Durability of some Weak Rocks Selected from Nineveh

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ABSTRACT

Some rocks are naturally weak, or it becomes weak due to weathering. Durability of weak rocks is one of the most important engineering properties to be evaluated. This study aims to determine the decrease of strength over time due to weathering processes for some weak rocks selected from four different locations within Nineveh. Rock samples were prepared for all types of selected rocks according to American Society for Testing Materials (ASTM) and International Society for Rock Mechanic (ISRM). Physical and mechanical properties of the samples were studied (dry density, absorption, Uniaxial compression test, Brazilian test, Point load test, and Slake–Durability test) in both dry and wet conditions. Slake - durability test used to determine the decrease in strength and weight loss% for studying rock samples using distilled water for all selected rock samples. Baghdad street and Talafare rocks samples were subject to a solution containing solute hydrochloric acid with 5%, and 10%, concentrations.

Results show that rock samples taken from Hay-AL-Quds and Hay-AL-Arab can be classified as very weak to weak with low durability, and weak with medium-high durability for samples selected from Baghdad street and Talafar. Results also indicate that there is a reduction in strength of treated rocks due to an increase in the level of weathering of rock. Higher values of reduction pointed out for samples treated with solute hydrochloric acid compared with the case when using distilled water with less effect in 5% concentration than that 10% concentration.

Keywords: Weak rocks, Slake-durability index, Weight loss.

ديمومة بعض الصخور الضعيفة المختارة من محافظة نينوى

الخلاصة

يمكن أن تتواجد الصخور في الطبيعة بصورة ضعيفة أو أنها تصبح ضعيفة نتيجة لعمليات التجوية. تعتبر ديمومة الصخور الضعيفة كاحدى الخواص الهندسية الأكثر أهمية التي تستلزم التقييم. تهدف الدراسة الحالية إلى تحديد مقدار النقصان في مقاومة نماذج من صخور مختارة من أربع مواقع في محافظة نينوى (شارع بغداد، تلعفر، حي القدس، حي العربي). تم تهيئة النماذج

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للصخور المواصفات العالمية للصخور (ISRM) (ASTM)، درس الخواص الفيزيائية والميكانيكية لنماذج الصخور المختارة (الكثافة الجافة، نسبة الامتصاص، فحص الانضغاط احادي المحور، الفحص البرازيلي، فحص التحميل النقطي، فحص الديمومة والتاكل) للحالتين الجافة والرطبة. تم دراسة ديمومة نماذج الصخور نتيجة تعريضها لدورات من الترطيب والتجفيف من خلال فحص قابلية التآكل باستخدام الماء المقطر لجميع النماذج وكذلك محلول حامض الهايدروكلوريك بنسبة تركيز 5% و 10% لنماذج شارع بغداد وتلعفر.

أظهرت النتائج بأنه يمكن تصنيف نماذج الصخور المأخوذة من منطقتي حي القدس وحي العربي على أنها صخور ضعيفة إلى ضعيفة جدا، في حين صنفت نماذج الصخور المأخوذة من منطقتي تلعفر وشارع بغداد إلى أنها صخور ذات ديمومة متوسط إلى عالية. كما أظهرت النتائج أيضا أن هنالك نقصان في مقدار مقاومة التحمل للصخور باستخدام محلول حامض الهايدروكلوريك بمقدار أعلى مقارنة بتحمل نفس الصخور باستخدام الماء المقطر وبنسبة اقل عند التركيز 5% عنه عند 10%.

INTRODUCTION

Sedimentary rocks are widespread in Iraq, especially in Mosul city. The study of strength and weight loss of this rock as an indication of weathering resistance is one of the important objectives of a geotechnical engineer when dealing with very weak to weak rock.

In the national standards (e. g. DIN 4022 TI, O-Norm B 2203 resp. DINEN 14689-1, ASTM D4644) weak rocks are a part of a group of rocks in contraction to the soil. The difference in hard rock is their nature to disintegrate within a short time period (days or several years) when being exposed to water and climatic changes. This loss of strength is not reversible under normal conditions, in cohesive soils; it is possible due to changes in water content. Due to their geotechnical behavior, weak rocks constitute an intermediate stage between cohesive soils and hard rock; these groups are linked by geological processes as shown in Figure (1). [1]

