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EFFECT OF PETROGRAPHIC AND CHEMICAL COMPOSITION ON THE PHYSICAL AND MECHANICAL PROPERTIES OF SOME EGYPTIAN BUILDING STONES

W. M. Draz
Al-Azhar University, Faculty of Engineering, Mining and Petroleum Engineering Department.
waleeddraz2000@yajoo.com

ABSTRACT
Building stones have a wide variety in their mineralogical, texture, microstructure, physical and mechanical properties. In this article, seven types of Egyptian building stones have been chosen, to be examining petrographically and chemically and determine their physical properties and mechanical behavior. these types of studied building stones including; red granite, grey granite (granodiorite), El-Minya marble, Red Sea marble, South Sinai marble, El-Minya limestone and Helwan limestone were tested to obtain their physical and mechanical properties such as; dry density, apparent porosity, water absorption, uniaxial compressive strength, stress-strain curves, abrasion resistance and durability. Experimental and calculated results indicated that, the physical properties and mechanical behavior of the same type of the studied samples are generally a function of a wide range of mineralogy and microstructure including, texture, grain size, pores, fossils and diagenesis presence. These properties affecting the uses of stones as building or decorative stones.
KEYWORDS: Building stones / Petrography / Physical / mechanical behavior.

الملخص:
تتنوع أحجار البناء تنوعاً كبيراً في خواصها المعدنية والنسيجية والبنية المجهرية كما تتنوع خواصها الطبيعية والميكانيكية. في هذا البحث تم اختيار سبعة أنواع من أحجار البناء المصرية لدراسة خواصها الصخرية وتركيبها الكيميائي وتعيين خواصها الطبيعية وسلوكها الميكانيكي. وتضم أحجار البناء المدروسة كلاً من الجرانيت الأحمر والرمادي والرخام من المنيا والبحر الأحمر وجنوب سيناء والحجر الجيري من المنيا وحلوان وعين خواصها الطبيعية والميكانيكية مثل الكثافة الجافة والمسامية الظاهرية وامتصاص الماء وإجهاد الضغط المحوري وسلوك منحنيات الإجهاد والإنفعال ومقاومة البري الجاف والرطب. والنتائج المعملية والحسابات أكدت علي تأثر الخواص الطبيعية والميكانيكية بالتنوع الكبير في الخصائص المعدنية والبنية المجهرية للصخور كالنسيج وحجم الحبيبات والمسامية والحفريات ونسبة التحول. لذا تؤثر هذه الخواص علي استخدام الصخور كأحجار بناء أو صخور زينة.
الكلمات الدالة : احجار البناء/الجرانيت الاحمر /الخواص الطبيعيه والمكانيكيه

1. INTRODUCTION
Stones are used as building or decorative stones depending on its resistance to external factors; abrasion, durability and internal factors; color richness and texture diversity. The most preferred hard natural stone for uses in internal and external facade as cladding, flooring and paving in plate, tile and border forms based on its permanent aesthetic appearance. In historical and modern architecture granite has been a symbol of prestige for protecting buildings, requiring minimum periodic maintenance and keeping its initial appearance for a long time [1].The engineering properties of any rock depends on the following characteristics; percentage and hardness of its constituent minerals, grain size and crystal form. Quartz is one of the commonest hardest minerals in rocks [2].

Granitic rocks show a variety of engineering properties that may affect the use of rock as construction materials according to their high strength, abrasion resistance, and structural and textural characteristics [3]. The mechanical properties of rocks are depend on their mineralogy, texture, microstructure and weathering, where rock texture is a consequence of its mineral size, shape, and spatial arrangement which frequently reflect its origin and geological setting. Micro-voids or pore spaces have a significant effect on mechanical performance. It was reported that, in sedimentary rocks all strength properties decrease with increasing porosity [4]. The physical explanation of this criteria is that, high porosity assists a networking (propagation) of stress which induced micro-fractures [5].

