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Effect of Freezing-Thawing Cycles on the Physical and Mechanical Properties of Some Sedimentary Rocks Located Near Mosul City

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Abstract

This study is aimed to investigate the surfacial deterioration of some common sedimentary rocks near Mosul city as a result of freezing-thawing cycles on physical and mechanical properties of two types of Limestone denoted as (L1 and L2), Sandstone (S) and Mosul Marble (M). Physical and mechanical tests include; uniaxial, triaxial compression tests, point load test and the indirect tensile strength (Brazilian test) have been performed on both the fresh specimens and the specimens subjected to a number of freezing-thawing cycles (5, 10, 15 and 20). Test results showed that the freezing and thawing is a process of physical deterioration, a significant reduction in different percentages in uniaxial and triaxial compressive and tensile strength was observed in all the rocks tested. A little variation was observed in the slaking durability indices (IS-D) of (L1, L2 and M) rocks among three conducted cycles at fresh state, while (S) rock showed high percent loss of about 45.81% in its durability. On the other hand, the water absorption percent of the tested rocks showed a clear increase with the increase of number of freezing-thawing cycles.

Keywords: freezing- thawing cycles , deterioration, durability, sedimentary rocks.

تأثير دورات الإنجماد والذوبان على الخواص الفيزيائية والميكانيكية لبعض الصخور الرسوبية الواقعة بالقرب من مدينة الموصل

الخلاصة

إن الهدف من هذا البحث هو دراسة خاصية التآكل والتداعي لبعض أنواع الصخور الرسوبية الشائعة بالقرب من مدينة الموصل. تم اختيار نوعين من صخور الحجر الجيري نوع (L1 and L2) مع صخور الحجر الرملي(S) بالإضافة إلى صخور مرمر الموصل (M) وذلك لإيجاد تأثير خاصية الإنجماد والذوبان على خصائص الإنجماد والذوبان على عدد من الدورات (5، 10، 15، 20) على خصائصها الميكانيكية والفيزيائية من خلال الفحوصات الخاصة بالانضغاط الأحادي والثلاثي المحاور، فحص التحميل النقطي وقوة الشد غير المباشر (الطريقة البرازيلية) بالإضافة إلى تأثير الإنجماد والذوبان على خصائص التآكل ونسبة التشبع المائي للصخور. أظهرت الدراسة بان خاصية الإنجماد والذوبان للدورات المستمرة هي عملية تدهور فيزيائية مهمة تعمل على إضعاف قوة تحمل الصخور موضوع الدراسة في كلا حالتي الضغط (أحادي وثلاثي المحاور) والشد وبنسب مختلفة تعتمد على نوع الصخور التي فحصت وخصائصها الفيزيائية والهيكلية. كما بينت فحوصات التدهور والديمومة ولثلاث دورات بان تأثيرها قليل على الصخور نوع (L1, L2 and M) بينما كانت نسبة التآكل والتدهور لصخور الحجر الرملي عالية وبحدود 45.81% مقارنة بالصخور الغير متعرضة لدورات الإنجماد والذوبان. كما أظهرت النتائج زيادة نسبة امتصاص الماء بزيادة دورات الإنجماد والذوبان لكافة النماذج الصخرية قيد الدراسة.

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Introduction

The sedimentary rocks is considered as the most popular types in engineering constructions, it faces the civil engineer as a foundation rock, building stone and in facing works. These rocks make up about 90% of the Iraq surface rocks [1]. Durability is an important rock characteristic controlling the stability of natural and artificial slopes [2]. The slaking behavior of a rock is a crucial factor that plays a major role in its failure [3], like wise, freezing-thawing has enormous effect on the rock strength if it undergoes cycles of freezing during winter and thawing during spring. Many geoenviromental problems such as slope failures, slope deterioration, ground subsidence … etc, are associated with the natural processes of ground freezing and thawing [4], The cyclic freezing-thawing test simulates environmental loading/unloading conditions similar to these processes.

Several studies concerning the effect of weathering on the engineering properties of rocks were done. [5, 6, 7 and 8] revealed that weathering is an important processes for the strength effect on the rocks. [9] carried out durability tests and evaluation of sub-zero temperature effects to some argillaceous clastic rocks, the slaking tests were performed on all samples in pure water. The results reveal that the slaking index of a rock having low porosity is found higher than that of a rock with high porosity except in the case of fractured and cracked schist from Japan.

The property of freeze-thawing durability is one of the several Engineering properties which are conducted on five types of rocks and were examined by [10], to determine the commonly specified engineering property values for rock fill applications in highway construction. The Freeze-thawing tests were conducted through working of [11], who made a statistically comparison of the results of many durability tests on Ontario's Paleozoic shales which included freezing-thawing, adsorption, slake durability test, density and abrasion, to arrive at a multivariate model of shale durability. The degree of slaking after three slaking cycles is given by the expression:

Slake loss = -12.0 + 0.5$\times$ (12 cycle freeze-thaw loss)
+ 4.49 $\times$ (45% relative humidity water adsorption)
- 21.2 $\times$ (dry abrasion),
with a coefficient of correlation
$R = 0.921$

Therefore in this study comprehensive tests of different sedimentary rocks namely: limestone, sandstone and Mosul marble under sub-zero temperature condition are essential, on investigation regarding the slake durability and the cyclic effect of temperature variations on the rock strength in its triaxial and uniaxial compression, indirect tension (Brazilian test) and point load tests were carried out. Such studies are considered useful to assess rocks for various application namely; dam constructions, suitability of rocks as riprap material, slope stability analysis … etc.

2. Description of Rocks

The district of Mosul is situated on the folded zone of the Iraqi topography. The greater part of the city is situated on the lower Fars Formation and partly on the Upper Fars Formation (Miocene). The Lower Fars Formation consists of alternating sedimentary cycles of succession layers of anhydrite, gypsum, and limestone [12].

