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Geotechnical Characterization of Jordanian Limestone

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Abstract

Full knowledge of the physical and mechanical behavior of limestone rocks is required for the safe design of structures. Little work has been done to characterize the physical and mechanical properties of Jordanian limestone especially under watery environment. Therefore, in this study the physical and mechanical properties of some Jordanian limestone were investigated. The limestone samples were collected from five different parts of the country. The porosity and dry density of the selected limestone were compared. The reduction on the compressive strength and tensile strength for dry, 50% and 100% water saturation were determined. All rock experienced a reduction on both the compressive strength and tensile strength as a function of saturation degree. Large reduction happens on the strength properties for the Zarka limestone than the other limestone when the samples are fully saturated.

Keywords

Limestone, Rock Mechanics, Physco-Mechanical Properties

1. Introduction

Limestone is a sedimentary rock composed of more than 50% of the mineral calcite ($CaCO_3$). The magnesium can substitute the calcium to produce dolomite ($CaMg(CO_3)_2$). Limestone covers extensive areas in Jordan. They are mostly quarried and used as construction materials such as concrete aggregate, highway construction, building face stone, etc, [1].

Jordanian limestones are being quarried in areas of Ma'an, Ajlun, Irbid, Al-Azraq, and the desert plains. They reveal variability in their geomechanical, physical and chemical properties. Naghoj *et al.* studied the mechanical properties of six limestone rocks [2]. They suggested a new formula for estimating the modulus of elasticity of limestone when compressive strength is known. Tarawneh *et al.* studied the geological, petrographic and physico-mechanical properties of Ma'an limestone [3]. They concluded that the controlling factor of the classification of Ma'an area limestone is the uniaxial unconfined compressive strength.

It has been reported that mechanical properties of rock are adversely affected by watery environments, especially when they are exposed for a longer time, where it is reported that 20% - 90% of the uniaxial compressive strength was lost after the rocks were saturated from a dry state depending on the rock type [4] [5] [6] [7]. The influence of water content on the strength of the Miocene limestone was studied by Vasarhelyi [8]. He found that the Miocene limestone suffered from a maximum of 74% reduction in uniaxial compressive strength and 53% reduction in modulus due to saturation. He also observed that the UCS of Miocene limestone increases exponentially with the rock density.

To the best of author's knowledge, no research was made to quantify the effect of degree of saturation of Jordanian limestone. For this reason in this research, the physical and mechanical properties for five limestone rocks collected from different parts of the country were studied. And an attempt has been made to see the variation in the mechanical properties of the selected limestone under different watery environment. This has been done by studying the effect of degree of saturation on the mechanical properties of the selected limestone.

2. Experimental Study

A representative rock blocks were collected from different parts of the country mainly from Ajlon (A), Zarka (Z), and tow limestone type from Ma'an district Sateh (S) and dabish (D). Ajlon and Ma'an limestone blocks are characterized as pure and homogeneous and they are mostly white to grayish white in color. However, Zarka limestone is an impure limestone and can be characterized as marly limestone and has a yellow color. The NX size cylindrical cores were prepared with the help of diamond core drilling machine as per ISRM standard [9]. The coring process was applied perpendicular to the bedding planes of the rock. Samples with cracks or defects were excluded from further analysis.

Firstly the dry density and porosity of all rock types were determined. For this purpose the caliper method according to the (ISRM) was adopted. At least three samples of each rock type were tested. The weight of the specimen was determined by a balance, capable of weighing to an accuracy of 0.01 g. The specimens firstly were dried in an oven for 24 hours at 105 Co and then placed in a desiccators to cool. Immediately upon cooling, the specimens were weighed. The specimens were then immersed in water for 24 h. To insure full saturation, the samples were immersed in water under a vacuum of less than 800 Pa for a period of at least 1 hr. Specimens were then removed, patted dry with a lint free cloth, and weighed. The result for dry porosity and density are shown in **Table 1**.

The mechanical properties of limestone (uniaxial compressive strength and tensile strength) were firstly evaluated for dry condition. The tensile strength was determined indirectly by means of the "Brazilian" test. It consists in imposing a diametrical compressive stress on cylindrical samples which generates tensile stress perpendicular to the loading direction. To ensure a better load distribution and avoid stress concentration, the contact between sample and testing machine is done with a piece of cardboard.