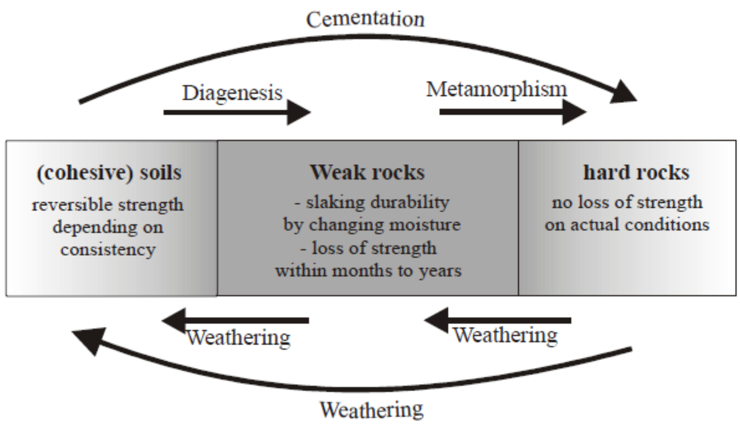


Figure (1) Position of weak rocks between cohesive soils and hard rocks.

The slake - durability Index is one of the important test, to evaluate the weak rock. This parameter is used for planning and stability analysis of structures in or on these rocks. In order to measure this parameter, the slake durability test is proposed. The slake - durability test is a test that measures the resistance of a rock sample to weakening resulting from a cycle of drying and wetting. The slake - durability test is regarded as a simple test for assessing the influence of weathering of rock. The test has been standardized by the ISRM. [2]

The slake Durability test was calculated as a percentage ratio of the amount of selected rock remaining after each cycle to the initial dry sample weight. Many studies on slaking mechanisms have been done (Terzaghi and Peck 1967, Taylor and Spears, 1970, Vallejo et. al. 1993). (2002)[3]. Agustawijaya, D. S., (2004) modeled the mechanisms in the slake-durability test for weak rocks. The results show that the slake-durability Index of weak rocks was influenced by degree of weathering and shape of the sample used [2]. While Fuenkajorn, K. (2011) give an experimental assessment of long-term durability of some weak rocks to predict the influence of the weathering process (simulated by wetting and drying and heating and cooling) on the durability and strength of volcanic, metamorphic and sedimentary rocks outcropping in eastern Thailand [4]. Moradian, Z. A. et al. (2010) predict Slake Durability Index of soft sandstone using indirect tests. The statistical regression modeling technique was used to evaluate the relationship between the slake - durability Index and other parameters as P-wave velocity, density, porosity, and uniaxial compressive strength. [5]

In this work, index, mechanical properties, and the decrease of strength and weight loss over time due to weathering processes are investigated for some weak rocks selected from different locations within Nineveh. Samples will be subjected to cycles using of slake-durability approaches, effect of distilled water and a solution containing solute hydrochloric acid with 10% and 5% concentration will be studied also.

MATERIALS AND METHODS

Rock samples used in this research were taken from four locations within Nineveh governorate: Baghdad street, Talafar, Hay-AL-Quds and Hay-AL-Araby from depth ranges between 2-7 m. All tests were carried out under dry and wet conditions after drying the samples at temperature 110^{o}C. Samples were prepared for testing according to American Society for Testing Materials (ASTM) and International Society for Rock Mechanic (ISRM):

Physical tests included: dry density and rate of absorption,

$$\boldsymbol{dry\ density\ (\gamma d)} = \frac{\boldsymbol{Ws}}{\boldsymbol{V}} \qquad \dots (1)$$

$$\boldsymbol{Abs}\ \% = \left(\frac{\boldsymbol{W1 - W0}}{\boldsymbol{W0}}\right) * \boldsymbol{100} \qquad \dots (2)$$

Where:

Ws: solid weight of specimen, V: volume of specimen, Abs(%) : absorption, Wo : weight of dried specimen (gm) at 105 C^{o} after 24 hours, W1 : weight of dried specimen (gm) in addition to the water absorbed for one week.

while the mechanical tests included:

1. Uniaxial compression test: the samples used in this test were cylindrical and it prepared by core cylindrical samples of 112 × 55 mm length and diameters to achieve the ratio (L/D=2). Samples were taken perpendicular to the stratification of the rock. Test was carried out with a loading rate of 0.75 N/mm^{2}/Sec, so that the failure occurs during (5-10 min). [7]

$$\boldsymbol{\sigma c = \frac{P}{A}} \quad \dots (3)$$

Where:

σc: Uniaxial compression strength (N/mm^2), P: Applied load at failure (N), A: Specimen cross sectional area (mm^2).