2.1 Limestone

Two types of limestone rocks were selected in this study, the first , denoted as (L1) is brought from district at Aski Mosul quarry, (town of about 45 km to the Northern-West of Mosul city). The second type, denoted as (L2) taken from district at Ain Ghahish, (village 40 km to the Southern-West of Mosul city). Both limestone types were considered from Miocene Age [12]. It is worth mentioning that limestone type (L1) is characterized as more fossiliferous than the limestone type (L2). Block samples were taken from a depth of two-three meters from massive limestone horizon. Figure (1) shows the map of the studied locations.

2.2 Mosul Marble

In the present study the Mosul Marble (M), was brought from district at Wady AL-Kasup (village 25 km to the Southern-West of Mosul city). This type of rock is used in building construction in Mosul, for the previous 50 years when their use dwindled. It is also called the calcium sulphate rock when fresh with characteristically grayish-blue to white in colour and called locally Mosul Marble.

2.3 Sandstone

Sandstone is widely spreading in Iraq which is located stratigraphically in the most upper part of the lower Fars formation (Middle Miocene). The sandstone under study is brown colored brought from Hay-AL-Intisar (about 8 km east of Mosul center). A block of sandstone samples was cut from large bedded sandstone layer at depth of 1.5 meters.

3. Experimental Work

3.1 Specimen Preparation

Cylindrical Specimens (54.7) mm in diameter (NX-core) with length to diameter ratio of two (length=109.4mm) were cored from blocks using core drilling machine with respect to the bedding planes. The specimen ends, then lapped, polished to obtain the final measurements according to the limits recommended by ISRM [13] and ASTM [14]. The prepared specimen cores were used for the uniaxial and triaxial compression tests. However, rock specimens were prepared with diameter of (65) mm to get length to diameter ratio of (1.5) and (0.5) for point load and indirect tensile strength (Brazilian) test, respectively.

All tests were performed on the specimens at wet conditions after the end of freezing-thawing cycles to represent the natural and the freezing-thawing cyclic cases in the field.

3.2 Freezing-Thawing Test Methodology

This test method is performed to determine the effects of freezing and thawing action on the some engineering properties of the sedimentary rock and showing their resistance to deterioration.

The test rock specimens were placed in the container that contains a special solution consists of 0.5 % isopropyl alcohol/water, then the system of the container and rock specimens were placed in home freezer that satisfy a minimum temperatures of (-18 ± 2.5 ºC) for timed cycling of 16 hours of freezing. The freezing portion of the cycle will begin when the test specimens are manually placed in the freezer at the end of the workday. The test specimens must be removed from the home freezer at the beginning of the workday to begin the thawing portion of the cycle using an oven at temperature of (+32 ± 2.5 ºC) of 8 hours. The test were running continuously till reaching the required number of freezing-thawing cycle. This test were carried out according to standard testing procedure of the ASTM [15]. Figure (2) shows the schematic sketch of 1 cycle freeze-thaw test.

4. Test Procedures

In order to examine the effect of freezing-thawing test on the compression and tensile strength of the different rock specimens, many types of tests were carried out. The compression test performed including uniaxial, triaxial, and point load test. The tensile strength has been found through Brazilian test. However the slake-durability test were done to identify the durability index of the rocks according to specifications. The Sandstone rock was not included in the effect of freezing-thawing tests on their mechanical properties where some difficulties were observed in the specimens preparation

4.1 Triaxial Compression Test

This test was conducted to obtain the parameters of shear stress, deviator stress, cohesion, and angle of internal friction. The effect of (5, 10, 15 and 20 cycles) of freezing-thawing on the shear strength parameters of the three rock types was observed. The prepared cylindrical rock specimens with 54 mm in diameter and 110 mm in height were jacketed in a highly elastic rubber membrane, sealed from both ends to the hardened steel platens in the Hoek triaxial cell developed by [16]. Three different confining pressures (4, 8, and 12) MPa were applied to the specimens using triaxial fluid pressure vessel 75 MPa capacity, while the vertical stress was applied by mean of digital hydraulic compression machine 1500 kN capacity with 0.5 mm/min as the rate of axial loading to ensure specimen failure within (5-15) minutes. The test was conducted according to the procedure given by ASTM [14].

4.2 Uniaxial Compression test

The uniaxial compression test was performed according to the specifications given by ISRM [17]. The test was conducted on the prepared cylindrical specimens by using 1500 kN digital compression machine with 0.1 kN accuracy at a rate of 70 MPa/sec. The measurements of axial strain were recorded using a dial gauge with accurate to 0.01 mm per division. Both of axial stress and strain readings were recorded continuously until failure. The effect of freezing-thawing cycles on the rock strength and the shape of the stress-strain curves was observed.

4.3 Point Load Test

The point load test is used to identify the strength of rocks by using quick and simple method. It can be done in the field as well as in the lab. Rocks specimens in the form of either core, cut blocks, or irregular lumps can be tested by applying concentrated loads achieving steady increase in the load so the failure occurs within 2 to 60 seconds ASTM [18], using two hard ends steel cones, causing failure as development of tensile cracks parallel to the load axis.

The schematic diagram of the diametral test which performed is shown in Figure (3), the point load strength index was calculated using the formula:

$$Is = \frac{p}{D^2{}_{54}}$$

Where:

Is: The point load strength index, (MPa).

P: The load value at rupture, (N).

D_{54}: The specimen diameter, (mm).

4.4 Brazilian Test

Brazilian test represents the indirect method for obtaining the tensile strength of the rocks. This test was performed according to the specifications given by ASTM [19]. The circular disk rock specimens were compressed across its diameter (D=54.7mm) and according to the assumption of the uniform tensile stress generated across the diameter, the strength was calculating using the formula:

$$st = \frac{2P}{p.D.t}$$

Where:

σt: The tensile strength normal to the loaded diameter, (MPa).

P: The failure load, (N).

D: The diameter of disk specimen, (mm).

t: The thickness of disk specimen, (mm).

5. Results and Discussion

5.1 Index Properties

Four types of sedimentary rocks were considered in the present study namely, Limestone (L1, L2), Mosul Marble (M), and sandstone (S). Table (1) shows the average values of the physical properties for the studied rocks which are conducted according to the standard procedure given by ISRM [20].

