Durability & Strength of Limestone Used in Building

Suhail Idrees . A. Khattab — Prof.
Hadeel Mohammed S. Othman — MSc. Student
University of Mosul-College of Engineering

Abstract

The deterioration of limestone rocks selected from three quarries in Mosul city (Baathra, Baghdad street & AL-Warshan), due to different liquids movement inside the pore network was studied. The durability was examined using slake-durability apparatus through wetting _ drying cycles. These cycles induce dissolution, recrystallization and lead to the deterioration of this stone, and finally its effect on the strength of these rocks . Some engineering properties for rocks were studied too. The results showed a clear variation in the properties of limestone between three quarries and within each quarry. The studied Rocks have been classified into two types (weak & strong) according to the properties of these rocks. The results indicated that the rocks subjected to the durability test causes an increases of weight loss, reached to (7.0-14.0%). This test causes also a reduction of strength about (15-25%) for these rocks when treated with distilled water after 10 cycles. In the other hand, differ this range when the specimens rocks were treated with salt solution. This is attributed to variance amount of salt precipitate inside porous stones, due to the various in porosity values for these rocks. Also, the wetting/drying cycles leads to increase in weight loss for specimens due to increase of dissolution/ recrystallization of salts, which apply stress on the wall of porous stones and lead to a weight and strength reduction of the rocks.

متانة وديمومة أحجار البناء الكلسية المستخدمة في البناء

سهيل إدريس خطاب — أستاذ
هديل محمد صالح عثمان — طالبة ماجستير
جامعة الموصل/كلية الهندسة

الخلاصة

تم دراسة حالة التدهور (التلف) الحاصل للصخور الجيرية المختارة من ثلاث مقالع في مدينة الموصل وهي (باعذرا، شارع بغداد والورشان) والتي كان سببها الرئيسي هو حركة سوائل مختلفة داخل شبكة المسام وذلك عن طريق إجراء فحص الديمومة، والذي يتضمن تعريض هذه الصخور إلى دورات عديدة من الترطيب والتجفيف باستخدام جهاز الديمومة-التآكل. هذه الدورات تؤدي إلى حصول عمليات إذابة وإعادة تبلور للأملاح داخل مسام الصخرة والتي تؤدي بدورها إلى تدهور الصخرة وبالتالي إضعاف مقاومتها. تم أيضا دراسة بعض الخواص الهندسية لتلك الصخور. أظهرت النتائج بأن هنالك تباين واضح في خصائص الصخور الجيرية بين المقالع الثلاثة وكذلك بين صخور المقلع الواحد. حيث أنه تم تصنيف الصخور الجيرية لكل مقلع إلى صنفين استنادا إلى الخصائص التي تم إيجادها لهذه الصخور. كما أظهرت نتائج هذه الدراسة بأن التجوية التي تعرضت لها هذه الصخور من خلال فحص الديمومة أدت بشكل عام إلى انخفاض مقاومة هذه الصخور حيث تراوح مقدار الانخفاض بين (15-25%)، كما تراوحت نسبة الفقدان بالوزن بين (7.0-14.0%) بعد عشر دورات للنماذج المعاملة بالماء المقطر. من جهة أخرى يختلف هذا المدى عند معاملة النماذج الصخرية مع المحاليل الملحية ($CaSO_4$ & $MgSO_4$)، والسبب في ذلك يرجع إلى اختلاف كمية الملح المترسب داخل مسام الصخرة وذلك لاختلاف نسب المسامية لهذه الصخور . من جانب آخر فإن زيادة عدد دورات الترطيب والتجفيف تؤدي إلى زيادة نسبة الفقدان بالوزن للصخور المعاملة نتيجة لزيادة عمليات الإذابة وإعادة التبلور للأملاح والتي ينتج عنها إجهادات ضغط تسلط على جدران المسام تؤدي بدورها إلى خفض مقاومة الصخرة.

Received: 3 – 6 - 2012 **Accepted: 18 – 9 - 2012**

Introduction

Limestone is available in large amounts in many places in Iraq especially in Ninevah Governorate. These rocks with different kinds and composition depending on its formation and properties. Limestone used efficiently for different purposes such as a construction stone, roads and highways, and for cement industry etc. The various uses of limestone in the field of building, return to the variety of its features. Consequently, it is necessary to study the strength and durability of these rocks against weathering conditions. Slake-durability test has been used to identify the durability and water sensitivity of rocks. This test has been widely accepted and standardized by the American Society for Testing and Materials in 2002 (ASTM D4644).

The factors affecting rock strength and durability may include mineral compositions, microstructure (size, shape and geometry of grains), degrees of alteration (bonding, density and porosity) and texture **(Sousa, et al., 2006)**. Water plays a fundamental role in the stone deterioration, where it is well known that porous building materials absorb and desorbs water as a function of weather conditions (temperature, relative humidity, and rainwater). Furthermore, fluxes of water within the stone affect the behavior of the material and can be responsible for its deterioration **(Beck, et al., 2003)**, through dissolution and decomposition of certain mineral. Soluble salts weathering is one of the most important decay processes that affect the durability of rocks **(Aqudo, et al., 2007)**. The Proposed salt damage mechanisms include generation of crystallization pressure, hydration pressure, thermal expansion and chemical weathering**.** It is generally accepted that the damage to porous stones arises from repeated cycles of crystallization/dissolution of soluble salts with in the porous matrix of the stone **(Coussy, 2006)**. This damage depends on the quantity of salt in the stone as well as the characteristics of the porous network (**Benavente, et al., 2007).**

This research work intends to study the deterioration factors and their effects on the limestone rocks used in construction activities in Mosul city. Sampling from two different locations were obtained from each site and denoted as: **A & B for Baathra C & D for baghdad street and E & F for Al-Warshan sites.** Weathering and degradation characteristics of Limestone were studied using slake-durability apparatus. Different liquids (distilled water & salts) were used to simulate the field weathering process, and to predict the rock strength as affected by this process.

1. Rock sampling and characterization of Limestone

Samples of stones were collected from quarry in Baathra type (A & B) (about 45 Km north of Mosul center). Geologically, it belongs to the Pila Spi Formation (Upper Eocene), and could be classified as a Dolostone with existence some of limestone **(AL-Gawadi, 1978)**. The second quarry in Baghdad street type (C & D) (about 16 Km in the south of Mosul), is from Al-Fatha Formation (Middle Miocene). This consists of two layers from Limestone and interposition layer from Gypsum or Marl stone or together. The third quarry is Al-Warshan located near Mosul Dam (about 35 Km north of Mosul). The quarry consists of a thin layer of Limestone, with layers of Gypsum and Marl stone which are thicker than that of limestone **(Ma'alla et al., 1988)**.