Brazilian test: the objective of this test is to measure the Uniaxial tensile strength of rock samples indirectly. In this test samples were prepared by taking a core direction parallel to the stratification of the rock mass. The dimension of the samples in diameter 55 mm and thickness 25 mm to achieve the ratio (L/D=0. 5). The load was applied perpendicular to the sample with a rate of 200 N/Sec. [8]

$$\boldsymbol{\sigma t = \frac{2P}{\pi d t}} \quad \dots (4)$$

Where:

σt: Tensile strength(N/mm^2), P: Applied load at failure (N), d: Specimen diameter (mm), t: Specimen thickness (mm).

2. Point load index test: it is a quick and simple test to conduct where the rock sample can be cylindrical or even irregular shaped. Here, cylindrical samples were prepared as same as to Brazilian test but the length of the samples 8.4 cm to achieve the ratio (L/D=1. 5). [9]

$$\boldsymbol{Is = \frac{p}{D^2}} \quad \dots (5)$$

Where:

Is: Point load strength index (N/mm^2), P: Applied load at failure (N), d: Specimen diameter (mm).

3. Slake-durability index test: the slake durability test is useful in determining the disintegration nature of the rocks when it is subjected to drying and wetting conditions. This test properly defines the weathering behavior of rocks. A drum of 100 mm in length and 140 mm in diameter is rotated, at 20 rounds per minute. The drum is made of a 2×2 mm mesh. A 10 pieces of about 500 g of rock were used. After rotation for 10 minutes, the percent of rock retained inside the drum, on a dry weight basis, is reported as the slake durability index. [10]

$$\textbf{\% Slake} = (\Delta w / w_0) \times 100 \quad \dots (6)$$

Where:

ΔW: Weight loss of specimen (gm), W_o: weight of specimen (gm)

The liquids used in this test were distilled water and the solute hydrochloric acid with 10%, and 5% concentration, used for several cycles. After completing the slake-durability testing, the samples were dried out without washing it in order to keep the salts crystals in rock so as to find out the effect of this condition on the rock samples. Finally, samples were tested by point load test to establish the strength index of slaked rocks.

RESULTS AND DISCUSSION

The results of the dry density and absorption for the selected four rock samples were presented in Table (1). The dry density values are in the range of (1.882 to 1.905).

Table (1) Dry density and absorption values for the selected four rock samples.

Rock types	Dry density g/cm^3	Std. Dev.	Absorption (%)
Baghdad street	1.882	0.19	9.4
Talafar	1.865	0.11	10.7
Hay-AL-Quds	1.904	0.05	13.2
Hay-AL-Araby	1.905	0.16	-

The rate of absorption varied between (9.4 to 13.2%) due to the difference in the proportion of porosity of the rocks. The result of the Uniaxial compression test is shown in Table (2). The highest values in both dry and wet cases for the selected rock samples are from Baghdad street location, while the lowest values obtained of the selected rock samples taken from Hay-AL-Quds. Also, it should be pointed out that no samples could be obtained from Hay-AL-Araby due its weakness.

Table (2) Uniaxial compression tests results of dry and wet samples.

Rock Type	Uniaxial Compressive Strength σ_c N/mm^2		Strength reduction% due to wetting
	Dry	Wet	
Baghdad street	13.77	6.20	54.9%
Talafar	11.47	3.81	66.7%
Hay-AL-Quds	9.41	1.44	84.6%
Hay-AL-Araby	-	-	-

The results of the rate of decrease in the strength due to wetting are indicated in Table (2), the percentage of decrease in uniaxial compressive strength ranges between (54.9% - 84.6%). The higher reduction was indicated for Hay-AL-Quds and it is corresponding to the high absorption value of this rock compared with other samples. The absorption percentage might depend on the rate of porosity, so it increases with the porosity increase.

Correspondingly, rocks could be classified as weak – very weak depending on the comparison between the obtained results and that from the classification suggested by Franklin & Dusseault (1989), and Attewell & Framer (1976) respectively see Tables (3 and 4). [11] [12]

Table (3) Classification of rocks according to Franklin & Dusseault (1989). [11]

Uniaxial Comp. Strength (σ_c) N/mm^2	Classification
$\sigma_c \leq 2$	Extremely weak
$2 \leq \sigma_c \leq 6$	Very weak
$6 \leq \sigma_c \leq 20$	Weak
$20 \leq \sigma_c \leq 60$	Medium strong
$60 \leq \sigma_c \leq 200$	Very strong
$\sigma_c > 200$	Extremely strong

Table (4) Classification of rocks according to Uniaxial compressive strength, Attewell & Framer (1976) seen in Ref.12.