As can be seen from Table (1), there is very little difference in the physical properties for rocks type (L1 and L2) which can be attributed to similarity in their internal composition. The M-rock showed low values in its specific gravity and high values in its dry density with minimum results in its porosity and absorption due to its high hardness and cohesion between its grains. Sandstone rock has high porosity (27.1%) with low dry density due to its grain geometry and high voids inter between.

On the other hand, three cycles of slaking-durability tests were performed on the four types of fresh rock used in this research. The results are typically related to the rock type and their physical features. Figure (4) presents the changes in the shape of specimens in different cycles of the test representing their differences in the slake-durability property. The Sandstone (S) shows the characteristic more roundness in edges of specimens with an increase in the number of cycles comparing with the other rock types.

5.2 Effect of Freezing-Thawing Test on the Absorption Percent

The absorption property of the studied rocks was found during the freezing-thawing cycles, the results are shown in Figure (5), and presented in Table(2). The Figure shows little increase in the absorption percent for L1 and L2 rocks, the results ranges from (6.668-9.823 %). The rock type-M showed almost constant variation in its absorption due to its low porosity value.

5.3 Effect of Freezing-Thawing Test on the Slake Durability Index

Figure (6) shows the effect of freezing-thawing cycles on the slaking-durability index after the third 10-minutes of rotation (IS-D3). The rock type-M gave little difference in the index values (97.81-96.50)%, while the other types of rocks (L1 and L2) showed more varieties (96.23-90.04)% and (97.56-93.21)% for rocks type (L1 and L2) respectively. The physical deterioration in the rock specimens in their freezing-thawing cycles caused the reduction in the slake-durability index.

5.4 Effect of Freezing-Thawing Test on the Rock Strength

The effect of this test was performed to evaluate and show the behaviors of the rocks in their compression and tension state when subjected to 5, 10, 15 and 20 cycles of freezing-thawing.

5.4.1 Triaxial Compression Test

The results of triaxial tests conducted on the three types of rock specimens (L1, L2 and M) are drawn by means of Mohre envelope for each rock type and they are presented graphically in Figures (7, 8 and 9). The specimens which were subjected to different confining pressures (4, 8 and 12 MPa) gave their shear strength parameters, cohesion force (c) and friction angle (φ) at zero, 5, 10, 15, and 20 cycles of freezing-thawing. Table (3) shows the results of this test. It can be noticed that the parameters (c and φ) decrease with the cycles, and these results can be attributed to their binding material between their grains and the friction force which affected by the continuous cycles. Again, for a given Freezing-thawing condition the shear stress parameters is high for rock type-M followed by L2 and L1 respectively, for each case studied. This could be attributed to the high dry density and lower porosity values for rock type-M comparing with Limestone rocks.

5.4.2 Uniaxial Compression Test

The effect of various cycles of freezing-thawing on the strength of the three types of rocks (M, L1 and L2) is illustrated in Figure (10). The compressive strength of the three rock types showed clear reduction compared with their natural state for all the cycles used except for the 10th cycle which showed little increase in the strength followed by continuous reduction in the strength. The continuous repletion of the freezing-thawing cycles on the rock samples affect the bond between the grains and increase their porosities so a reduction in the strength was observed.

On the other hand, the relationships between the stress and axial strain for the rock samples tested at (0, 5, 10 and 20) cycles of freezing-thawing test are shown in Figures (11, 12 and 13). As the number of cycles increases, the rock strength and failure strain will decrease, these behaviors can be explained on the basis of micro-fracturing that take place during the application of load.

5.4.3 Point Load Test

Figure (14) illustrates the relation between the cycles No. of freezing-thawing versus the point load index of the rock samples tested. A continuous reduction in their indices is inferred and that due to the attrition forces between the specimen grains created during freezing-thawing which cause to deteriorate and break the bonds easily.

5.4.4 Indirect Tensile strength

The effect of freezing-thawing cycles on the indirect tensile strength of the tested rocks represented by Brazilian test is shown in Figure (15). A continuous reduction in the strength was also observed and extended to the 20 cycles. This phenomenon can be explained as pore water freezes, it expands and exerts pressure on the rock matrix. The pore water expansion about 9% at 0^{o}C, also exerts pressure across existing fractures or initiate a new crack from ice filled pore spaces.

6. Conclusions

The durability, physical and mechanical properties under different cycles of freezing-thawing were performed on rock specimens which were brought from surrounding areas of Mosul city. The results are presented (and compared when possible).

The following conclusions can be drawn out of the study:

1. A little variation at the fresh state was observed in the durability loss for Limestone and Mosul Marble rocks type (L1, L2 and M), while Sandstone rock type (S) showed 45.8 % loss in its slake-durability and was the weakest rock.
2. The continuous increase in the number of freezing-thawing cycles on the three rock types affects the following properties:
   a. The absorption percent was increased for all rock types, where rocks type (L1 and L2) showed similar increase in range (6.66 to 9.82%), while rock type (M) showed little increase (0.15 to 0.29%).
   b. The Slake-durability index was decreased for all rock types in a range of (90.04 to 97.56%) for rocks type (L1 and L2) and (96.50 to 97.81%) for rock type (M).
   c. The shear strength parameters (cohesion force and friction angle) were reduced for all the tested rocks in the triaxial compression test.
   d. The uniaxial compression strength and the failure strain, where continuous decrease in their values were observed.
   e. The indirect tensile strength and point load strength indices for all the tested rocks showed a continuous decrease with the increase number of freezing-thawing cycles.
3. The rocks type (L1 and L2) gave almost similar behavior toward the cycles of freezing-thawing. On the other hand, the rock type-(M) have a good resistance against the freezing-thawing cycles.

7. References

[1] Thabet, K., Khattab, S. A. and Nuri, TH. M. "Geeotechnical Characteristics of Mosul Marble", Dirasat Magazine, Vol. 21B, No. 6, 1994, PP. 25-40.

