtained based on the data of tables 1 and 2. As can be seen in Fig. 7, with the increase in the number of weathering cycles in running water, spring water, and salt saturated solution, the value of the point load index of limestone and sandstone has decreased with different degrees. The reason for this reduction can be explained in this way that in the immersion stage of the samples during the salt weathering test, the salt solution penetrates into the voids of the samples. In fallowing, if the pore structure and the rock strength are such that the salt crystallization pressure cannot overcome the rock strength and cause a change in the rock structure, the salt accumulation in the pore will not have an effect on reducing the point load index of the samples. Whereas, the salt crystallization pressure can overcome to rock strength, the pores structure of the samples will change, and thus point load index of the samples will decrease during the salt weathering test. However, with the increase in the number of salt weathering cycles, the accumulation of salt in the pores will increase, and as a result, the point load index due to salt crystallization pressure will be the more decreased.



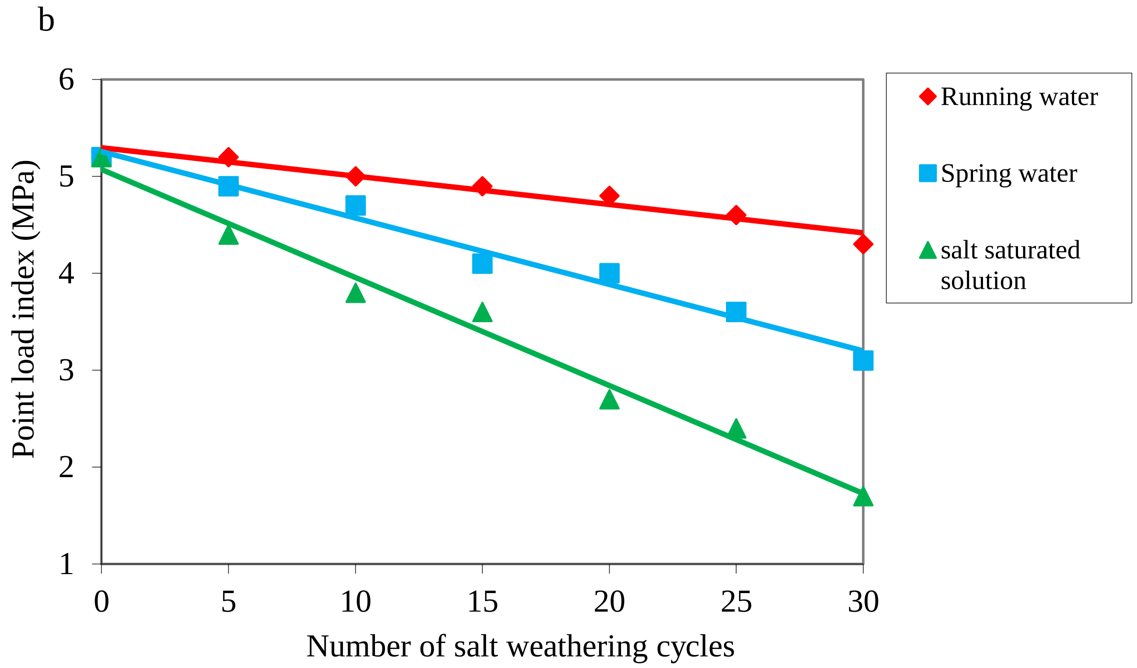
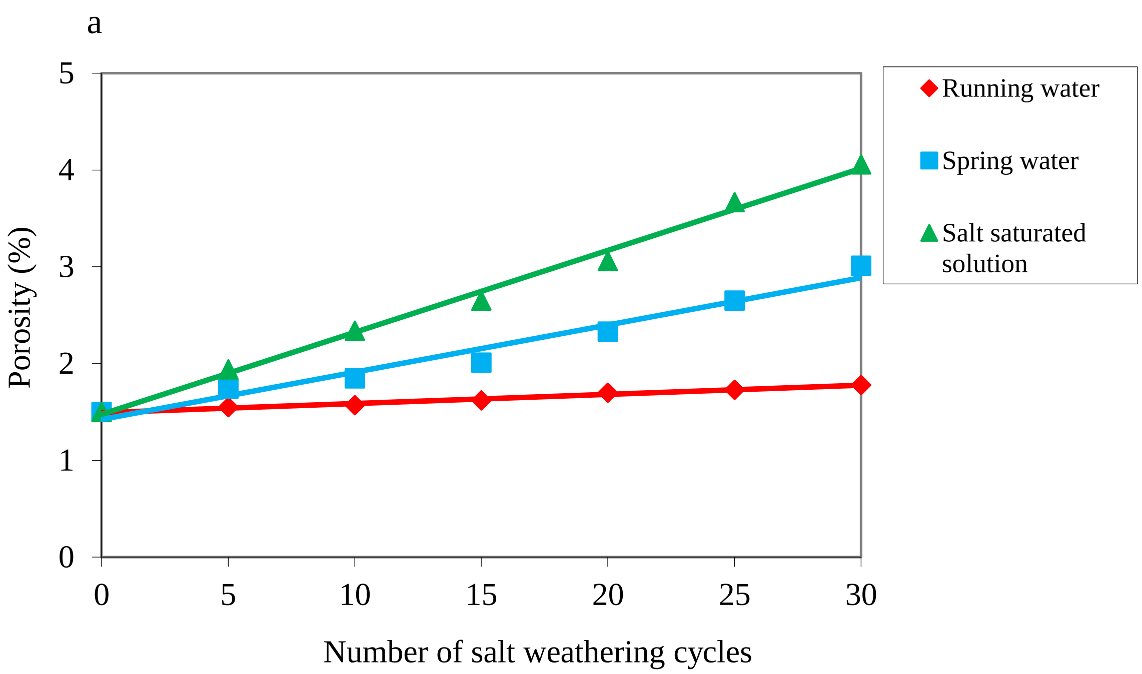