Strength Range (N/mm^2)	Strength Classification
10-20	Very weak
20-40	Weak
40-80	Medium strong
80-160	Strong
160-320	Very strong

Similar results for Brazilian and Point load tests can be presented as in Tables (5, and 6). The highest values for these tests in both dry and wet cases for the selected rock samples are for samples obtained from Baghdad Street, while the lower values obtained of the selected rock samples taken from Hay-AL-Quds, in both wet and dry cases. It could be noted that the rate of decrease of resistance varied between (69.4% -89.7%) for Brazilian test and (62.5% -91.1%) for Point load.

Table (5) Test results Brazilian test of dry and wet samples.

Rock Type	Tensile Strength, Brazilian σ_t N/mm^2		Strength reduction% due to wetting
	Dry	Wet	
Baghdad street	1.70	0.52	69.4%
Talafar	1.35	0.385	71.4%
Hay-AL-Quds	1.17	0.12	89.7%

Table (6) Test results Point load testing of dry and wet samples.

Rock Type	Point load index Is N/mm^2		Strength reduction% due to wetting
	Dry	Wet	
Baghdad street	1.60	0.60	62.5%
Talafar	1.30	0.36	72.3%

Hay-AL-Quds	1.13	0.10	91.1%

The results of conversion factors (K) are obtained for the selected rock samples in Table (7 and 8) for Uniaxial compression and Brazilian tests. It can be noticed that the values of conversion factor in dry condition varied between (8.8 to 8.3) and for wet condition varied (10.3 to 14.1). Also for Brazilian test the values of conversion factor in dry condition varied (1.03 to 1.06) and for wet condition varied (0.86 to 1.2).

Table (7) Conversion Factors obtain from Uniaxial Compression test.

Rock Type	Uniaxial Compressive Strength σ_c N/mm^2		Point load index Is N/mm^2		Conversion Factor $k=\sigma_c$/ Is	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
Baghdad street	13.77	6.20	1.60	0.60	8.6	10.3
Talafar	11.47	3.81	1.30	0.36	8.8	10.5
Hay-AL-Quds	9.41	1.44	1.13	0.10	8.3	14.1

Table (8) Conversion Factors obtain from Brazilian test.

Rock Type	Tensile Strength, Brazilian σ_t N/mm^2		Point load index Is N/mm^2		Conversion Factor $k=\sigma_t$/ Is	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
Baghdad street	1.70	0.52	1.60	0.60	1.06	0.86
Talafar	1.35	0.385	1.30	0.36	1.03	1.06
Hay-AL-Quds	1.17	0.12	1.13	0.10	1.04	1.20

Results of slake-durability test are presented in Table (9). In this table, the slake durability index I_d varied from 22.4% to 88.1% after three cycles, showing an index decrease of 66%. Similar results were also obtained and presented in table (11) from the test using solute containing hydrochloric acid with 10%, and 5% concentrations.

Table (9) Slake-Durability index I_d testing results of the rock samples using distilled water.

Rock Type	Slake-Durability index I_d for distilled Water		
	Cycle1	Cycle2	Cycle3
Baghdad street	96.5%	91.9%	88.1%
Talafar	94.9%	90.3%	85.7%
Hay-AL-Quds	81.4%	48.2%	29.8%
Hay-AL-Araby	85.3%	45.5%	22.4%

It is worth mentioning that the highest index values of slack-durability was measured in the rock samples taken from Baghdad street and a similar result for

Talafar rock samples, while lower index values were obtained for Hay-AL- Araby. The decrease in these values seems to be due to an increase in the degree of rock weathering. Rock Samples can be classified as medium to high durability for Baghdad street and Talafar samples, and low durability for Hay-AL-Quds and Hay-AL-Araby samples based on the slaking-durability classifications after two cycles-10 minute, Gamble (1981). [13]

Table (10) Classification of rocks based on the staking-durability, Gamble (1981), seen in Ref.13.

Group Name	%Retained After one Cycle-10 Minute (Dry Weight Basis)	%Retained After Two Cycle-10 Minute (Dry Weight Basis)
Very high durability	➢ 99	➢ 98
High durability	98 – 99	95 – 98
Medium high durability	95 – 98	85 – 95
Medium durability	85 – 95	60 – 85
Low durability	60 – 85	30 – 60
Very low durability	< 60	< 60