[2] Dick, J. C., Shakoor, A. "Characterizing Durability of Mud Rocks for Slope Stability Purposes", Geol. Soc. of America, rev. eng. geol., Vol. X, 1995, PP. 121-130.

[3] Dhakal, G. P. et al. "Slake Durability and Mineralogical Properties of Some Pyroclastic and Sedimentary Rocks",

International Journal of Engineering Geology, Elsevier science publication, the Netherlands, Vol. 61, Issue 1, 2002, PP. 31-45.

[4] Yamabe, T. and Neaupane, K. M. "Determination of some thermo-mechanical properties of Sirahama Sandstone under Subzero Temperature Condition", International Journal of rock Mechanics and Mining Science, 38, 2001, PP. 1029-1034.

[5] Lumb, P. "Engineering Properties of fresh and Decomposed Igneous Rock From Hong Kong", Engineering geology 19, 1983, PP. 81-94.

[6] Hudec, P. P. "Rock Properties and Physical Processes of Rapid Weathering and Deterioration",8th International IAEG Congress, Balkema, Rotterdam, 1998, ISBN 90 5410 990 4, PP. 335-341.

[7] Tugrul, A. "The Effect of Weathering on Pore G/eometry and Compressive Strength of Selected rock types From Turkey", Engineering geology 75: 2004, PP. 215-227.

[8] Teepawit, S. " Effect of Weathering on Joint Shear Strength of Some Weak Rocks", M. S. Thesis, Suranaree University of Technology, Thailand, 2007.

[9] Dhakal, G. P., Kodama, J., Yoneda, T. and Neaupane, K. " Durability and Subzero Temperature Effects on Argillaceous Clastic Rocks", ISRM 2003–Technology Roadmap for Rock Mechanics, South African Institute of Mining and Metallurgy.

[10] Griffin, J. A. " Development of A Rating Classification for Rock To be Used as Toe-Bench Material", M. S. Thesis, Kent State University, 2008.

[11] Hudec, P. P. " Statistical Analysis of Shale Durability Factors", IN: Overconsolidated Clays: Shales: Transport. Res. Record 873, 1982, PP. 28-35.

[12] Al-Naqip, S. Q. and Agwn, T.A. " Sedimentelogical Study of the Calstic Units of the Lower Fars Formation", Iraqi Geoogical Journal, 26 (3). 1993, PP. 108-121.

[13] ISRM "Suggested Methods for Determining the Strength of Rock Materials in Triaxial Compression", International Journal of rock Mechanics, Mining Science, Vol. 15, No. 2, 1979, PP. 49-51.

[14] ASTM "Standard Method for Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements", ASTM Designation: D 2664-95a.

[15] ASTM "Standard Test Method for Evaluation of Durability of Rock for Erosion Control Under Freezing and Thawing

Conditions", ASTM Designation: D 5312–04.
[16] Hoek, E. and Franklin, J. A. "Simple Triaxial Cell for Field Laboratory Testing of Rock", Trans Inst Min Metall, 77, A22, 1968 (section A).
[17] ISRM "Suggested Methods for Determining the Uniaxial Compression Strength and Deformability of Rock Material", ", International Journal of rock Mechanics, Mining Science, Vol. 16, 1979, PP. 137-140.
[18] ASTM "Standard Test Method for Determination of the Point Load strength Index of Rock", ASTM Designation: D 5731-02.
[19]ASTM "Standard Test Method for Splitting Tensile Strength of Intact Rock Core ", ASTM Designation: D 3967 – 95a.
[20] ISRM "Suggested Methods for Determining Water Content Porosity Density Absorption and Related Properties", International Journal for Rock Mechanics. Min Sci., Vol. 16, 1979, PP. 143-156.

Table (1) Physical properties of the studied rocks

Rock Type	Specific gravity (Gs)			Dry density (g/cm^3)			Porosity (%)			Absorption (%)		
	Value	Mean	Std. Dev.	Value	Mean	Std. Dev.	Value	Mean	Std. Dev.	Value	Mean	Std. Dev.
L1-1	2.631	2.626	0.017	2.113	2.096	0.016	19.68	20.39	0.608	7.723	7.018	0.550
L1-2	2.604			2.075			20.31			6.948		
L1-3	2.645			2.085			21.17			6.382		
L2-1	2.732	2.675	0.053	2.216	2.181	0.035	18.89	18.45	0.324	5.321	6.668	0.955
L2-2	2.688			2.195			18.34			7.252		
L2-3	2.604			2.132			18.12			7.431		
M-1	2.354	2.353	0.013	2.255	2.240	0.011	4.21	4.81	0.758	---	0.106	0.090
M-2	2.369			2.230			5.87			0.099		
M-3	2.336			2.235			4.32			0.220		
S1	2.631	2.581	0.051	1.894	1.880	0.044	28.01	27.16	0.879	11.66	12.77	1.043
S2	2.511			1.820			27.52			12.50		
S3	2.601			1.926			25.95			14.17		

Table (2) Effect of freezing-thawing test on absorption percent

No. of cycles	Average Absorption Percent (%)		
	M	L1	L2
Fresh rock	0.159	7.017	6.668
5	0.042	8.215	7.322
10	0.268	8.696	8.086
15	0.276	9.766	9.122
20	0.290	9.823	9.264

Table (3) Triaxial test results of rocks with different freezing-thawing cycles

Rock Type	Axial Stress σ1, (MPa)	Confining Pressure σ3, (MPa)	Deviator Stress (σ1- σ3), (MPa)	Cohesion c, (kN/m^2)	Friction Angle φ
Fresh rock					
M	47.2 58.3 71.9	4 8 12	43.2 50.3 59.9	9.5	30.5
L1	35.1 47.3` 58.8	4 8 12	31.1 39.3 46.8	6.8	29
L2	39.7 53.2 67.0	4 8 12	35.7 45.2 55.0	7.6	30
Cycle No. 5					
M	40.8 49.7 61.9	4 8 12	36.8 41.7 49.9	9.1	28
L1	32.0 41.8 52.1	4 8 12	28.0 33.8 40.1	6.4	25.5
L2	37.0 49.2 60.8	4 8 12	33.0 41.2 48.8	6.6	29.5
Cycle No. 10					
M	33.0 42.4 54.8	4 8 12	29.0 34.5 42.8	6.8	26.0
L1	28.2 38.0 45.6	4 8 12	24.2 30.0 33.6	5.9	23.0
L2	35.3 44.4 58.1	4 8 12	31.3 36.4 46.1	6.4	29.0
Cycle No. 15					
M	29.2 37.5 47.0	4 8 12	25.2 29.5 35.0	6.4	23.0
L1	25.2 34.3 42.3	4 8 12	21.2 26.3 30.3	5.4	22.0