The compressive strength was measured indirectly using axial point load test on a

Table 1. Dry density and porosity.

Rock Type	Sample Number	Porosity, %	Dry Density, g/cm^3	Average Porosity, %	Average Density, g/cm^3
S	1	4.46	2.70	2.92	2.61
	2	3.93	2.54		
	3	2.00	2.61		
	4	1.29	2.60		
D	1	1.62	2.58	2.19	2.54
	2	2.73	2.58		
	3	2.21	2.46		
Z	1	14.00	2.36	12.87	2.36
	2	12.55	2.35		
	3	12.05	2.36		
A	1	1.35	2.65	1.66	2.64
	2	1.30	2.64		
	3	2.35	2.63		

core samples. The results were corrected to a specimen diameter of 50 mm and the uniaxial compressive strength of the samples was then estimated. The results for the uniaxial compressive strength and tensile strength for dry samples are presented in Table 2 and Table 3 respectively.

The same mechanical tests were then repeated for samples saturated with water (50% and 100% saturation). All samples were saturated in a vacuum by immersing it into water at a constant vacuum of 1000 Pa. Periodical stirring was engaged to release bubbles trapped in pores or voids. Additionally, the samples were weighed every 4 hours to monitor the saturation process. When constant mass was reached the specimens were considered fully saturated. Care was taken to prevent any loss of loose particles while the specimens were surface dried by means of a moist cloth before being weighed.

After the samples reached a full saturation state, some samples were then conditioned to a chosen level of saturation (50%). This was achieved by air drying of the samples to a chosen weight. To obtain even water distribution throughout the sample, the samples were shelf conditioned for one week in an air tight container with some water at the bottom. This method was confirmed as a good way of making an even water distribution throughout the samples [10] [11] [12] [13].

A comparison results for dry and saturated strength for limestone are presented in Table 4.

3. Results and Discussions

The test results given in Table 1 were analyzed: Figure 1 shows the variation of average porosity for all rocks. Zarka limestone shows the highest porosity value. It also noted that Zarka limestone has the lowest dry density as shown in Figure 2.

Figure 3 and Figure 4 show the average uniaxial compressive and tensile strength for dry limestone samples respectively. It is clear that rock with small porosity results in greater rock strength and vice versa. This is clear in the case of Zarka limestone where it

Table 2. Uniaxial compressive strength for dry limestone.

Rock Type	Sample Number	P, kN	Is(50)=	UCS, Mpa	Average UCS, Mpa
Z	12	5.66	1.99	47.67	48.22
	13	5.28	1.87	44.79	
	14	7.11	2.51	60.29	
	15	5.71	2.02	48.38	
	16	6.03	2.13	51.11	
	17	5.42	1.92	46.09	
	18	5.85	2.08	49.82	
	19	4.98	1.76	42.19	
	20	5.14	1.82	43.63	
D	12	6.88	2.44	58.51	64.70
	13	8.22	2.91	69.80	
	14	7.60	2.70	64.76	
	15	8.29	2.93	70.25	
	16	8.24	2.90	69.71	
	17	6.85	2.43	58.22	
	18	7.30	2.57	61.68	
A	12	5.33	1.89	45.27	56.09
	13	7.16	2.52	60.52	
	14	7.13	2.53	60.65	
	15	6.03	2.14	51.25	
	16	7.02	2.49	59.75	
	17	4.38	1.55	37.17	
	18	7.70	2.72	65.37	
	19	7.05	2.49	59.82	
	20	7.64	2.71	65.01	
S	11	6.90	2.44	58.44	51.18
	12	7.41	2.61	62.71	
	13	7.70	2.71	4.00	
	14	7.05	2.48	59.55	
	15	7.53	2.65	63.53	
	16	4.91	1.73	41.47	
	17	7.53	2.65	63.50	
	18	6.65	2.34	56.21	

has largest porosity and has the lowest tensile and compressive strength.