Stone microstructure has a major role in commercial granites. Explosives used in the production of stone blocks cause many defects especially “micro fissures” in the granite body in additional to that induced from the tectonic action which have adversely effect on the physical properties and mechanical behavior of stones. Experimental studies of damage process of granite specimens under uniaxial compression were carried out to determine the effect of micro-cracks and micro-cavities on rock strength [6-8].

A number of investigations had been studied the relationship between petrographic and mechanical properties of granites. The results of these investigations indicated that, the mechanical properties of granites are a function of a wide range of petrographic parameters including grain size, mineral composition and weathering [9-13].

Durability is the fundamental property of the resistance of rocks to a combination of wetting and abrasion. The slake durability test defines the weathering behavior of rocks and assess the resistance offered when subjected to two standard cycles of drying and wetting along with movement. In the slake durability test, the apparatus combines the effects of both soaking and abrasion in order to accelerate the rate of weathering that can be attained by water immersion alone. Due to the increase in the water content in the pores, fracture develops in the rock which leads to the weathering of rocks [16].

The main goal of the present research is that, studying the effect of microstructure, petrography and mineralogy on the physical properties (dry density, apparent porosity, water absorption) and mechanical behavior of the selected rocks (uniaxial compressive strength and abrasion resistance) which have widely use as construction materials and decorative stones, in additional to studying the mechanism of failure for these rocks under uniaxial compression and other related parameters such as; the modulus of elasticity, the Poisson`s ratio and the crack damage stress. The results of this study could be used in chosen the suitable type of decorative stones for specific purpose and predict the behavior of decorative stones in different usage environments.

2. MATERIALS AND METHOD

2.1. Raw Materials

Seven of Egyptian building stones with different origin have been chosen to studying. Granitic samples were collected from two different quarries in Aswan, red and grey granite (granodiorite), while marble samples were collected from three different quarries El-Minya marble, Red Sea marble and South Sinai marble, in addition limestone samples were collected from two different quarries El-Minya limestone and Helwan limestone. The locations coordinates of the studied stones are listed in table (1).

Table 1: The locations coordinate of the studied stones.

Rock category	Name of samples	Longitudes E.	Latitudes N.
Granite	Red granite	32° 58′	24° 03′
	Gray granite	33° 23′	23° 05′
Marble	El-Minya	31° 48′	28° 21′
	Red Sea	32° 33′	28° 52′
	South Sinai	33° 10′	29° 19′
Limestone	El-Minya	30° 50′	28° 20′
	Helwan	31° 22′	29° 48′

2.2 Methods and Tests

2.2.1. Petrographic Analysis

The petrographic analysis carried out at the Central Laboratories Sector of The Egyptian Mineral Resources Authority. Thin sections were prepared from each stone for Polarizing microscopic investigation. The petrographic analysis of studied granitic samples revealed that; Red granite samples (fig. 1.A) composed mainly of potash feldspars (50-55%), quartz (15-20%), plagioclase (15-20%) and mafic minerals as biotite and hornblende (7-10%) with rare amounts of muscovite and opaque minerals. Quartz occurs as coarse to medium grained, anhedral crystals, display wavy extinction and sutured boundaries. Quartz slightly deformed and cracked in some parts.

Grey granite samples (fig. 1.B) composed mainly of plagioclase feldspars (35-40%), quartz (25-30%), potash feldspars (15-20%), biotite and hornblende (10-12%) as essential minerals associated with rare opaque minerals (1%). Quartz occurs as medium to fine grained, anhedral to subhedral crystals intercalated with other minerals constituents.