L2	30.7 41.3 51.2	4 8 12	26.7 33.3 39.2	6.1	27.5
Cycle NO. 20					
M	25.4 33.8 41.0	4 8 12	21.4 25.8 29.0	5.8	20.0
L1	22.0 30.4 39.7	4 8 12	18.0 22.4 27.7	5.1	21.0
L2	31.8 40.2 49.2	4 8 12	27.8 32.2 37.2	6.0	26.0

Figure (1) Location Map of the Studied Area

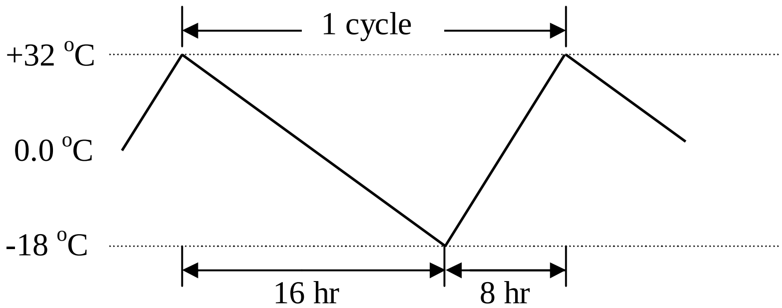

Figure (2) Schematic sketch of 1 cycle freeze-thaw test

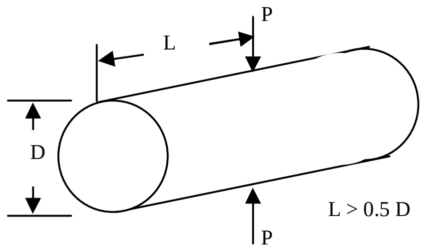

Figure (3), Specimen dimension in the point load test

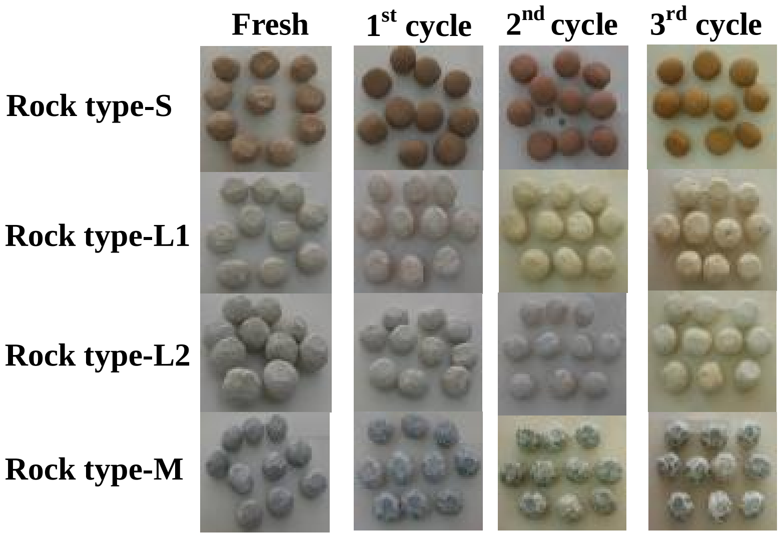

Figure (4) Changes in Shape of Specimens During Slaking Durability Test

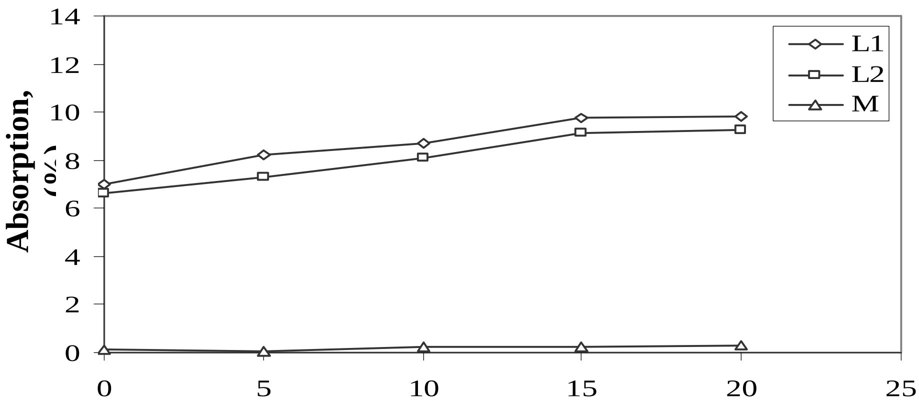

Figure (5) Effect of Freezing-Thawing Cycles on the Absorption Percent of the Studied Rocks