Using the method of least-squares regression, the equation of the best-fit line, and the correlation coefficient (R^2), correlation equations were determined to correlate between density and porosity (**Figure 5**). It can be seen that there is a good correlation between porosity and density as R^2 is nearly 0.94.

Table 3. Tensile strength for dry limestone.

Rock Type	Sample Number	P, kN	Tensile Strength, Mpa	Average Tensile Strength, Mpa
Z	6	15.12	5.62	5.37
	7	14.43	5.52	
	8	12.62	4.75	
	9	17.16	6.49	
	10	14.58	5.42	
	11	11.70	4.43	
D	5	16.66	6.54	6.34
	6	16.35	6.51	
	7	17.03	6.73	
	8	14.56	5.70	
	9	16.25	6.14	
	10	17.72	6.53	
	11	16.01	6.22	
A1	4	14.33	5.44	6.08
	5	13.24	4.95	
	6	11.94	4.56	
	7	15.87	6.06	
	8	11.84	4.97	
	9	21.35	7.92	
	10	21.01	7.73	
	11	18.72	7.03	
S2	5	14.95	6.31	5.61
	6	11.87	4.56	
	7	14.77	5.76	
	8	9.23	3.96	
	9	17.10	6.36	
	10	16.33	6.71	

Table 4. A comparisons of the testing results for dry, 50% saturation and 100% saturation.

Rock	Average Porosity, %	Average Density, g/cm^3	Average UCS, MPa	Average UCS, MPa 50% sat.	Average UCS, MPa 100% sat.	Average Tensile Strength, Mpa	Average Tensile Strength, MPa 50% sat.	Average Tensile Strength, MPa 100% sat.
Z	12.87	2.36	48.22	20.1	18.4	5.37	2.02	1.5
D	2.17	2.58	64.7	56.6	48.3	6.33808	5.02	4.96
S	2.92	2.61	51.18	47.2	45.1	5.61	5.46	4.95
A	1.66	2.64	56.09	53.7	49.9	6.08	5.66	5.48

Another correlation was made between the uniaxial compressive strength and the tensile strength as shown in Figure 6. A good correlation was also obtained as R^2 was about 0.93.

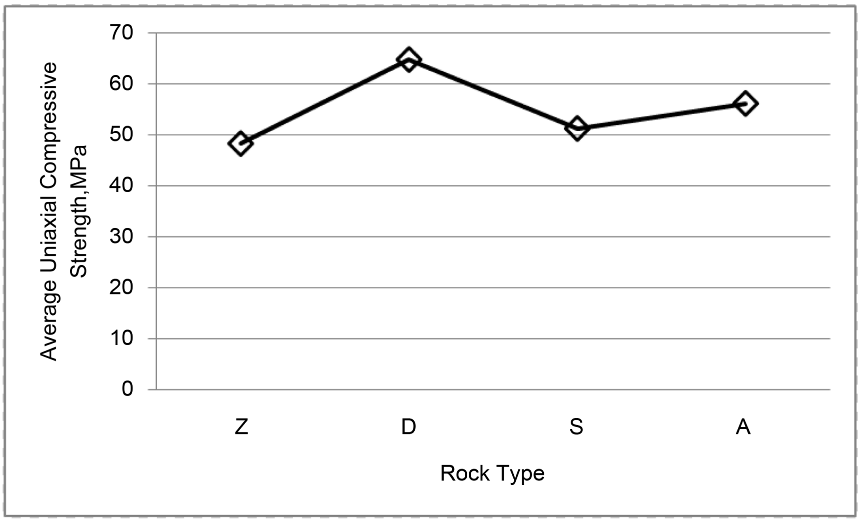

Figure 1. Average porosity for dry samples.