Figure 7. Point load index changes with salt weathering cycles a) limestone, and b) sandstone



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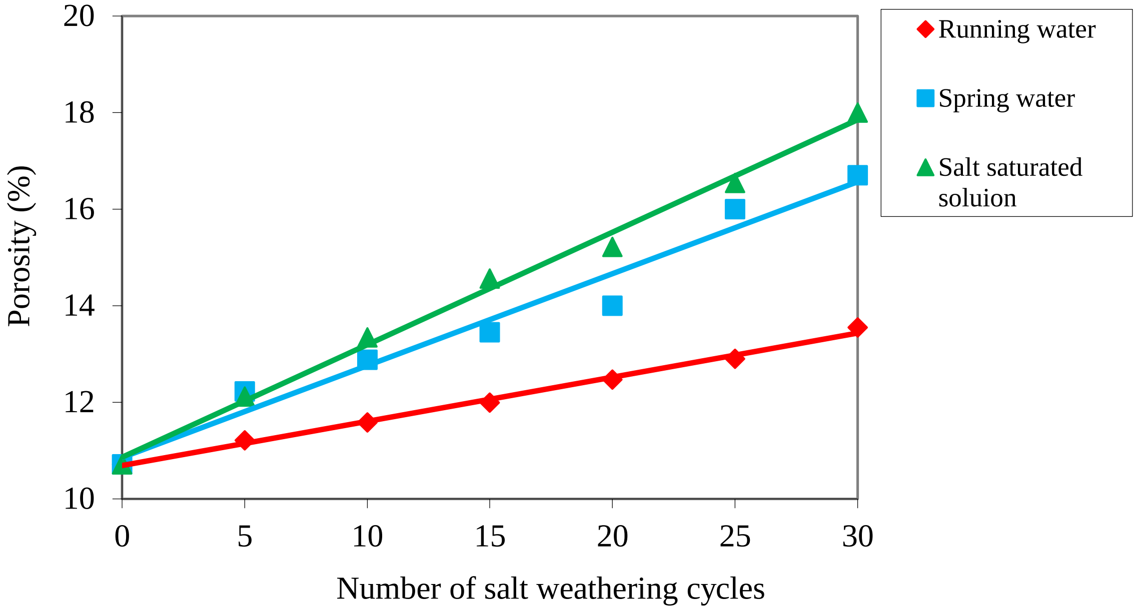