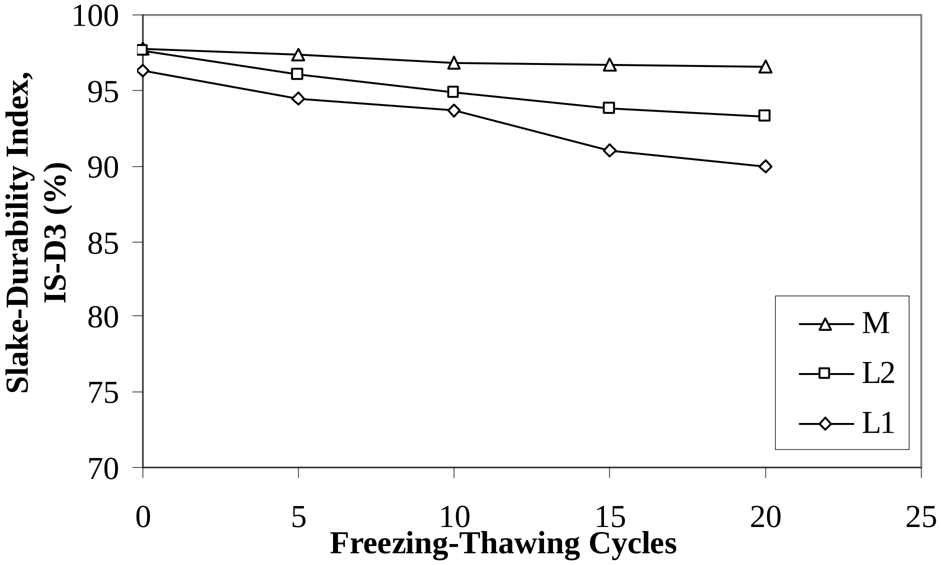

Figure (6) Effect of Freezing-Thawing Cycles on the Slake-Durability Index of the Studied Rocks

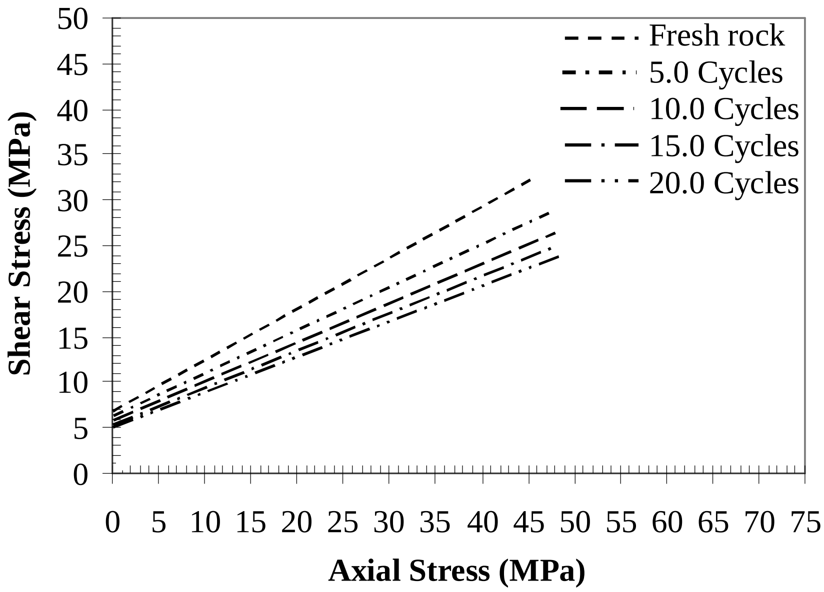

Figure (7) Mohre Envelope for Rock Type (L1) from Triaxial Test at Various Freezing-Thawing Cycles

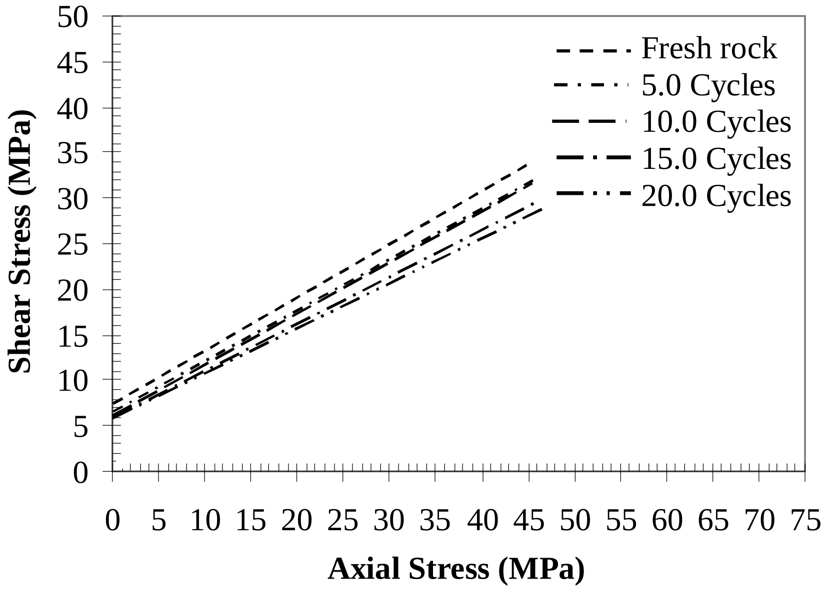

Figure (8) Mohre Envelope for Rock Type (L2) from Triaxial Test at Various Freezing-Thawing Cycles

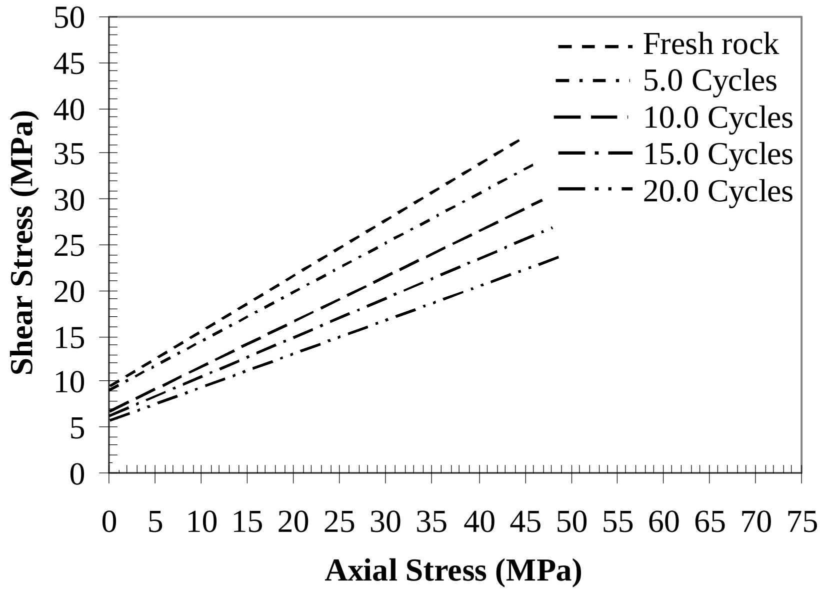

Figure (9) Mohre Envelope for Rock Type (M) from Triaxial Test at Various Freezing-Thawing Cycles