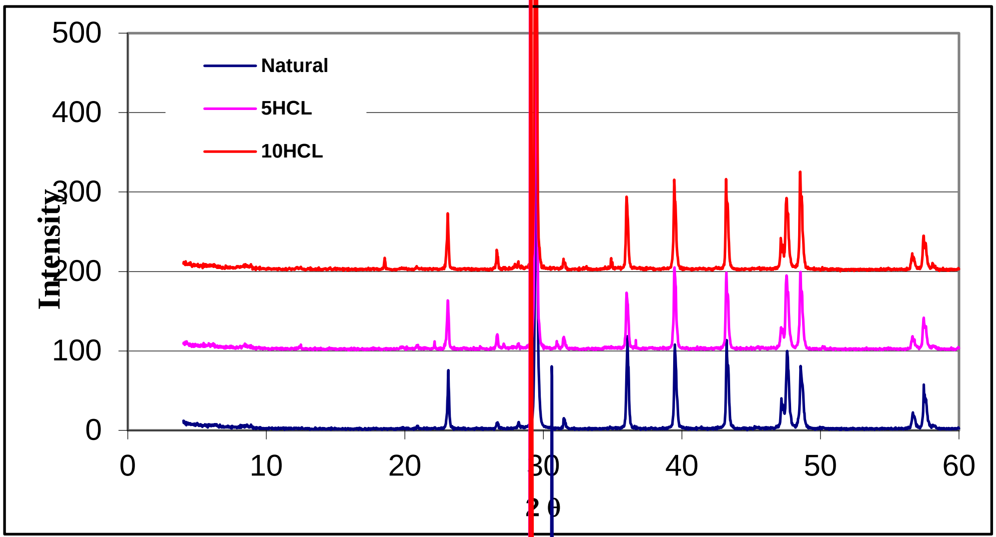
Table (11) Slake-Durability index I_d results of the rocks using solute hydrochloric acid with 10%, and 5% concentrations.

Rock Type	Slake-Durability index I_d for Solute hydrochloric acid with 5% concentration					
	Cycle1	Cycle2	Cycle3	Cycle4	Cycle5	Cycle6
Baghdad street	91.4%	87.9%	86.9%	72.3%	68.7%	64.6%
Talafar	89.3%	87.6%	84.9%	70.3%	68.5%	68.2%

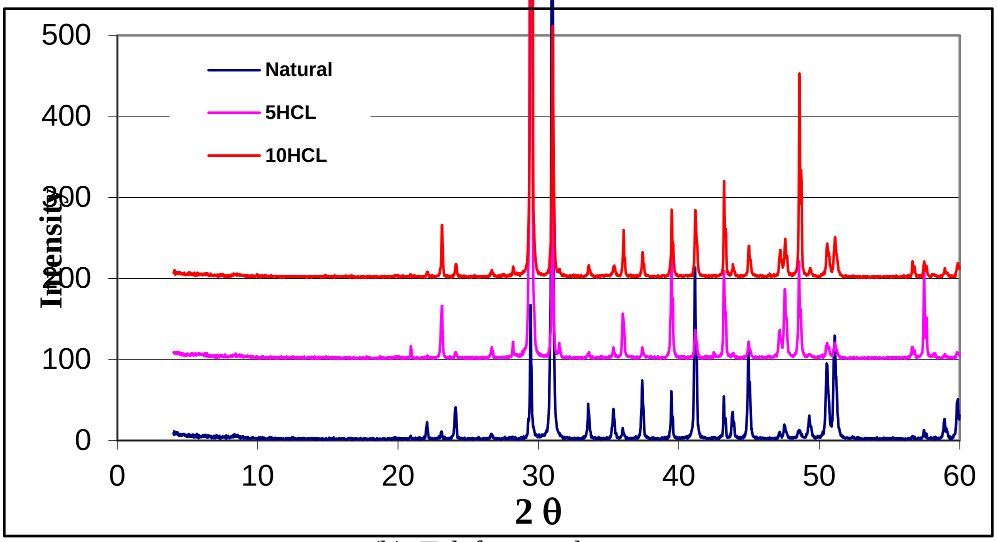
Rock Type	Slake-Durability index I_d for Solute hydrochloric acid with 10% concentration					
	Cycle1	Cycle2	Cycle3	Cycle4	Cycle5	Cycle6
Baghdad street	86.6%	75.6%	73.8%	43.3%	41.6%	40.3%
Talafar	77.5%	75.4%	73.6%	39.7%	38.6%	37.8%

X-rays diffraction and pore size distribution assessment were carried out for both natural and treated rock samples to study the mineralogical and physical properties of Baghdad street and Talafar samples. Results shown in Figure (2), indicate that there is a very limited effect on the treated rock samples for both Baghdad street and Talafar samples compared with natural rock samples.

Pore size distribution test presented in Figure (3), shows that generally, there is an increase in pore size of samples subjected to hydrochloric acid. Large pores between (10-100 μm) were reduced, while an increase in the smaller voids between (0.1-10 μm) was noticed for Talafar samples, While the effect is not clearly appears for Baghdad street samples except a slight decrease for total pore size.