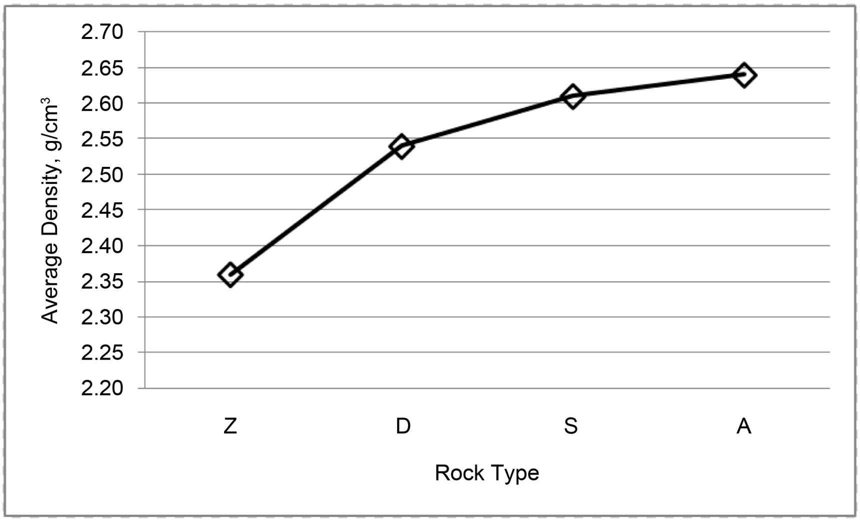

Figure 2. Average density for dry samples.

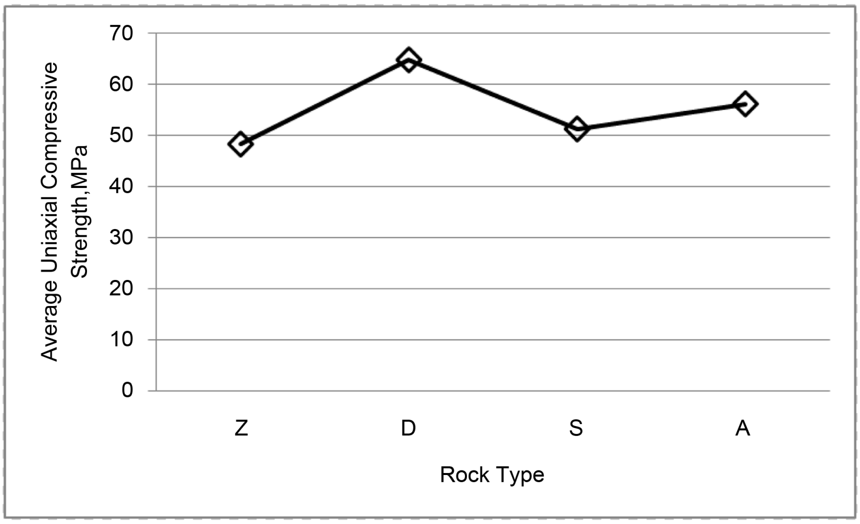

Figure 3. Average uniaxial compressive strength for dry samples.

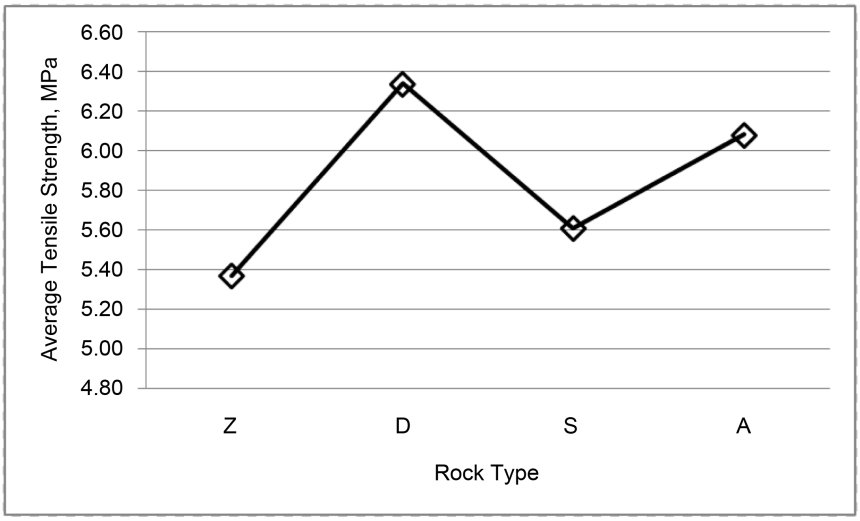

Figure 4. Average tensile strength for dry samples.