1.2. Mineralogical characterization:

Mineralogical analysis was performed on a slices obtained from the studied rock. Results indicated that the rock was composed from very fine crystalline dolomite $MgCO_3$ and some of calcite $CaCO_3$ for type B with the existence some of ghost of miliolids for type A. On the other hand ,from the mineralogical analysis believe that the recrystallization for type B was more than type A. Many fossils were found in types C & D, so, these rocks is called

(Fossiliferous Limestone). Also, from the Mineralogical analysis believe that the recrystallization for type D was more than type C. Fine crystalline limestone $CaCO_3$ with some fossils such as miliolid, bioclast and peliods were noted for type E. While type F composed from very fine crystalline limestone $CaCO_3$.

2.2. Physical properties

Physical properties of the limestone including dry unit weight, specific gravity, total porosity and absorption% were determined in the laboratory according to the **ISRM standard**. The average values of at least [5] results were given in table (1).

Table (1): Physical Properties of the Rocks

Rock Type	Dry unit weight (KN/m^3)	Standard Deviation (S.D)	Total Porosity (n %)	Standard Deviation (S.D)	degree of saturation(S %)	Specific Gravity (Gs)	Absorption (n %)	Standard Deviation (S.D)
A	18.02	0.376	33.0	0.012	17.94	2.689	14.43	0.630
B	20.42	0.351	27.5	0.012	13.73	2.817	12.210	0.605
C	18.57	0.510	24.0	0.032	21.02	2.443	10.376	0.583
D	20.40	0.197	20.0	0.018	18.39	2.550	9.038	0.263
E	19.44	0.527	23.5	0.018	18.47	2.541	8.632	1.255
F	18.73	0.184	25.5	0.022	14.00	2.514	14.256	0.045

The results indicated that there is a variety in the Physical properties of Limestone taken from the same site. This is expected due to its mode of formation as explained in petrographic test. This rock is highly porous compared with the known average range between (2-20%) & (1-10%) for Limestone & Dolomite rocks **(Peng& Zhang, 2007).** The values of dry unit weight for every stone depend on the porosity, cracks and the existed metals. On the other hand, the values of dry unit weight reduce with increases of porosity as shown in figure 1). The absorption increases with increase of porosity and of connected porosity as shown in figure (2).

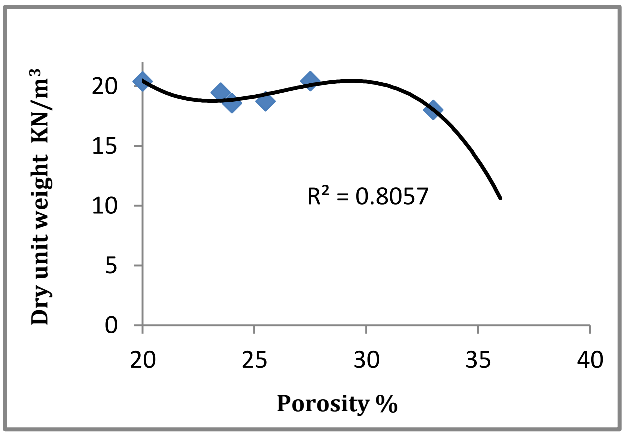

Figure (1) : Relationship between dry unit weight and porosity

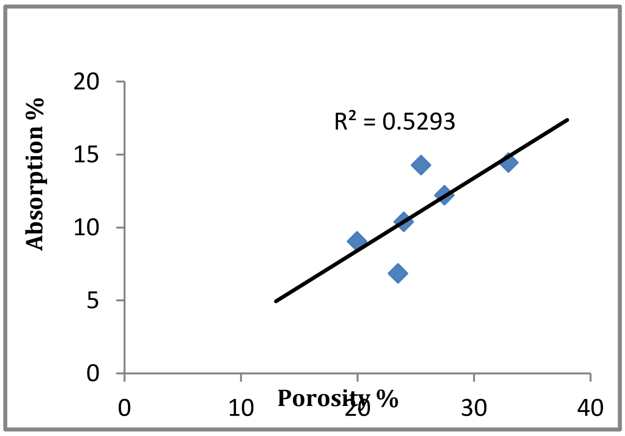

Figure (2) : Relationship between rate of absorption and porosity

3.2. Mechanical properties

The behaviors of limestone using different mechanical tests were studied according to standards **(ASTM)** listed in table (2). These are Uniaxial compression, point load, Brazilian tension and Triaxial compression tests. Samples with dimensions listed in table (2) were selected carefully to keep the real state of the quarry. Core specimens were prepared in the laboratory from

Table (2): Mechanical Properties of the Rocks

Test	Condition	Dimension (D * L) mm	Rate of loading	Standard ASTM	A	B	C	D	E	F
Unconfined compressive strength (MPa)	Dry & Saturated	56 * 112	0.75 $N/mm^2/sec$	D2938	16.443 & 9.744	22.330 & 13.094	14.170 & 4.959	21.360 & 8.624	16.646 & 5.292	15.863 & 4.312
Point load strength(MPa)	Dry	56 * 84	1.0mm/min	D5731	1.802	2.380	1.702	2.512	2.314	2.083
Brazilian tensile strength(MPa)	Dry & Saturated	56 * 28	200 N/sec	D3967	2.487 & 1.015	3.284 & 1.263	2.582 & 1.060	3.388 & 1.436	3.303 & 1.207	2.650 & 0.667
Triaxial compressive strength σ_1 MPa @ σ_3=8 MPa	Dry	54 * 11	0.75 $N/mm^2/sec$	D2664	45.27	56.74	27.25	41.5	44.98	41.92
S.D for U.C.T.	_	_	_	_	0.292 & 1.033	0.575 & 0.429	0.803 & 0.170	0.279 & 0.444	0.406 & 0.389	1.369 & 0.167
S.D for P.L.T.	_	_	_	_	0.071	0.055	0.210	0.141	0.232	0.327
S.D for B.T.T.	_	_	_	_	0.473 & 0.071	0.476 & 0.055	0.126 & 0.077	0.071 & 0.055	0.560 & 0.032	0.397 & 0.122
S.D for T.C.T.	_	_	_	_	1.287	1.004	0.905	0.736	0.453	0.410

S.D : stander deviation

U.C.T. : Unconfined Compressive Strength

P.L.T. : Point Load Strength

B.T.T. : Brazilian Tensile Strength

T.C.T. : Triaxial Compressive Strength

blocks brought from the field, using core drilling and cutting saw machines. Drilling was conducted perpendicular to the bedding of the rock. The Uniaxial compression & Brazilian tension tests were studied on samples in both dry and saturated conditions. To saturate the rock specimens, a procedure suggested by **(Hawkes & Mellor, 1970)**, by which the specimen should be essentially about 100 percent saturated was followed.

Results indicated that the failure shape in the Uniaxial compression test; specimens of Baathra type A & B were failed in longitudinal splitting with a major cracks parallel to the applied load. While specimens of Baghdad street type C & D and specimens of AL-warshan type E & F were failed in Conical end fragment and in the shearing along single plane, respectively. In the point load tested specimens, a sudden failure was noted with a fracture line joining the loading contact points, dividing the samples into two equal parts after failure. On the other hand, all specimens were failed in tension in the Brazilian test, since the fracture was originated near the center of the specimen and extended from the center to the loading contact points. Consequently, each specimen was divided into two approximately equal halves. Finally, the tested specimens in Triaxial were failed with splitting, several shear planes, single shear plane and random fracture. The shape of failure converts from Splitting to ductile with increasing the confining pressure as shown in figure (3).