Figure 8. Porosity changes with salt weathering cycles a) limestone, and b) sandstone

Figs. 7 and 8 shows that the changes of point load index and porosity in various cycles of salt weathering test follow the linear models with determination coefficients between 0.89 to 0.99. The linear model shows that the intensity of changes in point load index and porosity in the initial and final cycles of the salt weathering test are almost similar and follow a linear pattern. As can be seen in Figs. 7 and 8, the form of the linear model for point load index and porosity is as Eqs. 2 and 3, respectively:

$$Is_N = -\lambda N + Is_0 \quad (2)$$

$$n_N = \lambda N + n_0 \quad (3)$$

where N is the number of salt weathering test cycles, λ is the decay constant of the point load index or porosity, Is_N and n_N are point load index and porosity in the Nth cycle of the salt weathering test, respectively, and Is_0 and n_0 are point load index and porosity in intact conditions (without applying the salt weathering cycles).

The negative sign in the Eq. 2 indicates the reduction of the point load index during the salt weathering test, and the positive sign in the Eq. 3 indicates the increase in porosity during the salt weathering test. In the linear models of Eqs. 2 and 3, the decay constant parameter, with the abbreviation λ, has been introduced, which is an important parameter for evaluating the changes in point load index and porosity of samples during the salt weathering test. In fact, if the value of this parameter is multiplied by the value of the point load index or porosity in intact conditions, the resulting answer shows the average value of changes in the point load index or porosity in one cycle of salt weathering test. For example, in Fig. 7a, the constant value of the deterioration of the point charge index of limestone in running water is equal to -0.0143, which when multiplied by the intact value of the point load index (6.7 MPa), its value will be 0.1 MPa. This means that in each salt weathering test cycle, 0.1 MPa is reduced from the point load index.

According to the presented contents, it seems that although the decay constant can be a suitable and important parameter in the evaluation of the deterioration of the point load index and the porosity of the samples, but its analysis for researchers who are active in the field of rock materials durability is not simple and somewhat is complicated Therefore, Mutluturk et al. [27] introduced a parameter called half-life ($N_{1/2}$), which is believed to be more appropriate and tangible than the decay constant (λ) in the context of evaluating the geomechanical properties of rock materials. The number of cycles of the salt weathering test in which the value of a property is required to reach half or twice its value in intact conditions is called the half-life of that property.

Using the models obtained from the salt weathering test (Eqs. 2 and 3), the half-life of the point load index and porosity can be determined.

In order to determine the half-life of the point load index, by putting $Is_0/2$ instead of Is_N in Eq. 2, the following Eq is obtained:

$$Is_0/2= -\lambda N_{1/2} + Is_0 \quad (4)$$

By solving the above Eq., the half-life of the point load index is obtained from Eq. 5:

$$N_{1/2}= Is_0 /2\lambda \quad (5)$$

To determine the half-life of porosity, by putting $2n_0$ instead of n_N in Eq. 3, the following Eq. is obtained:

$$2n_0= \lambda N_{1/2} + n_0 \quad (6)$$

By solving the above equation, the half-life of the porosity is obtained from Eq. 7:

$$N_{1/2}= n_0 /\lambda \quad (7)$$

According to the decay constant of point load index and porosity in salt weathering tests (Figs. 7 and 8), the half-life of point load index and porosity were calculated by Eqs. 5 and 7, respectively, and the results are presented in Table 3.

Table 3. Values of decay constant and half-life of point load index and porosity in the various salt weathering tests

Sandstone			Limestone				
Salt saturated solution	Spring water	Running water	Salt saturated solution	Spring water	Running water	Parameter	Geomechanical property
0.1114	0.0686	0.0293	0.1157	0.0757	0.0143	Decay constant (λ)	Point load index
23	38	89	29	44	234	Half-life ($N_{1/2}$)	
0.2328	0.1904	0.0914	0.0847	0.0488	0.0095	Decay constant (λ)	Porosity
46	56	117	19	32	158	Half-life ($N_{1/2}$)	

The results of Table 3 are shown schematically in Figs. 9 and 10. It can be seen in Fig. 9 that half-life of point load index of limestone is the lowest (29 cycles) in saturated salt solution and the highest (234 cycles) in running water. This shows that value of the point load index in the salt saturated solution compared to running water with a lower cycle's number in the salt weathering test reaches half of its value in intact conditions. Based on this, it can be said that the durability of limestone is the lowest in saturated salt solution and the highest in running water.