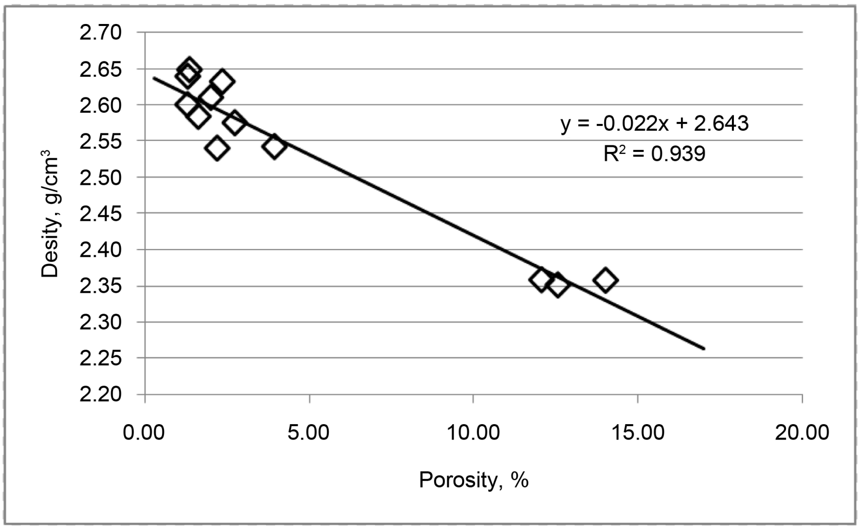

Figure 5. Density vs porosity for all rock.

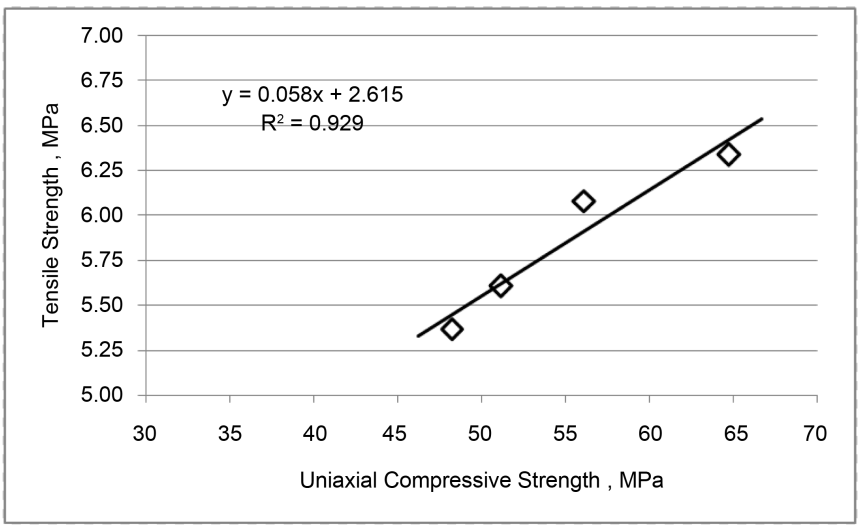

Figure 6. Tensile strength vs uniaxial compressive strength for dry samples.

The effect of degree of saturation on the uniaxial compressive strength and the tensile strength for all limestone samples are shown in Figures 7-14. It can be seen that all

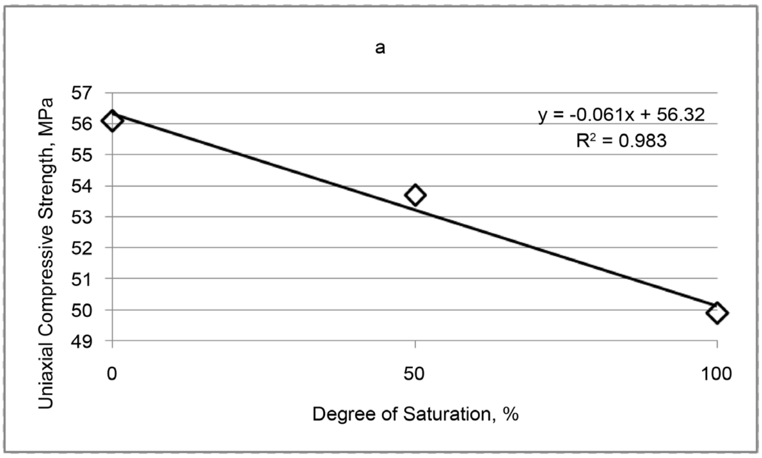

Figure 7. Average uniaxial compressive strength vs degree of saturation for Ajlon limestone.