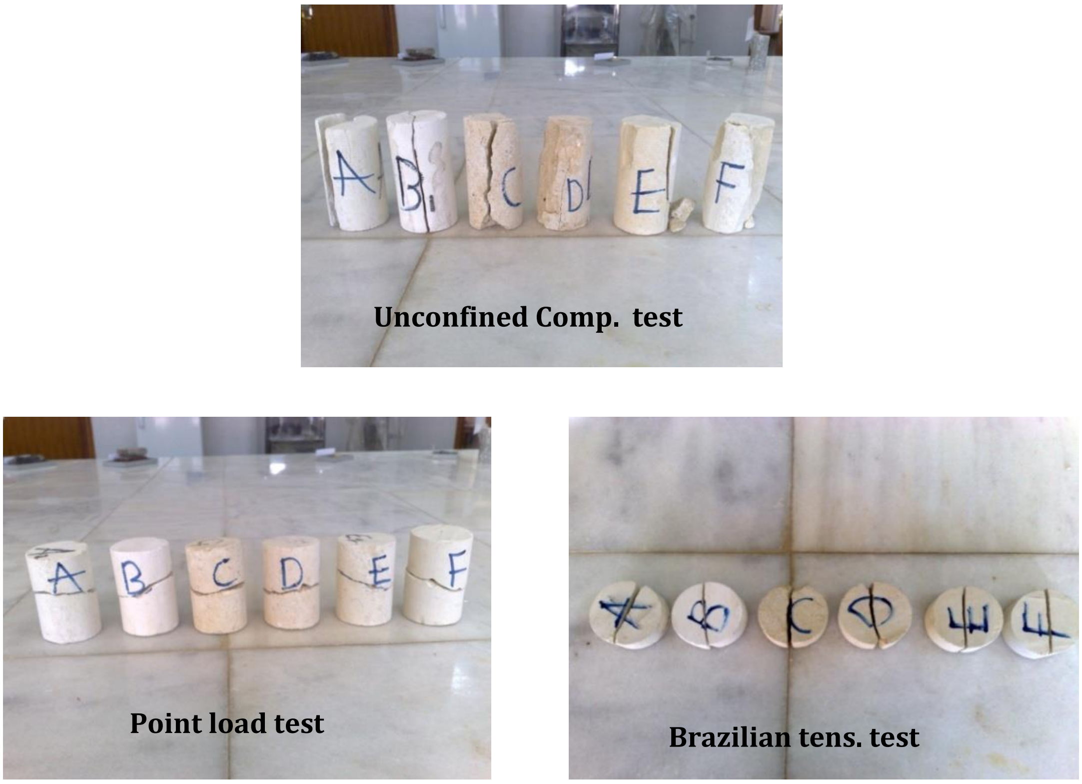

Figure (3): Failure of specimens rocks in mechanical tests

Strength results given in table (2) shows that, in general, the strength of rocks of Baathra and Baghdad sites, type B and D is greater than type A and C respectively. This could be attributed maybe to the high degree of recrystallization and lower values of the porosity for type B & D compared with the other type at the same quarries. The Warshan site rocks type E & F has almost identical strength properties. Subsequently, many studies indicate that the mechanical properties of rocks were increase with increasing the unit weight and with decreasing the porosity **(Va'sa'rhelyi, 2005)** as shown in the figure (4). Where, increase of stresses concentration on the limits of gaps and decrease of solid area of rocks reduce strength of rocks, and the gaps may be filled with water or with other liquids which lead to development of cracking through the interactions **(Lama & Vutukuri, 1978)**.

The rocks strength decreases in the saturated state for all the quarries. This reduction in strength was due to lowering of the free surface energy upon saturation. Furthermore, the saturation causes dissolution and decomposition of a certain mineral forming the rock and the water weakening the cementing material binding the rock crystals and grains **(Romana & Va'sa'rhelyi, 2006)**. According to the classification of **(Franklin & Dusseault, 1989),** rock types (A, C, E & F) is considered as a weak rock and each type of (B & D) could be classified as a medium-strong rocks based on the unconfined compression strength results shown in table (2).

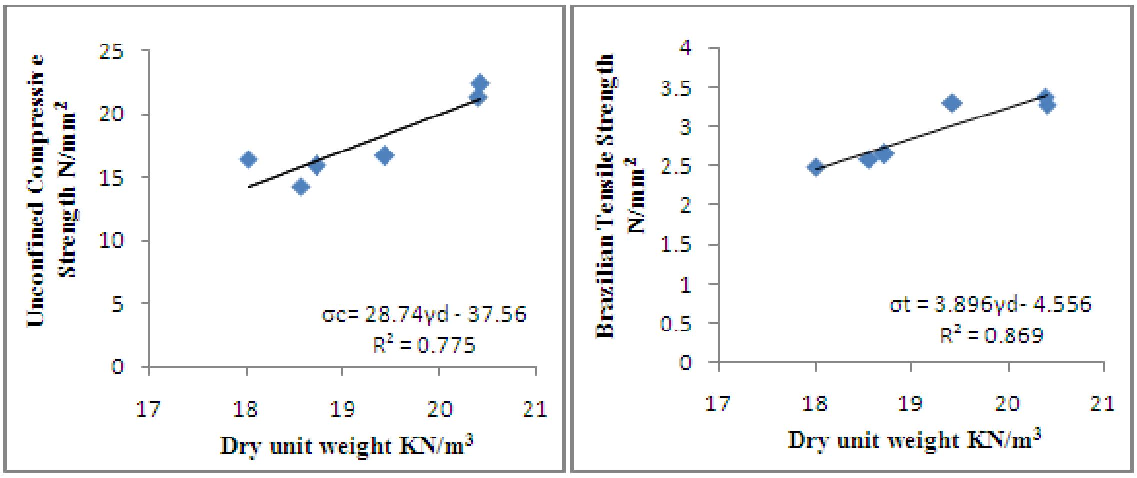

Figure (4) : Relationship between the strength and dry unit weight

Table (3) : Results of Triaxial compression test

Rock Type	Axial stress (σ_1) MPa	Lateral confining pressure (σ_3)MPa	Deviator stress (σ_1-σ_3) MPa
A	35.25	4	31.25
	45.27	8	37.27
	55.56	12	43.56
B	44.43	4	40.43
	56.74	8	48.74
	69.63	12	57.63
C	19.5	4	15.5
	27.25	8	19.25
	35.03	12	23.03
D	32.62	4	28.62
	41.50	8	33.5
	50.68	12	38.68
E	35.75	4	31.75
	44.98	8	36.98
	55.01	12	43.01
F	32.37	4	28.37
	41.92	8	33.92
	51.65	12	39.65

Triaxial Compression Test

Triaxial compression test was performed in a multistage ways by applying the confining pressure in the beginning, and then to steadily increase the axial load until reaching a complete failure. The deviator stress increases with increasing the confining pressure, due to axial stress increase, **(Abdul Alim, et al., 2006)** figure (5). Table (4) give the parameters (C & ϕ^0) through drawing of Mohr circle as shown in figure (6). To measure strain during the Triaxial compression test, strain gauges were used to find the stress-strain curves, figure (7).