Similar conditions exist for sandstone (Fig. 9). The half-life of point load index for sandstone in running water, spring water, and saturated salt solution are equal to 89, 38, and 23 cycles respectively. Therefore, the durability of sandstone is the highest in running water and the lowest in saturated salt solution.

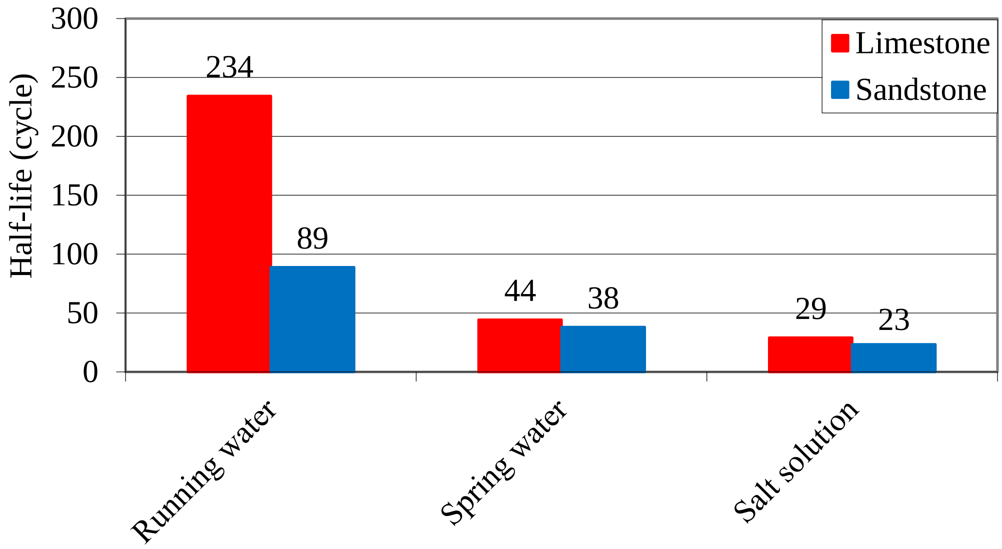

Figure 9. Half-life values of point load index of samples in the various salt weathering tests

From Fig. 10, it can be seen that the half-life of porosity for limestone in running water, spring water, and saturated salt solution are 158, 32, and 19 cycles, respectively. These results show that the rate of increase of limestone porosity is the lowest in running water and the highest in saturated salt solution. Therefore, the durability of limestone is the highest in running water and the lowest in saturated salt solution.

Similar results to limestone also exist for sandstone. As Fig.10 shows, the half-life value of sandstone porosity is the highest for running water (117 cycles) and the lowest for saturated salt solution (46 cycles). Therefore, the durability of sandstone based on the porosity half-life is Max. in running water and Min. in saturated salt solution.