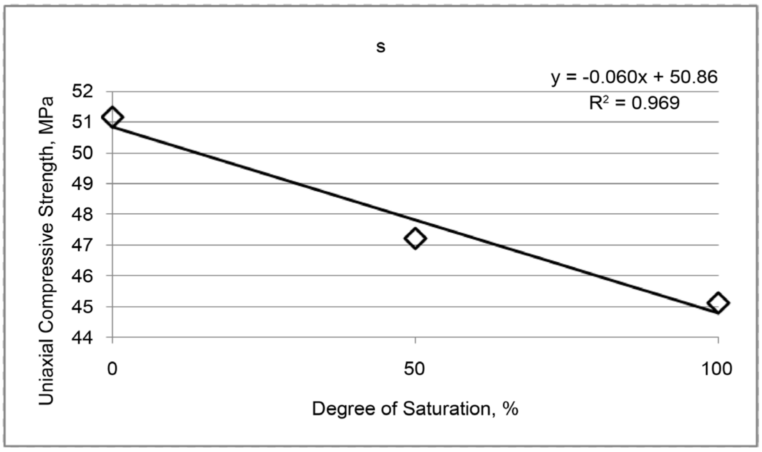

Figure 8. Average uniaxial compressive strength vs degree of saturation for Sateh limestone.

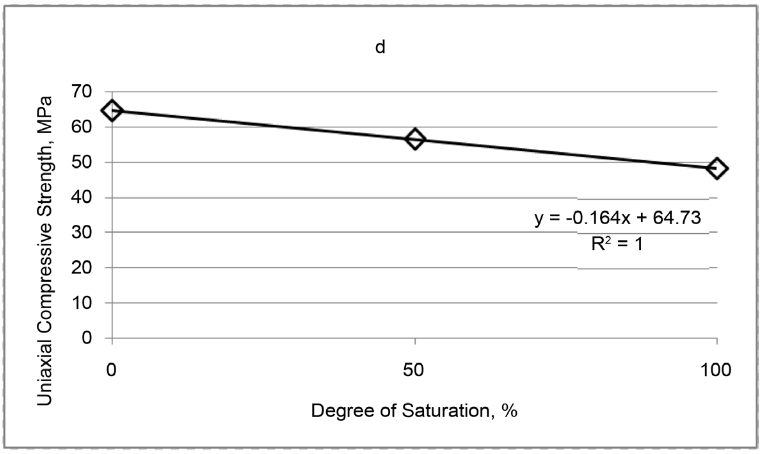

Figure 9. Average uniaxial compressive strength vs degree of saturation for Dabish limestone.

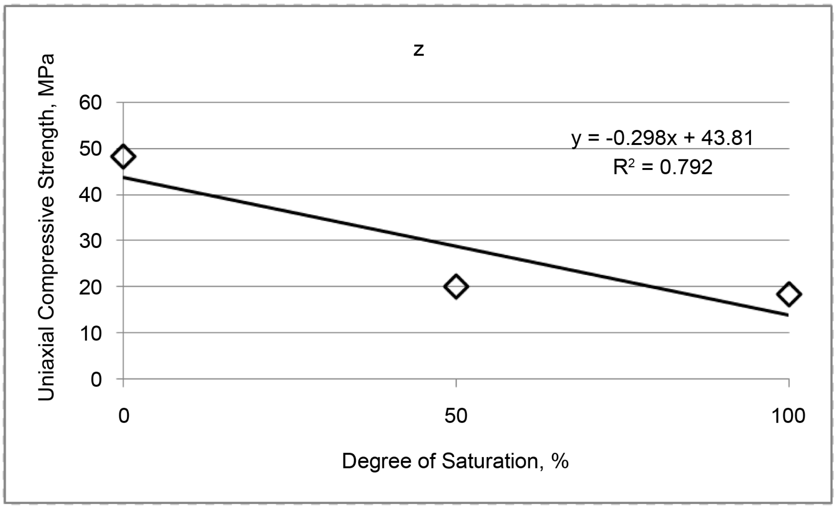

Figure 10. Average uniaxial compressive strength vs. degree of saturation for Zarka limestone.