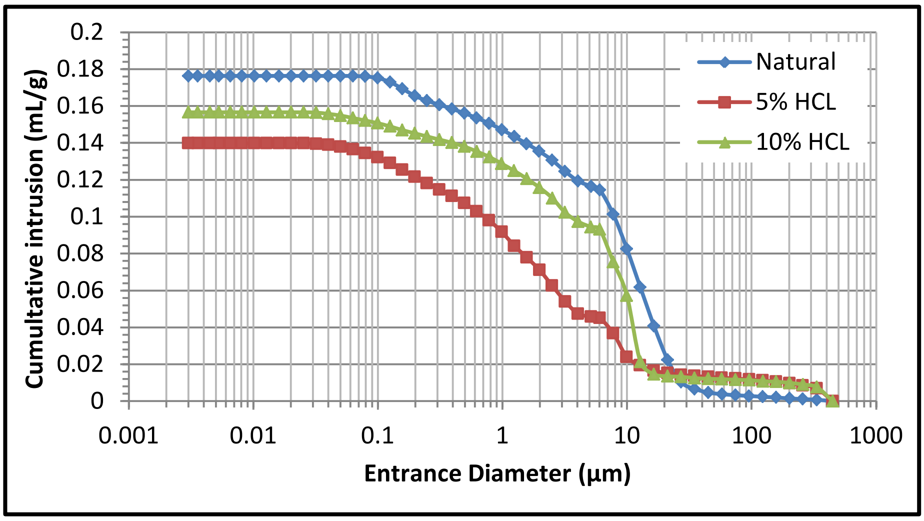


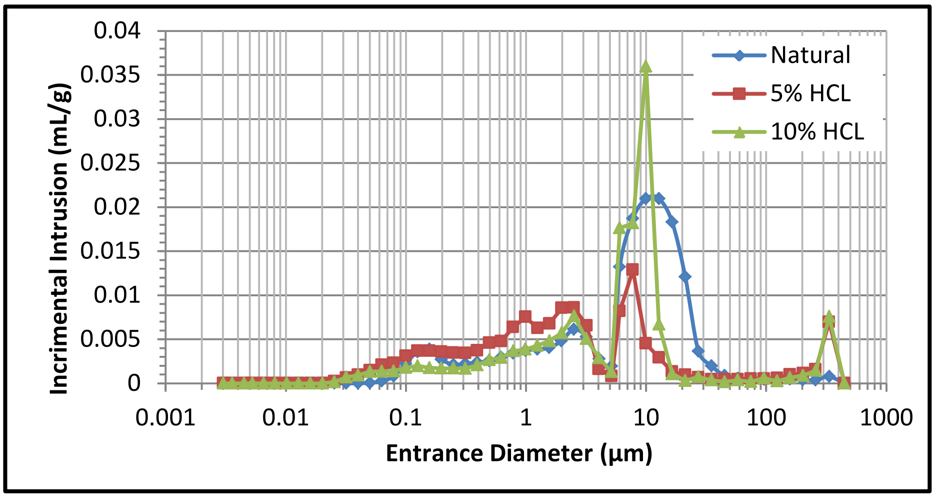
(a): Baghdad street sample



(b): Talafar sample

Figure (2) X-rays diffraction results.