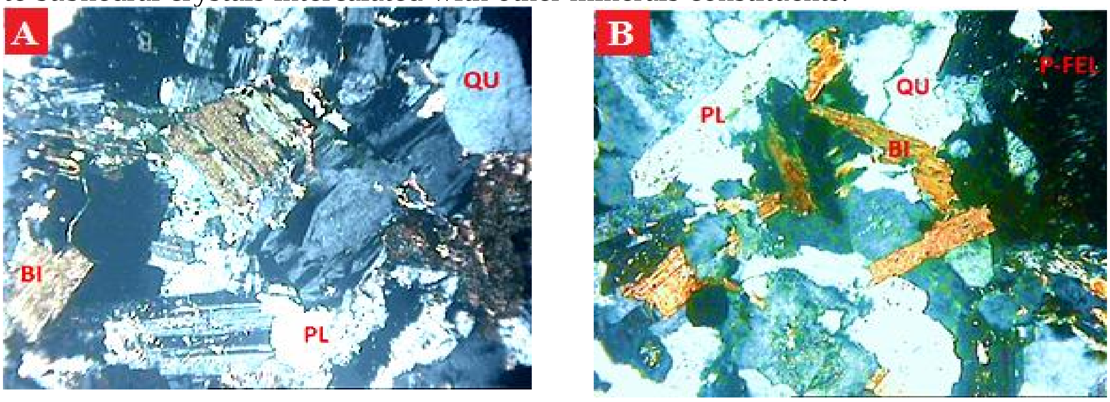

Figure 1: Photo-micrograph of:
(A) Red granite C.N. X.40, (B) Grey granite (granodiorite) C.N. X.63.
Where; QU= Quartz, P- FEL= Potash Feldspars, PL= Plagioclase, BI= Biotite.

The petrographic analysis of studied marble samples revealed that;

El-Minya marble samples (fig. 2.A) composed of calcite as major constituent associated with traces of iron oxides and opaque minerals. The matrix of stone composed of very fine grained calcite (micrite). Microfossils are presented as large to medium sized. Microfossils composed of mainly of sparite (recrystallized calcite) and/or micrite in some parts due to incompletely recrystallization. Some pores are detected in the stone scattered in calcite matrix.

Red Sea marble samples (fig. 2.B) composed of calcite as major mineral constituent associated with minor amounts of dolomite and traces of quartz, iron oxides and opaque minerals. Calcite occurs in two forms, as micrite (very fine-grained matrix of calcite) and/or sparite (fine to medium- grained, recrystallized calcite). Microfossils are presented in considerable amounts as very fine sized of different shapes of recrystallized calcite. Pores are detected in the stone as fine pore spaces.

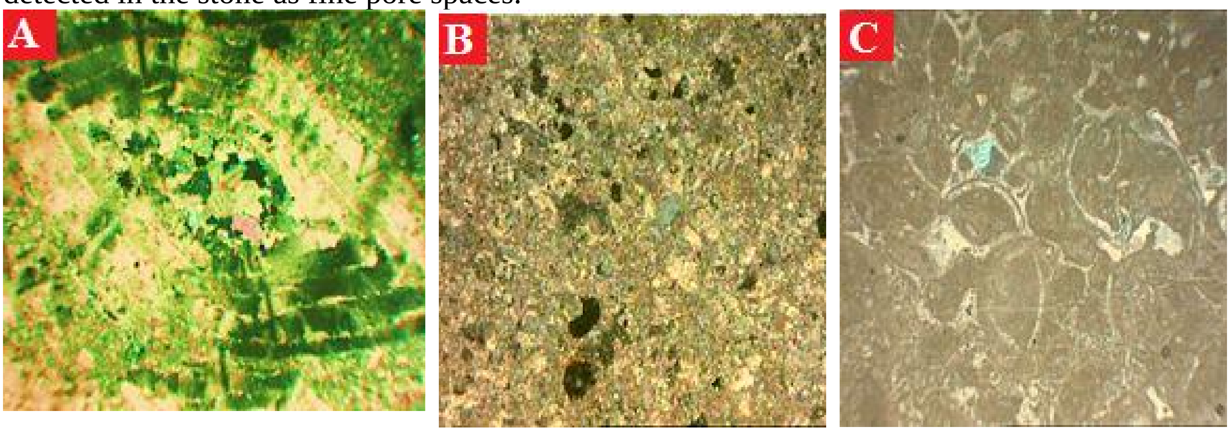

Figure 2: Photo-micrograph of:
(A) El-Minya marble C.N. X.25, (B) Red Sea marble C.N. X.63, (C) South Sinai marble C.N. X.25.