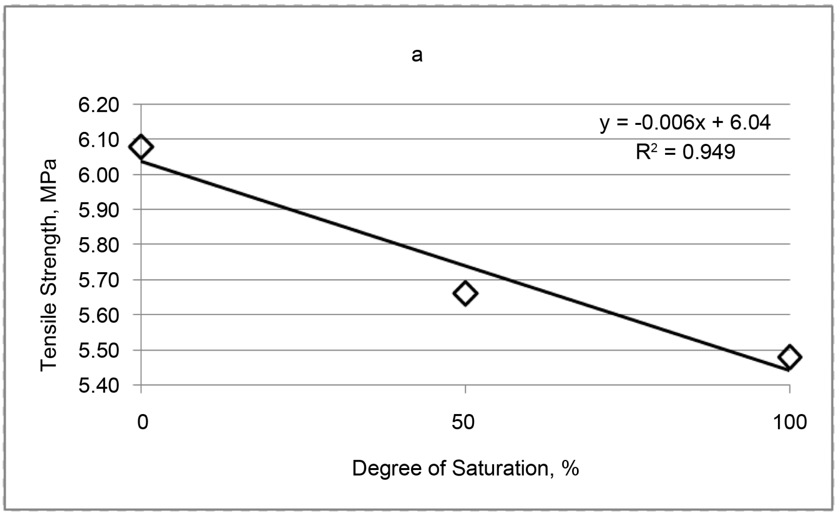

Figure 11. Average tensile strength vs. degree of saturation for Ajlon limestone.

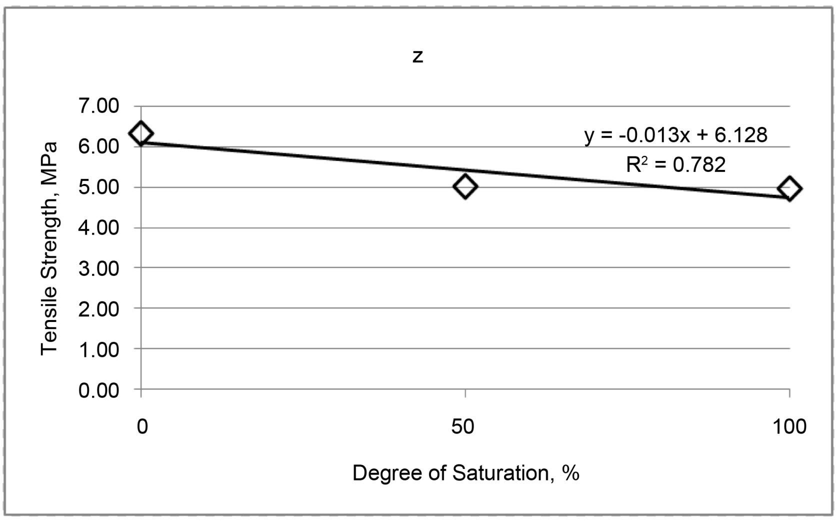

Figure 12. Average tensile strength vs. degree of saturation for Zarka limestone.

rocks experienced a reduction on both the compressive strength and tensile strength as a function of saturation degree. However the reduction degree on the strength is not the same for all limestone rocks.