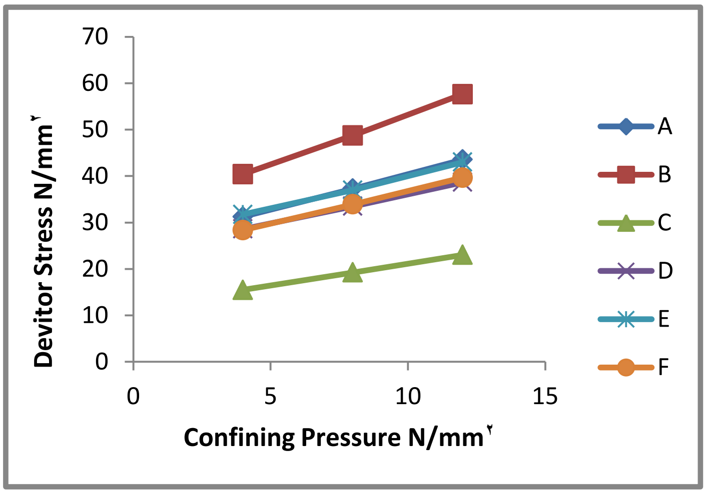

Figure (5) : Relationship between deviators stress and confining pressure

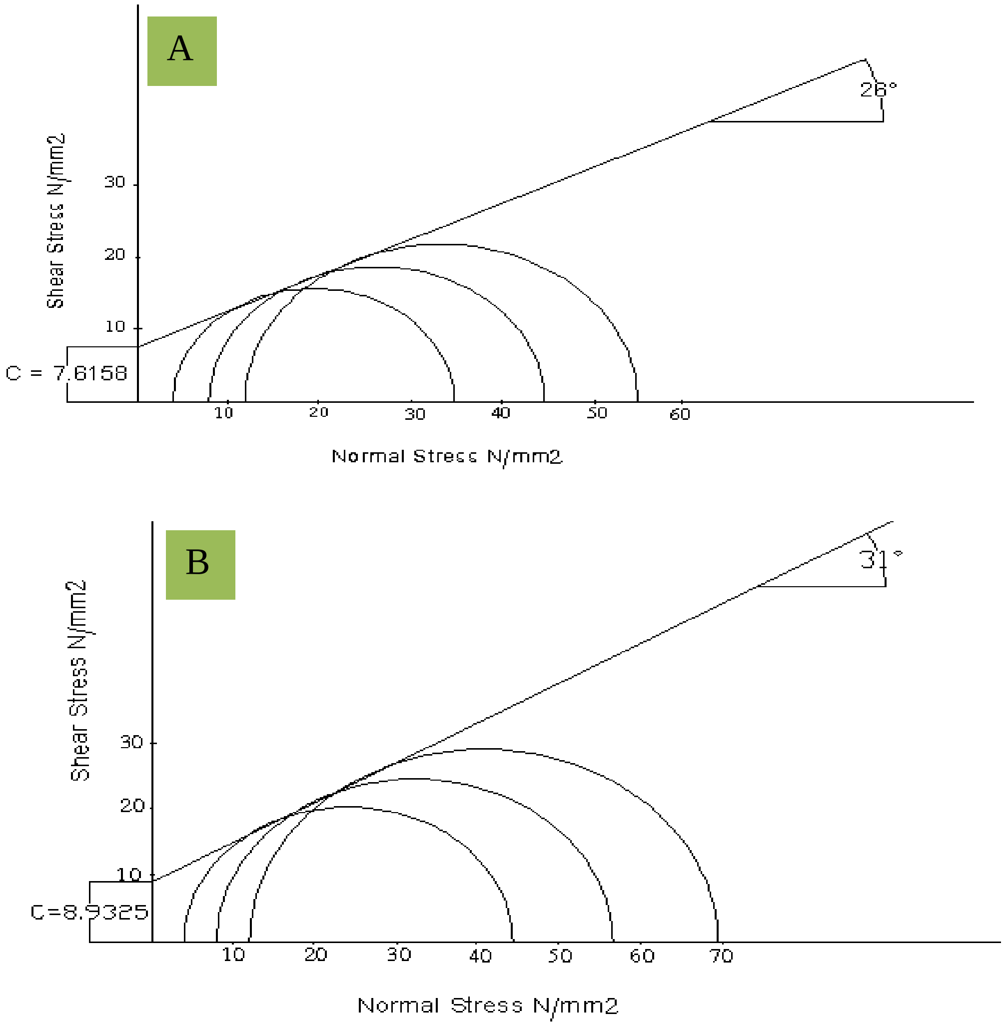

Figure (6) : Mohr circles for Baathra rocks

Table (4) : Parameters resulting from Triaxial compression test

Rock Type	Cohesion (C) MPa	Angle of internal friction (ϕ^0)	* Modulus of elasticity (E) $N/mm^2 *10^3$
A	7.616	26	17.778
B	8.933	31	19.592
C	4.156	19	17.500
D	8.003	22	18.750
E	8.022	25	16.666
F	7.150	26	11.448