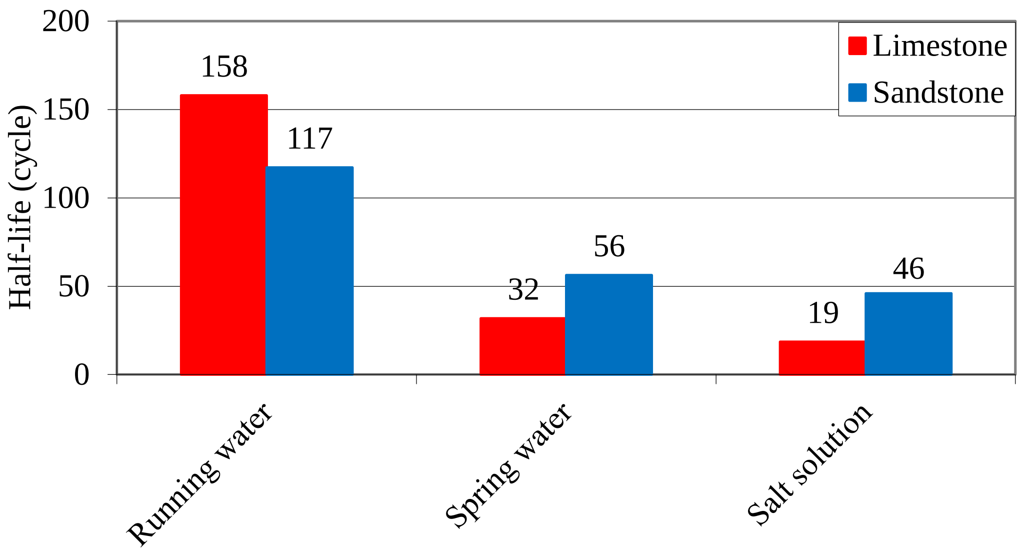

Figure 10. Half-life values of porosity of samples in the various salt weathering tests

In addition to the half-life, percentage of changes of point load index and porosity also has been used to evaluate the durability of the samples against salt weathering. Figs. 11 and 12 show the percentage of changes of point load index and porosity of the samples in the various salt weathering tests, respectively. The following Eq. is used to determine the percentage of changes:

$$P\ (\%) = ((M_0 - M_f)/M_0) \times 100 \qquad (8)$$

where P is the percentage of reduction of the point load index or porosity in intact conditions compared to the 30th cycle of salt weathering test, M_0 is the point load index or porosity in intact conditions and M_f is the point load index or porosity in the 30th cycle of salt weathering test.

As can be seen from Fig. 11, the highest (50.7) and the lowest (7.5) percentage of reduction in point load index for limestone occurred in saturated salt solution and running water, respectively. For sandstone, the highest (67.3) and lowest (17.3) percentages of reduction are related to saturated salt solution and running water, respectively.

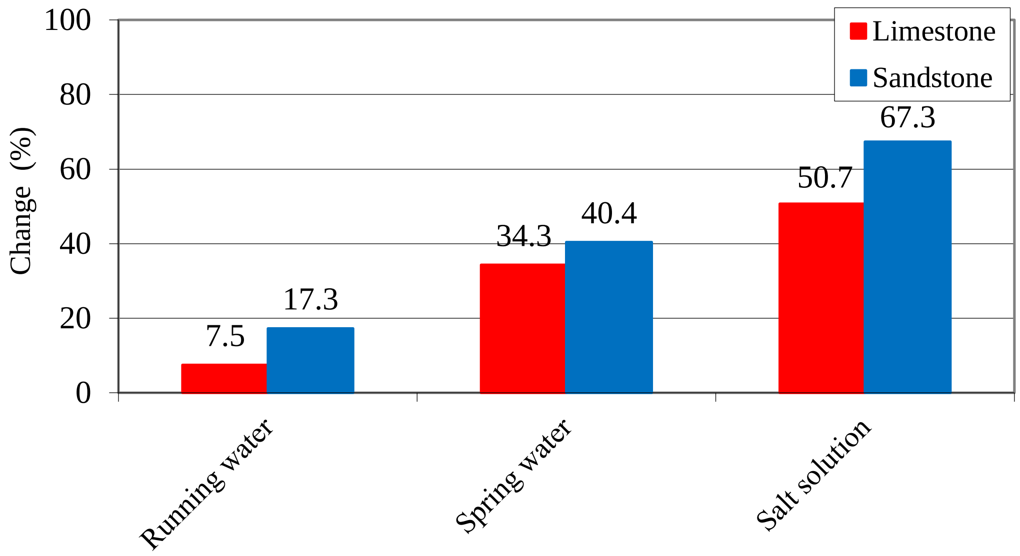

Figure 11. Percentage of changes of point load index of the samples in the various salt weathering tests

In Fig. 12, it can be seen that the percentage of increase of porosity for limestone during the salt weathering tests in running water, spring water and saturated salt solution is 18.7%, 100.7% and 170.7%, respectively. This indicates that, based on the assessment of porosity changes, the durability of limestone in running water and saturated salt solution is Max. and Min., respectively. Similar results also have been obtained for sandstone. Fig. 12 shows that the lowest and highest percentage of increase in the porosity (26.5 and 68.1) occurred for salt weathering tests in running water and salt saturated solution, respectively. Therefore, it can be concluded that sandstone was more durable in running water than that in saturated salt solution.