The variation on percentage reduction in the compressive and tensile strength for all limestone rocks is summarized in Table 5. It is clearly observed that water definitely

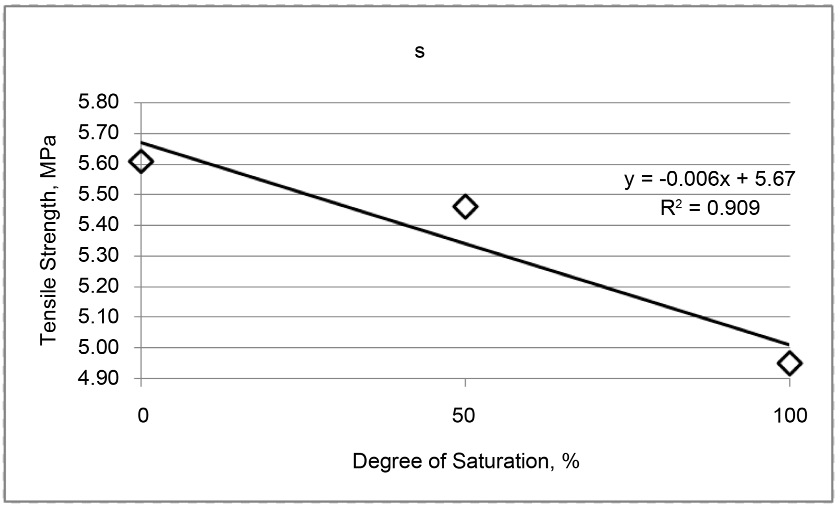

Figure 13. Average tensile strength vs degree of saturation for Sateh limestone.

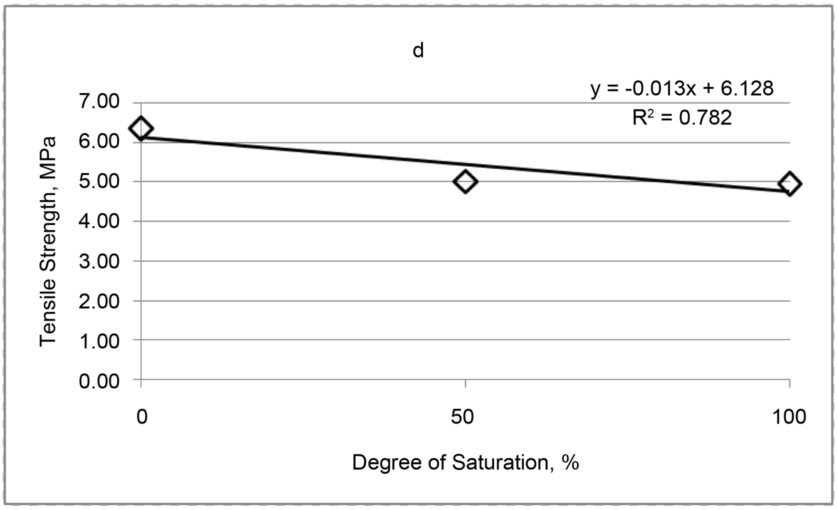

Figure 14. Average tensile strength vs. degree of saturation for Dabish limestone.

Table 5. Percentage reduction on rock strength as a function of saturation degree for all limestone rocks.

Rock	Uniaxial Compressive Strength		Tensile Strength	
	% reduction at 50% saturation	% reduction at 100% saturation	% reduction at 50% saturation	% reduction at 100% saturation
Z	58.3	61.8	62.4	72.1
D	12.5	25.3	20.8	21.7
S	7.8	11.9	2.7	11.8
A	4.3	11.0	6.9	9.9

has detrimental effects on the rock strength parameters. Additionally, the Zarka limestone is more sensitive to the presence of water. A bigger reduction happens on the strength properties for the Zarka limestone than the other limestone when the samples are fully saturated, probably because of the presence of more water sensitive minerals in the Zarka limestone.

4. Conclusion

The density, porosity, Brazilian tensile strength and the uniaxial compressive strength (using axial point load test) for five limestone rocks were determined in the laboratory. The effect of degree of saturation on the strength properties of the five limestones was also examined. It was found that rock with small porosity results in greater rock strength and vice versa. This is clear in the case of Zarka limestone where it has largest porosity and has the lowest tensile and compressive strength. All rock experienced a reduction on both the compressive strength and tensile strength as a function of saturation degree. Large reduction happens on the strength properties for the Zarka limestone than the other limestone when the samples are fully saturated. A good correlation was made between the uniaxial compressive strength and the tensile strength and also between density and porosity. This study will help to understand the behaviour of rock structures which are suffering due to the presence of different watery environments. However, to propose a generalized empirical equation, more tests and data set are required.

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