South Sinai marble samples (fig. 2.C) composed of calcite as major mineral constituent associated with minor amounts of dolomite, traces of quartz, iron oxides and opaque minerals. Microfossils are presented in great amounts as medium to fine sized. Microfossils composed of mainly of micrite and sometimes sparite. Few pores are detected in the rock.
The petrographic analysis of limestone samples revealed that;
El-Minya limestone samples (fig. 3.A) showing that, the rock is medium to coarse grained and composed mainly of calcite as essential component with rare amounts of dolomite, quartz and iron oxides, opaque and clay minerals. Microfossils present in huge amount and scattered in the matrix of calcite. A high amount of pores are detected in the stone as medium to fine pore spaces and pockets scattered in calcite matrix.
Helwan limestone samples (fig. 3.B) showing that, the stone is fine grained, and composed mainly of calcite associated with trace amounts of dolomite, quartz, iron oxides and clay minerals. Calcite occurs as very fine grained and represents the matrix of the stone. Some microfossils and shell fragments are presented in trace amounts. Quartz occurs as fine grains of sub-angular to sub-rounded outlines are detected in the matrix of calcite. Some pockets are presented and filled with calcite.

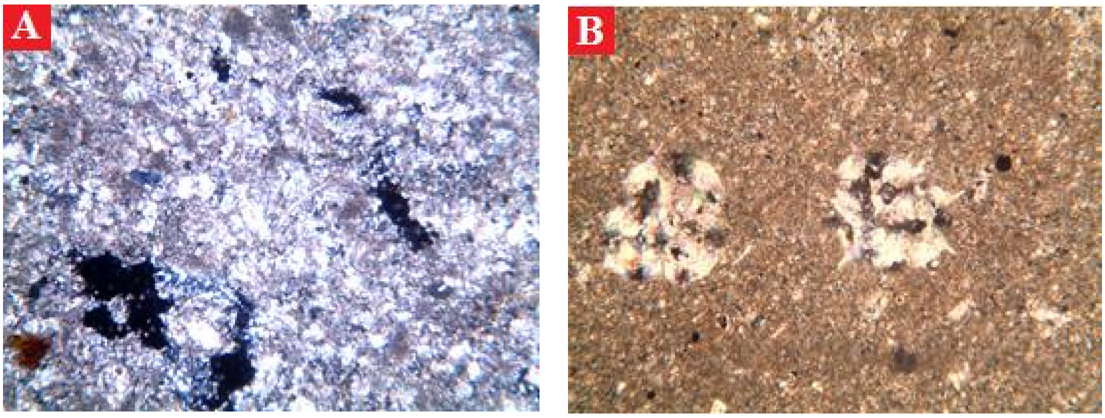

Figure 3: Photo-micrograph of:
(A) El-Minya limestone C.N. X.25, (B) Helwan limestone C.N. X.40.

2.2.2. Chemical Analysis

A complete chemical analysis was carried out at the Central Laboratories Sector of The Egyptian Mineral Resources Authority. Selected samples of building stones were geochemically analyzed. The major oxides of the selected samples were determined by using XRF. Chemical analysis of major oxides for studied granite, marble and limestone rocks are given in table (2).

Table 2: Chemical analysis of studied granite, marble and limestone (%).

Granite			Marble				Limestone		
Major oxides	Red	Grey	Major oxides	El-Minya	Red sea	South Sinai	Major oxides	El-Minya	Helwan
SiO_2	69.40	74.60	SiO_2	Traces	0.45	0.75	SiO_2	0.25	4.95
Fe_2O_3	3.76	2.17	Fe_2O_3	0.09	0.15	0.37	Fe_2O_3	0.08	0.27
CaO	2.49	2.10	CaO	55.45	55.18	54.92	CaO	54.72	51.92
MgO	0.78	0.68	MgO	0.38	0.32	0.06	MgO	0.47	0.60
Al_2O_3	13.09	13.23	Al_2O_3	0.07	0.05	0.16	Al_2O_3	Traces	0.69
TiO_2	0.68	0.36	L.O.I	43.71	43.15	43.15	L.O.I	43.94	40.87
MnO	0.16	0.11	In. R	0.17	0.56	0.41	In. R	0.45	0.53
Na_2O	4.05	3.27							
K_2O	4.65	2.60							
L.O.I	0.93	0.81							