* E values were found as a tangent E at 50% strength

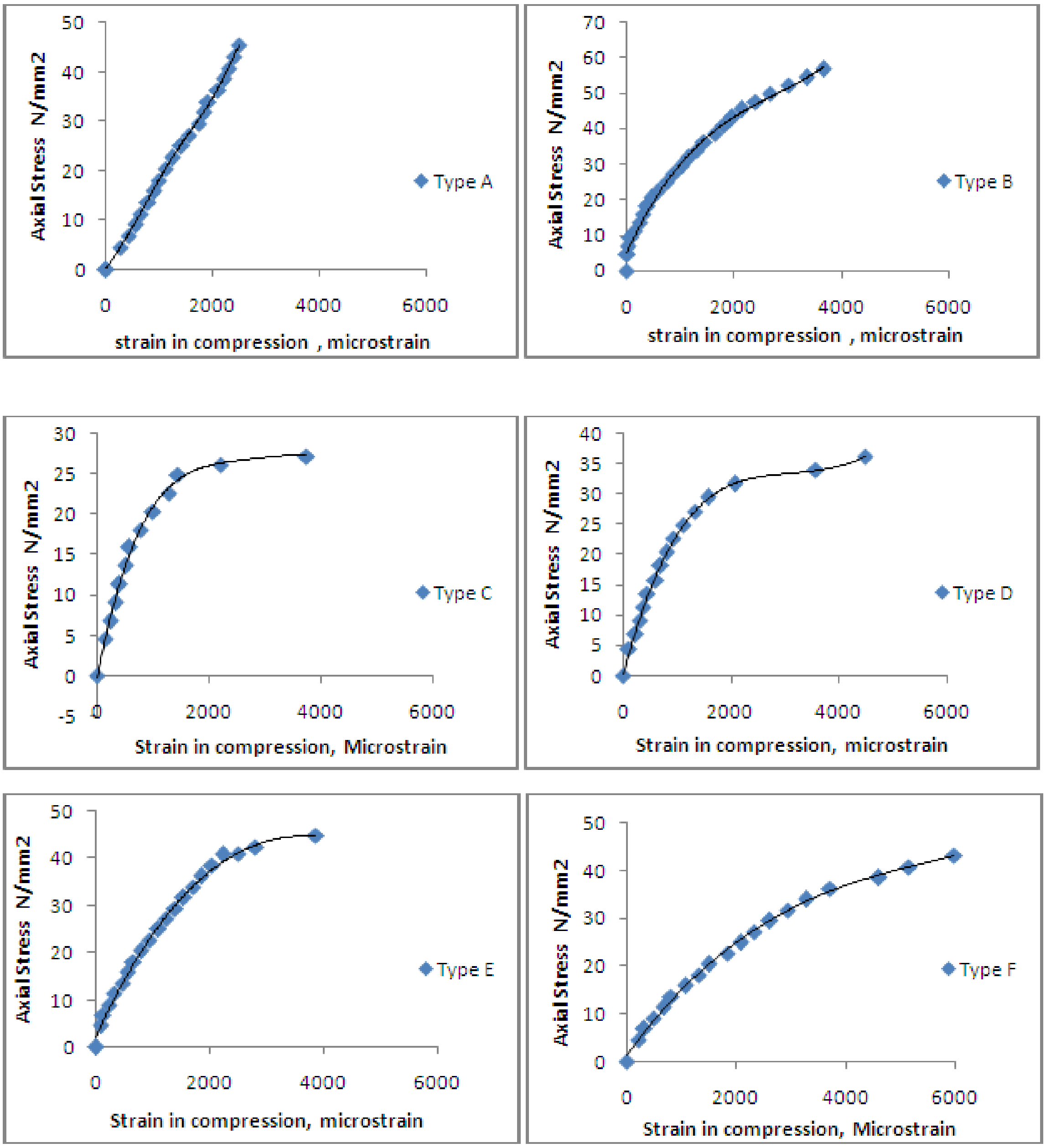

Figure (7) : Stress strain curve for specimens rocks in Triaxial Compressive test

3. Slake-Durability Test

Main objectives of the slaking durability test are to predict the long-term durability of the rock specimens, to establish weathering and degradation characteristics of each rock type, and to assess the impact of water on the rock degradation. The test procedure and data reduction were similar to that of the standard practice (ASTM D4644, 1987), except that the tests were performed up to **(10 cycles)**, instead of two cycles as specified by the standard. This was primarily to establish a longer trend of weight loss as the rock continued to subject to more cycles of scrubbing in the drum. Different liquids were used in the test **(saturated salts solutions $CaSO_4$ & $MgSO_4$ 2.09 gm/l & 335 gm/l respectively & distilled water),** to study the effect of these liquids on the rocks. It is important to indicate that the samples remained without washing after terminating the test.

It is shown from figures (8 & 9) that the rate of weight loss increases with increasing the number of wetting/drying cycles. These cycles induce dissolution, recrystallization and lead to the deterioration of this stone. On the other hand, the rate of weight loss for specimens of type A & E, were greater than that of the other types (B & F). This is attributed to the existence of some fossils on type A and E, which help to increase the solubility of these rocks, and also due to the lower values of porosity for type B compared with type A. Also, the recrystallization for type B was higher than type A as indicated previously in the mineralogical analysis. The same reasons could be assumed for rocks specimens obtained from Baghdad street, where the porosity for type D is smaller than type C, and also, the recrystallization for type D was higher than type C. The rate of weight loss in the case of employment the distilled water was reached after 10 cycles in the slake- durability apparatus to: (9.761 & 7.697 %), (13.197 & 11.989 %) & (13.006 و 11.229 %), respectively for (A & B), (C & D) & (E& F).

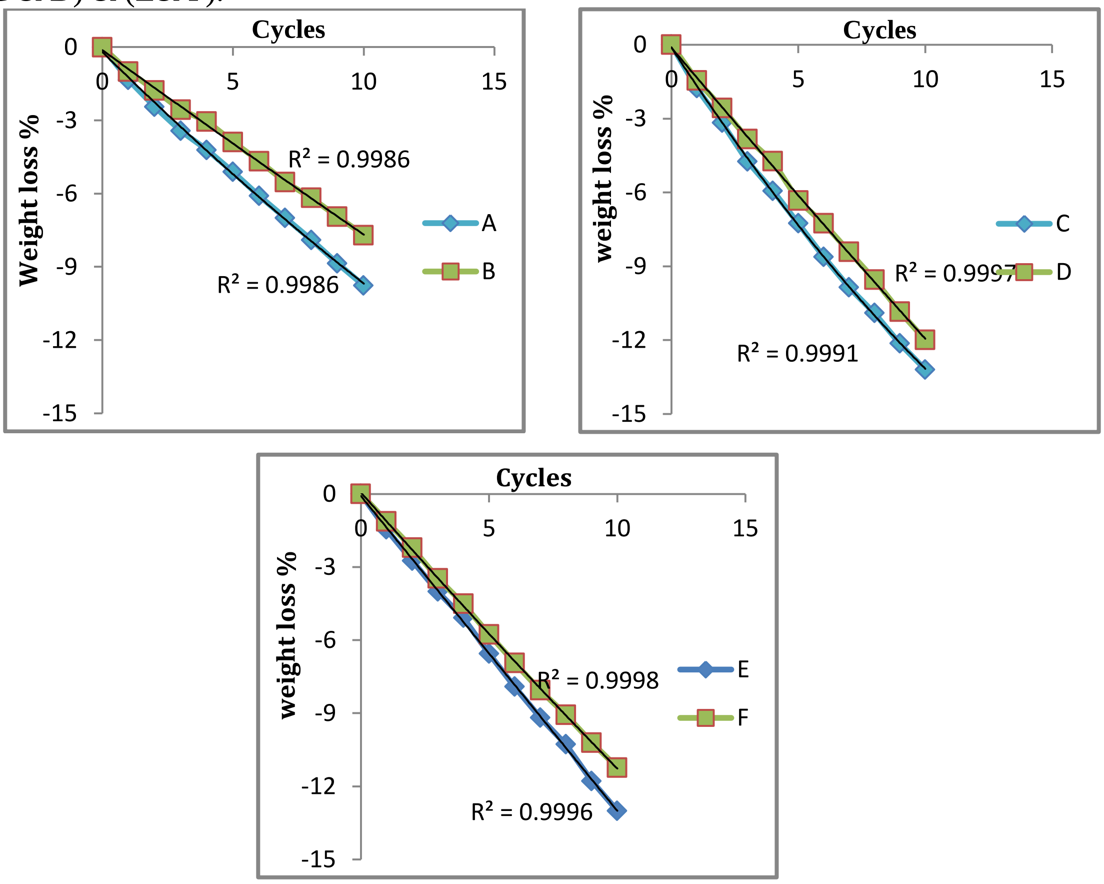

Figure (8) : relationship between weight loss % & cycles in the case of distilled water