(a): Baghdad street sample

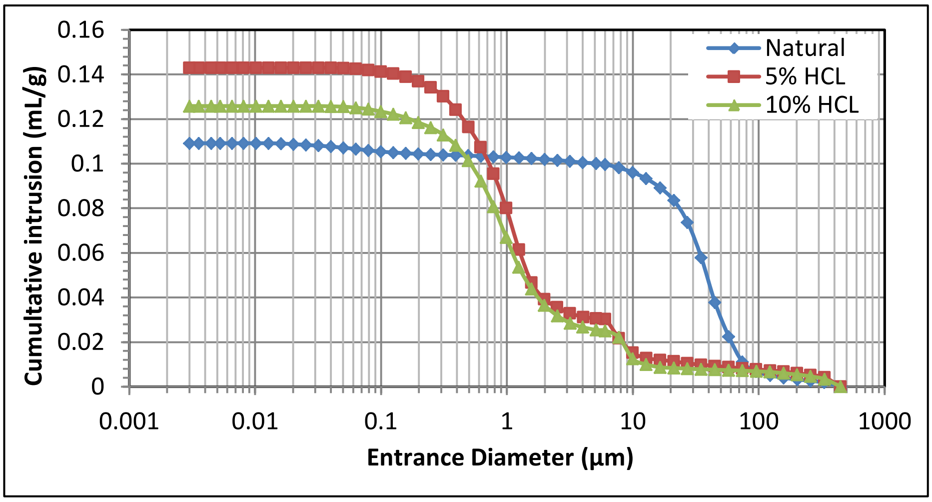
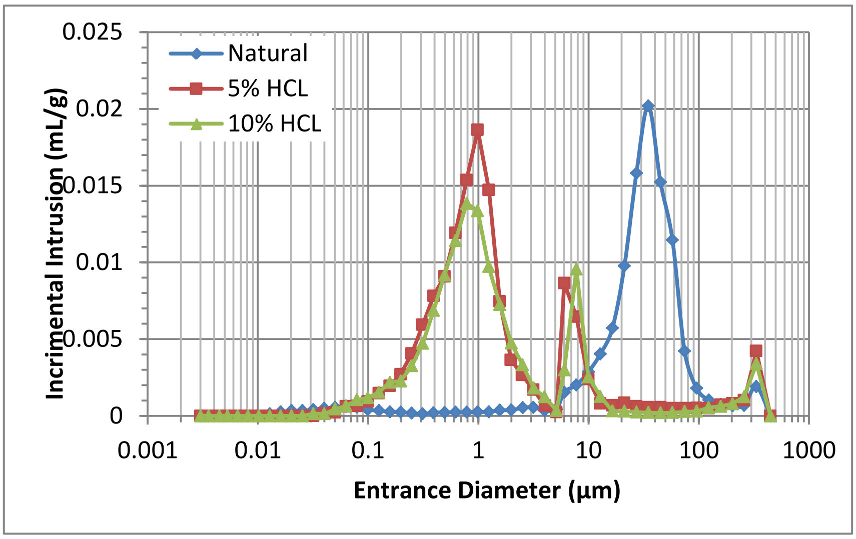


Figure (3) to be continued



(b): Talafar sample

Figure (3) Pore size distribution results.

The rate of weight loss % results plotted in Figures (4, 5, and 6), indicated that the weight loss increase with the number of slake-durability cycles using distilled water and also using solute containing hydrochloric acid. From the figures, it can be noted that the rock samples taken from Hay-AL-Quds and Hay-AL-Araby are more influenced than the rock samples taken from Baghdad street and Talafar locations. a higher effect was noted when using a solute containing hydrochloric acid with 10% if it compared with the same samples treated with distilled water Baghdad street and Talafar locations.

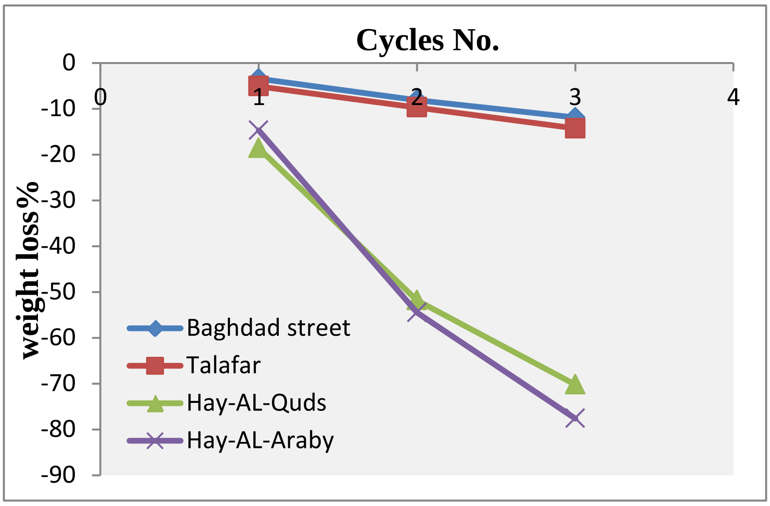


Figure (4) Relation between weight loss% and cycles No. using distilled water.