Total	**99.99**	**99.93**	**Total**	**99.87**	**99.86**	**99.82**	**Total**	**99.91**	**99.83**

2.2.3. Physical Properties

The physical properties of studied building stones include; dry bulk density, apparent porosity and water absorption. Five samples of each type of studied stones were investigated in the Mineral Processing Laboratory, Faculty of Engineering, Al-Azhar University. The results of the physical properties for granite, marble and limestone samples are given in Table (3).

Table 3: Physical properties of studied granite, marble and limestone.

Name of sample	Dry density (gm/cm^3)	Apparent porosity (%)	Water absorption (%)
Red granite	2.616	0.650	0.252
Gray granite	2.620	0.554	0.190
El-Minya Marble	2.328	6.076	2.412
Red Sea Marble	2.566	3.010	1.194
South Sinai Marble	2.578	2.788	1.108
El-Minya Limestone	1.946	22.792	9.100
Helwan Limestone	2.140	17.040	6.940

2.2.4. Mechanical Properties

2.2.4.1. Uniaxial Compression Test

Five sample of each type of studied stones were tested under uniaxial compression. Tests were carried out in the Concrete Laboratory, Civil Engineering Department, Al-Azhar University using a Computerized Uniaxial Compression Machine. The samples were prepared as cubical samples with dimensions of 10 x 10 x 10 cm^3, which have a unity of height to length ratio. Each test accomplished by continuous recording of axial and lateral strains corresponding to applied load up to failure by using two vertical and two lateral strains measured by electric strain gauges. The uniaxial compressive strength was obtained from the recorded value of the force divided by the cross sectional area of the specimen as following formula [14]:

$$\sigma_c = P/A$$

Where; σ_c = Compressive strength, P = Applied load at failure and A = Cross sectional area of the specimen.

2.2.4.2. Stress-strain curves

The results of the uniaxial compressive tests are used in construct typical stress-axial strain, stress-lateral strain and stress-volumetric strain diagrams, which are indicate the behavior of the studied stones under the uniaxial compression. Each stress-strain curve was divided into four stages of fracture mechanism in uniaxial compression as the following; The first stage represents the micro-cracks and pores closure, the second stage represents the linear elastic deformation, the third stage represents the plastic deformation (induce joining of cracks and stable growing of it), and the fourth stage represents the crack damage and unstable crack growth. All stages of the stress-strain curves are shown for the most and the least compressive strength stone samples in figures (4, 5) respectively. The compressive strength (σ_c), volumetric strain (ε_v), modulus of elasticity (E), and Poisson's ratio (υ) were calculated for each stage, also when volumetric strain reached its maximum value ($\varepsilon_{v\ max}$), the stress level was determined, which known as the crack damage stress (σ_{cd}). The volumetric strain (ε_v) measure the relative volume change in the tested specimen ($\Delta V/V$) can be calculated by applying the following formula [12]:

$$\varepsilon_V = \varepsilon_a + 2\varepsilon_l$$

Where; ε_v = Volumetric strain, ε_a = Axial strain and ε_l = Lateral strain.

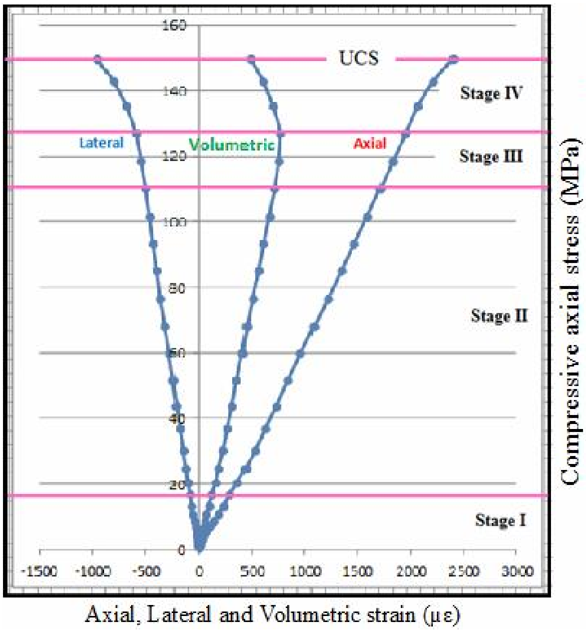

Figure 4: Stress-Strain curves for the most (σ_c) stone samples (Grey granite).