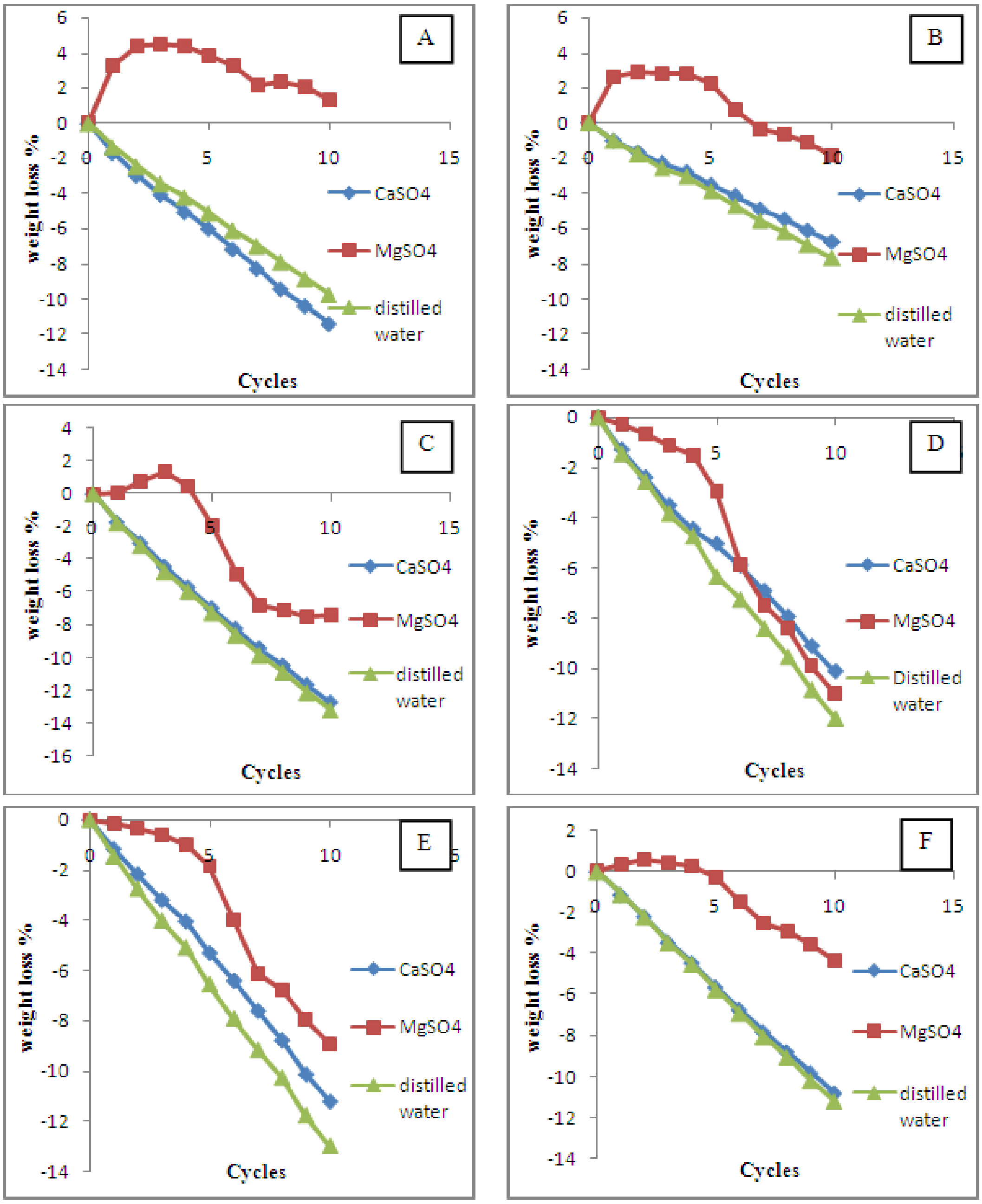

Figure (9) : Effect of various of solution on the rate of weight loss for specimens of rocks

Using magnesium sulphate $MgSO_4$ instead of water in slake-durability apparatus, The rate of weight loss was noted to follow two stages figure (9) ; weight increase due to salts presence which fill the voids, and weight decrease due to stone damage. Hence, Generally the higher rate of increase was reached after 2-3 cycles. After three cycles, the rate of increase reaches (4.444 %) for type A, then this value decreased to (1.267%) after 10 cycles. While the specimen of rock, type B reached a rate of increase after two cycle to (2.906%), then this rate decreased to (-1.814%) after 10 cycles. This could be attributed to the variation of the amounts of salt crystalline inside porous stone, due to difference of the porosity values for these rocks. On the other hand, the increase of wetting/drying cycles leads to increase in weight loss for specimens due to increase of dissolution/ recrystallization of salts, which apply stress on the wall of porous stones and lead to a weight and strength reduction of the rocks **(Trinh, et al., 1997)**. The same reasons can be said for other rocks, type (C & F) with a lower rate of increase as shown in the figure (9), due to the low porosity for this rocks compared with other specimens of rocks, type (A & B). The size of pores has a major influence on the rate of weight loss, where salt damage is closely related to pore size **(Steiger, 2005)**. Hence, the maximum pressure occurs when a large crystal grows within a pore with small entries. For this reasons, it could be observe that the rate of weight loss was a continuous for type D & E, also due to the low porosity for these rocks. Worth mentioning that the rate of weight loss was different in the case of treatment of this rocks with calcium sulphate & magnesium sulphate. This could be attributed to the high concentration of $MgSO_4$ (335 gm/l) compared with $CaSO_4$ (2.09 gm/l) . When the rocks are subjected to the effect of water, through its transition by (capillary force, gravity force & absorption)**,** this leads to dissolution of salts crystalline inside rock, which leads to increase the porosity and hence decrease the density and strength for these rocks **(Ali, 2011)**.

Strength variation due to slake-durability cycles

To understand the effects of weathering on the strength of rocks, the Point load strength index test was used to evaluate the strength of the rocks subjected to number of cycles in the slake-durability apparatus using specimens of irregular shape. Figure (10) shows a general reduction of strength of rocks with increase the number of cycles in the case of using distilled water. This reflect the deterioration increase of the studied rocks exposed to slaking test.