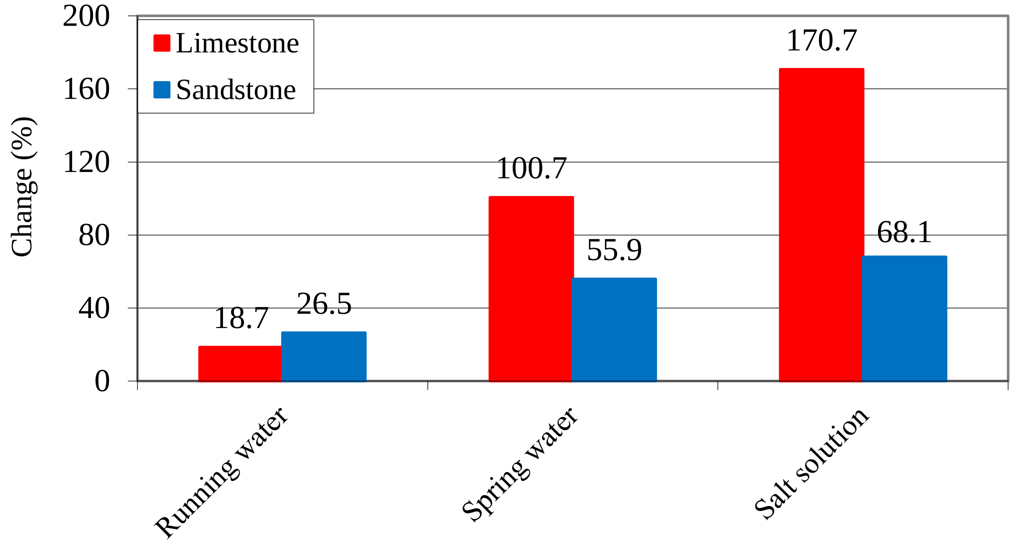

Figure 12. Percentage of changes of porosity of the samples in the various salt weathering tests

By comparing the half-life and percentage of changes of point charge index and porosity of limestone and sandstone in salt weathering tests, it can be seen that the effect of running water, spring water and saturated salt solution on sandstone was more than that limestone. In fact, sandstone shows less durability than limestone in salt weathering tests. The reason for the lower durability of sandstone can be attributed to its lower point load index and higher porosity compared to limestone. The lower strength of a rock, the less resistance it will have against salt crystallization pressures, and as a result, it will be less durable. Porosity is one of the most important parameters that control the behavior of different types of rocks, especially sedimentary rocks. When rock porosity is high, especially the effective porosity, the various destructive agents of the rock, such as the crystallization of dissolved salts, acts more intensively and affects the durability of the rock. In other words, the higher the effective porosity, the more interconnected the rock porous, and as a result, more water will be absorbed. Rocks with high water absorption are more susceptible to deterioration due to physical weathering caused by salt weathering cycles, and consequently, they will be less durable.

6. Conclusion

In the present research, two samples of limestone and sandstone were prepared from Robat Namaki region in the north of Khorramabad city. The salt weathering test was performed on these samples up to 30 cycles in running water, spring water, and saturated salt solution, and after every 5 cycles, the point load index and porosity were measured. Based on the regression analyses, two parameters of decay constant and half-life were introduced, which can be useful in evaluating changes in point load index and porosity, and consequently in evaluating the durability of rocks.

The results showed that the parameters of decay constant and half-life have acceptable precision and accuracy in evaluating the long-term durability of the studied samples against salt weathering test. These parameters reduce the cost, save time, and provide a quick assessment of the long-term durability of the samples in the salt weathering test, which requires weeks and even months.

Based on the parameters of decay constant and half-life, as well as the percentage of changes in point load index and porosity after salt weathering tests, the effect of saturated salt solution on point load index and porosity was greater than that of spring water and running water. In addition, the results showed that the changes of point load index and porosity were more severe in sandstone than that limestone. This issue can be attributed to the lower strength and higher porosity in sandstone compared to limestone.

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