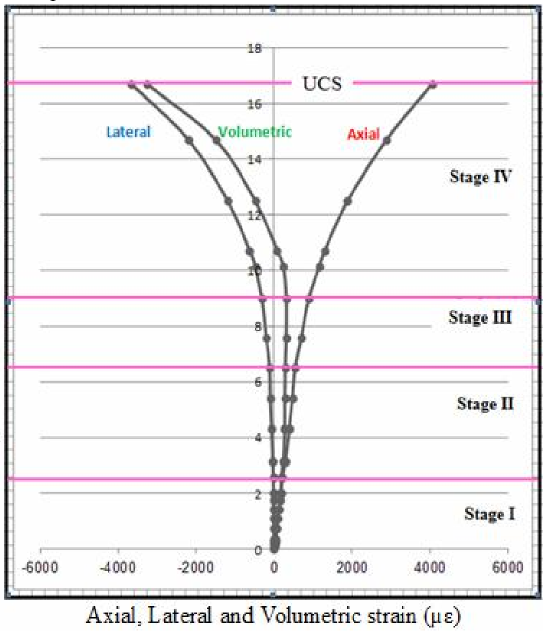

Figure 5: Stress-Strain curves for the least (σ_c) stone samples (El-Minya limestone).

The results of different stresses, volumetric strains, modulus of elasticity and Poisson's ratios delivered and calculated from uniaxial compression tests and stress-strain curves for each stage of fracture for granite, marble, in addition limestone samples are listed in the following tables (4, 5).

Table 4: Results of compressive stresses and volumetric strain of each stage of failure for granite, marble and limestone.

Name of sample	Stage 1		Stage 2		Stage 3		Stage 4	
	σ MPa	ε_v με	Σ MPa	ε_v με	σ_{cd} MPa	$\varepsilon_{v\,max}$ με	σ_c MPa	ε_v με
Red granite	14	152	76	458	90	514	111	21
Gray granite	16	125	110	717	127	769	150	488
El-Minya Marble	8	57	26	247	37	352	49	-1724
Red Sea Marble	14.50	103	52	350	70	454	87	-229
South Sinai Marble	10	156	45	490	66	625	82	-298
El-Minya Limestone	2.05	181	6.50	334	9	381	16.30	-2262
Helwan Limestone	2.60	171	9.20	323	13.5	376	22.20	-2047

Table 5: Results of modulus of elasticity and Poisson's ratio of each stage of failure for granite, marble and limestone.

Name of sample	Stage 1		Stage 2		Stage 3		Stage 4	
	E GPa	υ	E GPa	υ	E GPa	υ	E MPa	υ
Red granite	50	0.18	60	0.24	62	0.35	28	0.42
Gray granite	56	0.15	69	0.20	70.30	0.33	51	0.41
El-Minya Marble	24	0.26	40.30	0.32	25	0.39	4.1	0.48
Red Sea Marble	39	0.22	55.70	0.27	50.10	0.36	12.40	0.45
South Sinai Marble	36	0.23	53.70	0.29	48	0.37	15.50	0.45
El-Minya Limestone	3	0.29	5	0.38	4	0.44	2.5	0.49

Helwan Limestone	4	0.27	7	0.37	5	0.40	3	0.48

2.2.4.3. Abrasion Test

Abrasion investigation of studied stones samples was performed at Housing and Building National Research Center (HBNRC). The cross sectional area of the test specimens was 7 x 7 cm^2. These specimens were mounted in a rotating abrasion testing machine whose rate of rotation is 38 r.p.m. The loss in weight was determined after 352 revolutions. The granite and marble specimens were placed under a pressure of 600 $gm./cm^2$ while, limestone specimens were placed under a pressure of 300 $gm./cm^2$ and using sand (25-36 mesh) as abrasive material. The thickness loss was determined according to the formula [15]:

$$Thickness\ loss = \frac{M_1 - M_2}{A \times \rho}$$

Where; M_1 = Initial mass of specimen (gm.), M_2 = Final mass of specimen (gm.), ρ = Density of specimen (gm. /cm^3) and A = Cross sectional area of the specimen (cm^2).