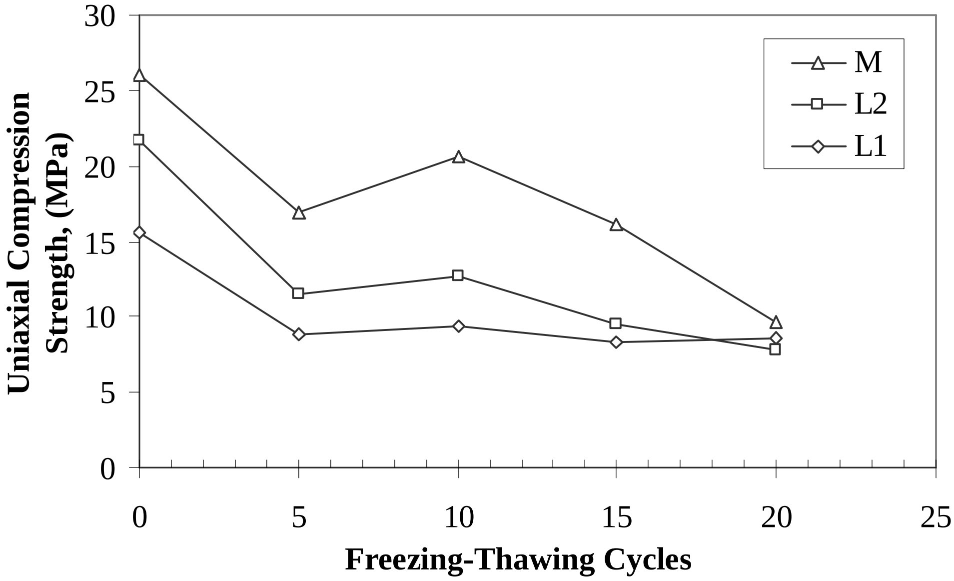

Figure (10) Effect of Freezing-Thawing Cycles on the Uniaxial Compression Strength of the Studies Rocks

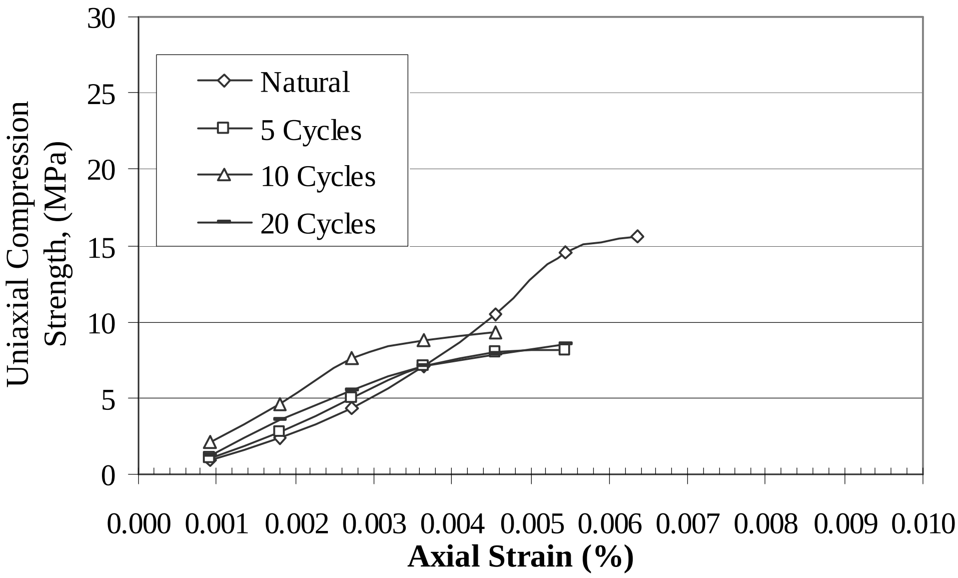

Figure (11) Effect of Freezing-Thawing Cycles on Stress-Strain Curves for Rock Type (L1)

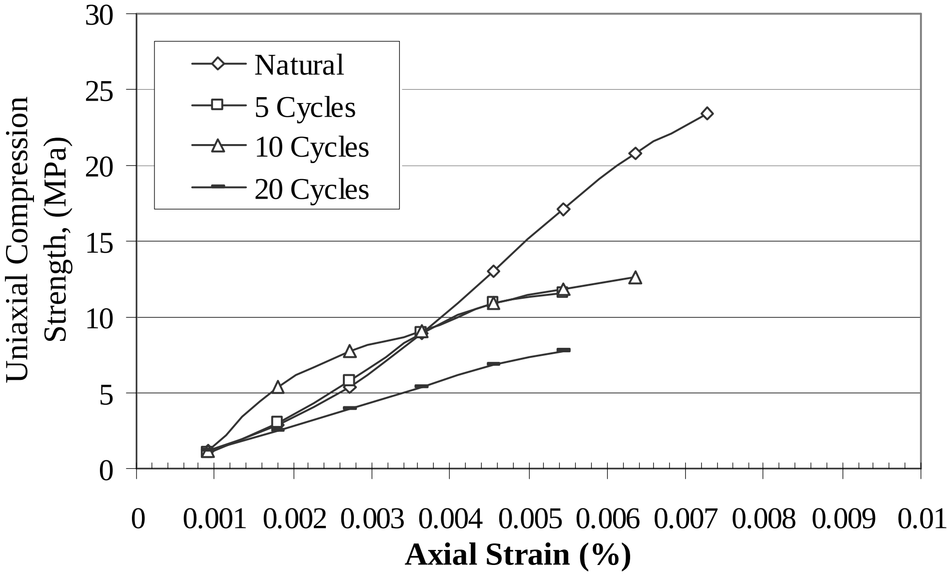

Figure (12) Effect of Freezing-Thawing Cycles on Stress-Strain Curves for Rock Type (L2)