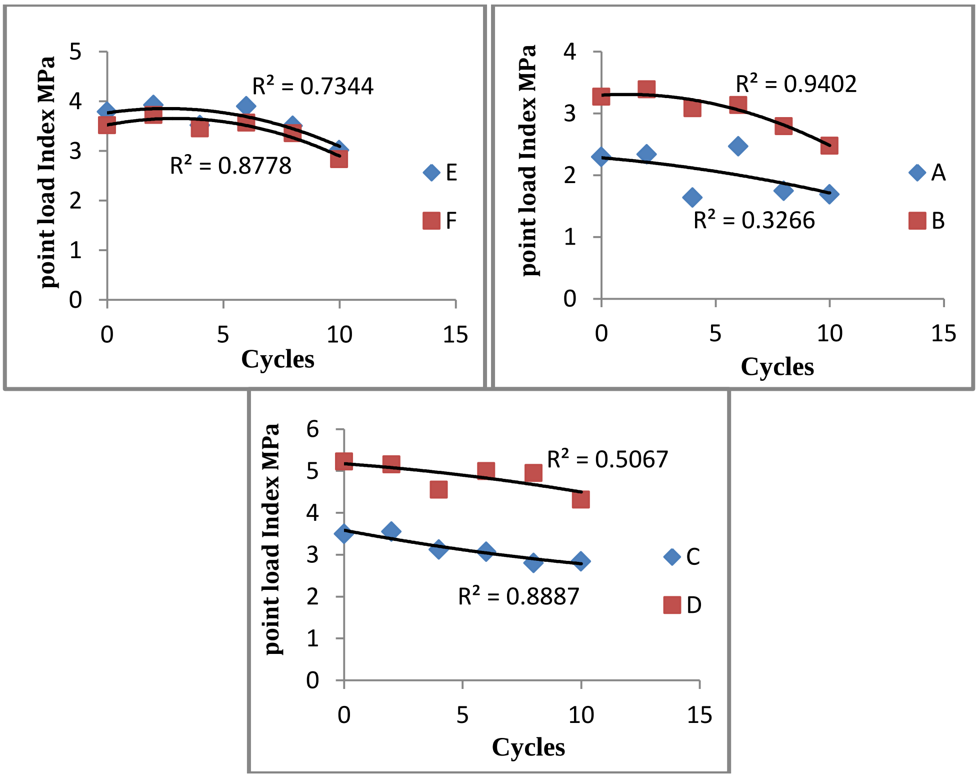

Figure (10) : The relationship between point load strength index and the cycles by distilled water

Concerning the salts effects, it is clear from figures (11 & 12), that the point load strength index increases at the earlier cycles followed by a reduction in this strength. This could be attributed to the deposition of an amount from this salts inside the stone pores by crystallization after water evaporation. These results agree with that obtained by **(Tri, 2008).** This is followed by a reduction in the strength with the increase of cycles, due to increase dissolution/recrystallization of salts in the confined pore spaces. This process leads to a loss

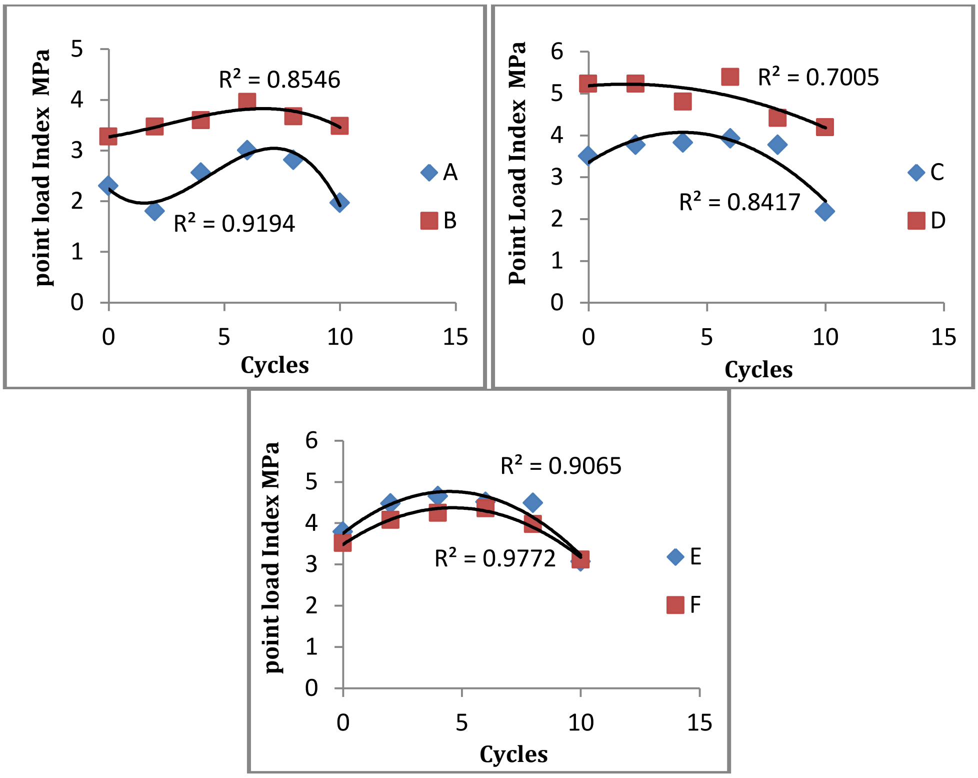

Figure (11) : The relationship between point load strength index and the cycles by salt solution ($CaSO_4$)

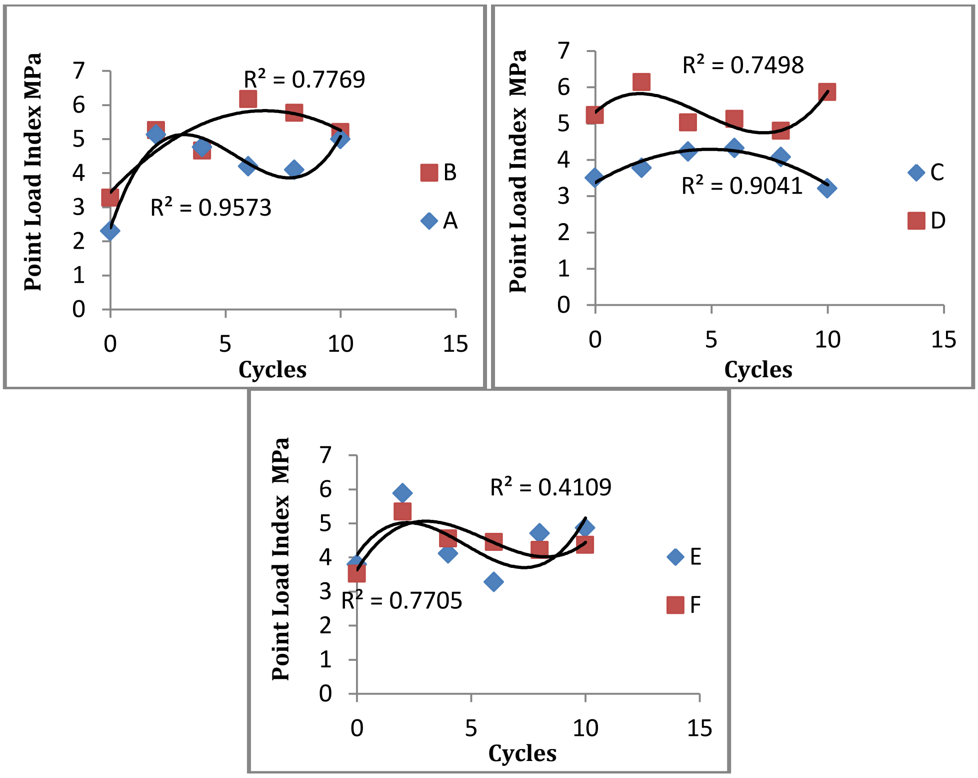

Figure (12) : The relationship between point load strength index and the cycles by salt solution ($MgSO_4$)