The results obtained from the abrasion test for granite, marble in addition limestone samples are given in table (6).

Table 6: Results of the abrasion test for granite, marble and limestone.

Name of sample	Av. initial weight (gm.)	Av. final weight (gm.)	Density (gm/cm^3)	Av. Loss of thickness (mm.)
Red granite	319.33	316.66	2.70	0.116
Gray granite	305.00	302.30	2.71	0.176
El-Minya Marble	277.00	248.33	2.46	2.276
Red Sea Marble	341.33	318.66	2.67	1.610
South Sinai Marble	298.66	287.00	2.69	0.823
El-Minya Limestone	250.66	224.33	2.06	2.586
Helwan Limestone	247.66	223.66	2.22	2.390

2.2.4.4. Slake durability

The slake durability test for the studied stones was investigated in The Rock Mechanics Lap, Faculty of Engineering, Al-Azhar University using the Slake durability apparatus. The sample should weigh (500±50 gm.). Rock samples were put into apparatus, with a drum rotations were 20 rpm. After slaking for the period of 10 minutes, these rock samples were dried at a temperature of 105^o for up to 6 hours. Finally, the dried samples were weighted to obtain the first cycle. The test was conducted over second cycles.

The results obtained from the slake durability test for granite, marble in addition to limestone samples are given in table (7).

Table7: Results of slake durability for studied granite, marble and limestone.

Name of sample	Av. initial wt. gm.	Av. wt. after 1st cycle gm.	Av. wt. after 2nd cycle gm.	Retained after 1st cycle %	Retained after 2nd cycle %	Category according to durability resistance
Red granite	499.20	495.90	491.62	99.39	98.48	Very high
Gray granite	499.60	498.16	495.92	**99.71**	**99.26**	Very high
El-Minya Marble	499.60	480.24	459.10	96.12	91.89	High
Red Sea Marble	499.20	489.52	478.92	98.06	95.94	High
South Sinai Marble	499.00	491.78	482.12	98.55	96.62	High
El-Minya Limestone	499.40	421.28	361.08	**84.36**	**72.30**	Medium
Helwan Limestone	499.40	459.40	418.00	91.99	83.70	Medium

3. DISCUSSIONS

3.1. Effect of mineralogy and microstructure on the physical properties and mechanical behavior of granite.

Comparing the mechanical properties of granitic samples, it can be seen that, red granite samples have lower values of uniaxial compressive strength than grey granite (111 and 150) respectively (table 4) because red granite has few amount of quartz about (15-20%) in addition to it has coarse grained texture in addition some crystals of quartz slightly deformed and cracked in some parts of stone. It is also observed that, red granite samples exhibit high resistance to abrasion as compared to grey granite by about (34%) (table 6). This explained by that when these rocks aggregates abrade during abrasion, the larger mineral grains of red granite have a lager surface area to abrade as compared to the smaller mineral grains for grey granite. Therefore it is preferable to use red granite in applications subjected to high friction i.e. stairs. Red granite samples have high value of apparent porosity as well as the water absorption corresponding with grey granite by about (14.8% and 24.6%) respectively (table 3).

Summary results of slake durability test for granitic samples (table 7) presents that, grey granite samples exhibit higher values of the retaining percentages as compared to red granite samples, this due to red granite samples have high value of apparent porosity and water absorption (table 3).

Grey granite samples exhibit the highest value of uniaxial compressive strength (150 MPa). This explained by presence of high amount of quartz in this stone with a range of (25-30%) also, these rocks have fine grained texture in addition it didn’t deformed and cracked as quartz in red granite (fig. 1).