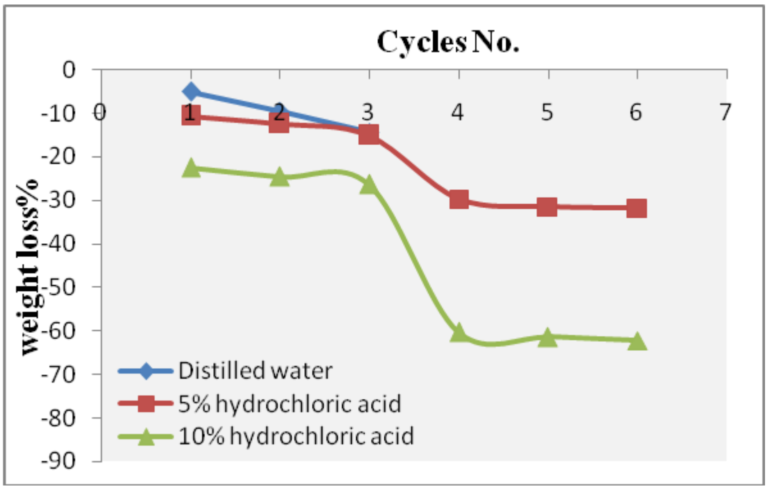


Figure (5) Relation between weight loss% and cycles No. for Talafar.

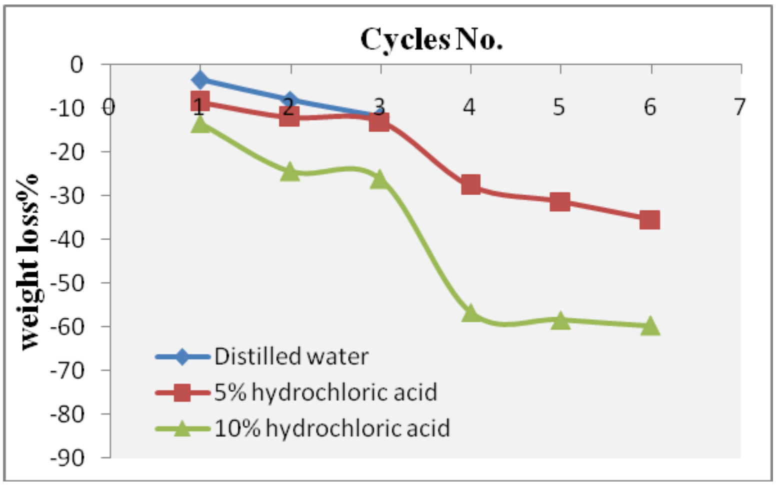


Figure (6) Relation between weight loss% and cycles No. for Baghdad street.

The point load index has been found for irregular shape samples according to ASTM 1995 at dry state after a number of cycles of slack-durability to determine the change in strength and its effect on the rock samples.

The relation between Point Load Index and percent of solute hydrochloric acid concentrations is shown in Figure (7). Results indicated that the strength of rock samples decreases with increasing the number of slake-durability cycles. The amount of decrease in the strength for samples taken from Talafar is greater than Baghdad street samples after three cycles when treated with solute containing hydrochloric acid. Maximum reduction is noted for samples treated with10% concentration.

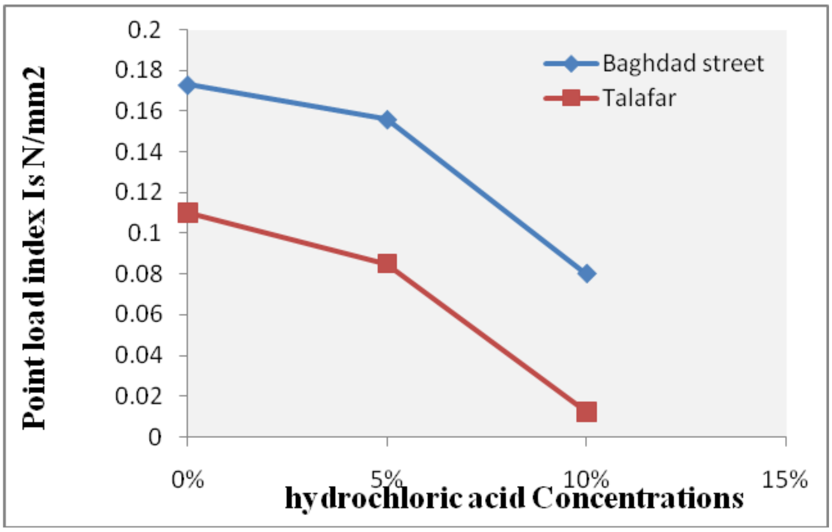


Figure (7) Relation between Point Load Index and hydrochloric acid Concentrations.

CONCLUSIONS

1. Increase the amount of weight loss of rock samples with increasing the number of slaking-durability cycles.
2. Low resistance of rock to weathering with increasing the number of slaking-durability cycles using solute containing hydrochloric acid with 10% than using 5% concentrations.
3. Decrease in the point load strength for rock samples generally with increasing the number of slaking-durability cycles (wetting and drying) under the solute containing hydrochloric acid with 10% than using 5% concentrations.

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