both in mass and strength **(Trinh, et al., 1997),** in addition to a considerable local expansion and cracking. Where, the differences in thermal expansion coefficient and temperature gradient between surface and inner layers lead to a tension force among some particles, helping in cracks formation, strength decrease, porosity rising, material surface rising and decrease of resistivity against water action**.** It is also noted that the strength of specimens in the case of using magnesium sulphate $MgSO_4$ is greater than that when using calcium sulphate $CaSO_4$ as shown in the figures (11 & 12). This could be explained by the higher concentration of magnesium sulphate (335 gm/l) compared with that of calcium sulphate (2.09 gm/l) as indicated previously.

Conclusion

Series of mechanical and durability tests under the effect of different liquids were performed on (Baathra, Baghdad street and AL-Warshan) rocks. Results indicated that:

1- The strength values for these rocks are diverse between and within the same quarry. Generally, these rocks could be classified according to some researchers as (medium-strong) , (weak-medium) and (weak) for specimens rocks (B,D), (E.F) and (A,C) respectively.
2- The strength decreased when the rocks became saturated.
3- Generally, the rate of weight loss increases with increasing number of wetting/drying cycles.
4- The weight of specimens increase at the earlier cycles followed by a reduction in this weight, this occur when treatment the specimens rocks with $MgSO_4$ solution.
5- A general reduction in the point load strength of rocks with increase number of cycles. While it is clear concerning the salt effects that the point load strength index increases at the earlier cycles followed by a reduction in this strength.

Finally, after all the previous explanations and discussions of laboratory results and the durability of (Baathra (type B), Baghdad street (type D) and AL-Warshan (type E & F)) could be said that these rocks can be used as a main material for the skeleton of buildings or for external garment purposes. Also type (A) can be used in locations not subjected to the effect of the water or moisture. Finally, rock type (C) is not suitable for employment as a construction materials.

References :

1- Sousa, L.O.M., Suarez del Rio, L.M. & Calleja, L., (2005), " Influence of Microfractures and Porosity on The Physico-Mechanical Properties and Weathering of Ornamental Granites", Engineering Geology, Vol. (77), pp. 153- 168.

2- Beck, K., AL-Mukhtar, M., Rozenbaum, O., and Rautureau, M., (2003), " Characterization Water Transfer Properties and Deterioration in Tuffeau: Building Materials in the Loire Valley- France", downloaded from http:// www.google.com

3- Agudo, E.R., Mess, F., Jacobs, P., & Navarro, C.R., (2007), "The Role of Saline Solution Properties on Porous Limestone Salt Weathering by Magnesium and Sodium Sulfates ", Environmental Geology, Vol. 52, Pp. 269-281.

4- Coussy, O., (2006), "Deformation and Stress from in-Pore Drying-Induced Crystallization of Salt ", J. Mech. Phys. Solids, Vol. 54, pp. 1517-1547.

5- Benavente, D., Cueto, N., Martinez, J., Garcia, M.A., & Canaveras, C., (2007), "The Influence of Petro physical Properties on the Salt Weathering of Porous Building Rocks ", Environ Geol, Vol. 52, pp. 215-224.

6- Al-Jawadi, A.F., (1978), "Mineralogical, Petrographical and Geological Studies of Pila Spi Formation Form Northern Iraq ",Unpublished M.Sc. thesis, University of Baghdad, Iraq.

7- Ma'ala, K.A., Mahdi, A.H., Fakhri, S., Al-Naqib, S.Q., and Lawa, F.A., (1988), " Detail Geological Mapping of Mosul-Fatha Area for Sulfur Exploration ", Eng. Geol. Of Geol. Survey. Miner. Invest., Baghdad.

8- ISRM., (1979)، "Suggested Methods for Determining Water Content, Porosity, Density, Absorption and Related Properties", ISRM. Committee on Standardization of Laboratory Tests, Int. J. Rock Mech. Min. Sci., Vol. 16 pp 143- 156.
9- Peng, S., & Zhang, J., (2007), "Engineering Geology for Underground Rocks ",Springer-Verlag Berlin Heidelberg New York.
10- ASTM, (1989), " American Society for Testing and Materials ", Vol. 04-08.
11- Hawkes, I. & Mellor, M., (1970), "Uniaxial Testing in Rock Mechanic Laboratory ", Engineering Geology, Vol. 4, pp.177-285.
12- Vasarhelyi, B., (2005), "Technical Note Statistical Analysis of the Influence of Water Content on the Strength of the Miocene Limestone", Rock Mech. Rock Eng. Vol. 38, No. 1, pp. 69-76.
13- Lama, R.D., & Vutukuri, V.S., (1978), "Handbook on Mechanical Properties of Rocks ",Trans. Tech. Publication.
14- Romana, M., & Vasarhelyi, B., (2006), " A Discussion on the Decrease of Unconfined Compressive Strength Between Saturated and Dry Rock Samples", http:// www.google.com
15- Franklin, J.A., and Dusseault, M.B., (1989), "Rock Engineering ",McGraw Hill, USA.
16- Abdul Alim, M.D., Suzuki, K., & Iwashita, K., (2006), " Effect of confining pressure on the strength behavior of granular material simulated by the discrete element method ", The Geological Society of London, No. 372.
17- Trinh, Cao., Bucea, L., & Ferguson, O., (1997), " Sulphate Resistance of Cementitious Materials Mechanisms, Deterioration Processes, Testing and Influence of Binder ", Proc. Concrete 97, Adelaide, Concrete Institute of Australia, pp. 263-268.
18- Steiger, M., (2005), "Crystal Growth in Porous Materials _ II: Influence of Crystal Size on the crystallization Pressure ", Journal of Crystal Growth, Vol. 282, pp. 470-481.
19- Ali, H.E., (2011), "Study the Mechanism of Deterioration on the Rocks Used in the Historical Building ", M.Sc. Thesis, Civil Eng. Dept., College of Engineering University of Mosul.
20- Tri, T.V., (2008), "Vieillissement du Tuffeau en présence de sels : approche experimental et numérique ", PhD. THÈSE, GÉNIE CIVIL, Discipline, UNIVERSITÉ D'ORLÉANS.

The work was carried out at the college of Engineering. University of Mosul