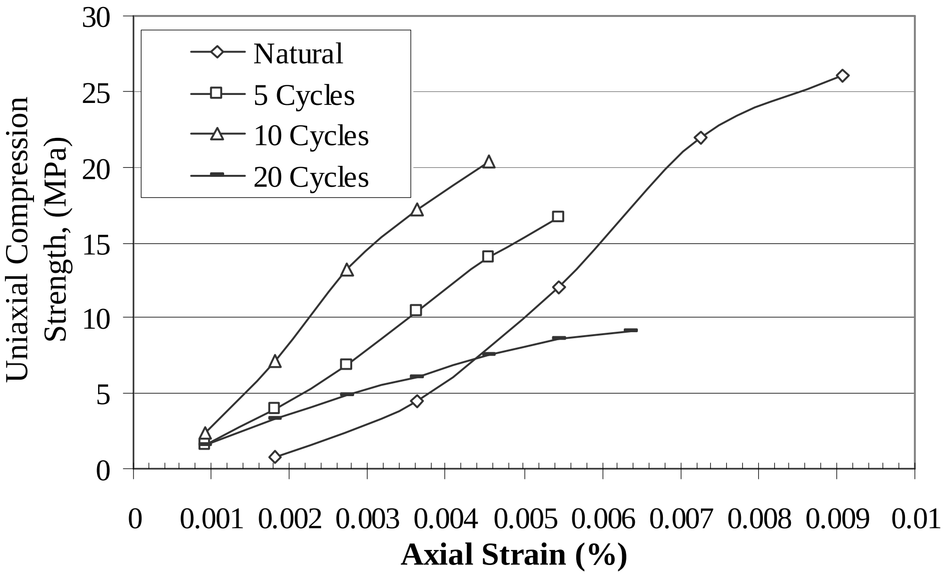

Figure (13) Effect of Freezing-Thawing Cycles on Stress-Strain Curves for Rock Type (M)

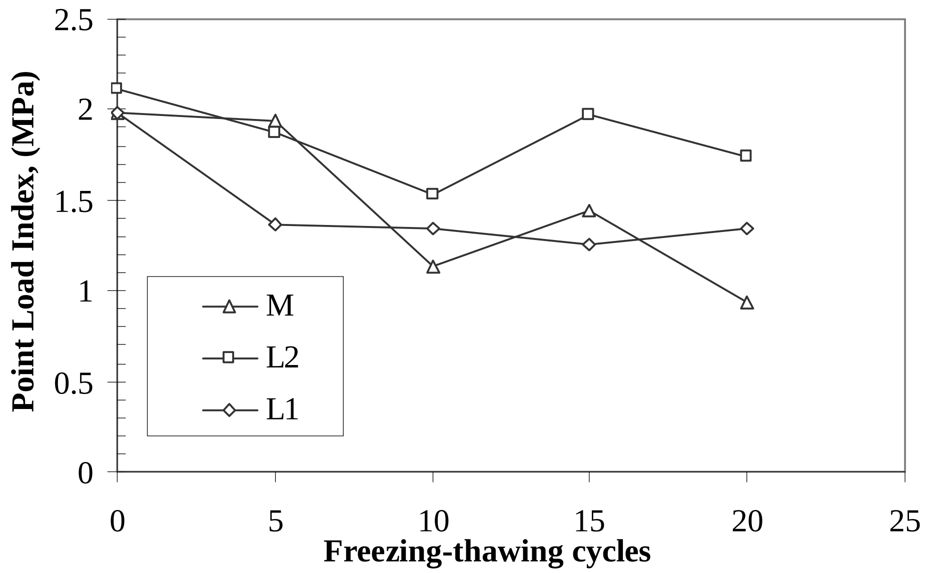

Figure (14) Effect of Freezing-Thawing Cycles on the Point Load Strength Index of the Studied Rock

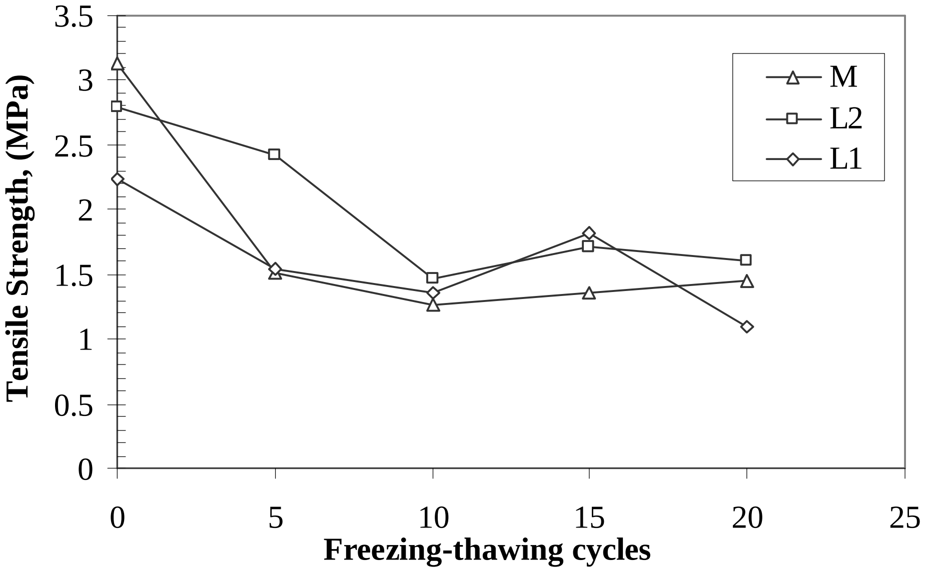

Figure (15) Effect of Freezing-Thawing Cycles on the Tensile Strength of the Studied Rocks