The failure behavior of red granite and grey granite samples (table 4, 5 and fig. 4). It can be observed that both stress-strain curves are considerably different. In crack closure region (stage I), red granite consumed ($^{14}/_{111} \times 100 = 12.6\%$) while, grey granite consumed ($^{16}/_{150} \times 100 = 10.7\%$) of its failure strength. This due to that, red granite have high porosity and some grains deformed and cracked as shown in (fig. 1). In case of perfect elastic region (stage II), grey granite exhibits the longest elastic region hence it has the highest elastic modulus (69 GPa) as shown in (table 4) which consumed (62.7%) of its failure strength. This can be explained that grey granite exhibits the high percentage of quartz and it has fine grained texture and the lowest porosity, while red granite exhibit low percentage of quartz besides coarse grained texture. In case of plastic deformation (stage III), grey granite possesses the highest crack damage stress (127 MPa) (table 4), this because it has fined grained texture. So grain size has adversely proportional with the crack damage stress, this mean that, increasing in grain boundaries due to coarse grain size, provided more continuous paths of weakness for growing cracks to propagate and promoting more rapid degradation of rock grains. So rock strength was found to decrease with increasing grain size.

3.2. Effect of mineralogy, microstructure and diagenesis on the physical properties and mechanical behavior of marble.

Comparing the mechanical properties of marble samples, it is observed that El-Minya marble exhibits the lowest values of uniaxial compressive strength and abrasion resistance (49 MPa and 2.276 mm.) respectively (table 4 and 6) in comparing with Red Sea and South Sinai marble samples, also it has the highest value for both of apparent porosity and water absorption (6.076% and 2.412%) respectively (table 3). This can explained by the presence of microfossils in great amounts which presented as large to medium sized and incompletely metamorphism (diagenesis) or recrystallization process of sparite (fine grained calcite) to micrite (recrystallized coarse grained calcite) in additional some pores are detected in thin-sections analysis of this stone (fig. 2-A).

Results of slake durability test for marble samples (table 7) presents that, South Sinai marble samples exhibit higher values of the retaining percentages as compared to Red Sea marble samples and El-Minya marble adversely its apparent porosity and water absorption values (table 3).

Red Sea marble has the highest values of uniaxial compressive strength (87 MPa) (table 4) in addition medium values of porosity and water absorption is low (3.010% and 1.194%) respectively (table 3). This due to these samples composed of very fine grained in a homogeneity texture (well sorted) besides presence of traces of quartz grains in this rock which lead to increasing in the hardness properties in addition low percent of pores and fossils were observed (fig. 2-B).

South Sinai marble has high values of uniaxial compressive strength (82 MPa) (table 4) in addition the lowest values of porosity hence water absorption (2.788% & 1.108%) respectively (table 3). This is due to it has very fine grained texture and few pores are detected. However, these samples contain microfossils in great amounts as medium to fine size which can affect the hardness properties of these rocks. It exhibits the highest resistance to abrasion (0.823 mm.) (table 6), this is due to containing high amount of silica and iron oxides (0.75% and 0.37%) respectively (table 2), as well as it has very little presence of pores and micro-fractures comparing with Red Sea and El-Minya marble samples. So South Sinai marble can be used for applications subjected to high friction and decoration purposes (indoor applications).

The failure behavior of studied marble types, El-Minya, Red Sea and South Sinai marble (table 4-5) indicated that, in the crack closure region (stage I), El-Minya marble consumed ($^{8}/_{49} \times 100 = 16.3\%$) of its failure strength, while Red Sea ($^{14.5}/_{87} \times 100 = 16.67\%$) and South Sinai marble ($^{10}/_{82} \times 100 = 12.19\%$). This due to that, El-Minya marble samples have micro defects such cracks, pores and microfossils in high amounts while Red Sea and South Sinai marble samples have few amount of micro defects. In case of perfect elastic region (stage II), it is observed that Red Sea marble have the highest value of elastic modulus followed by South Sinai and El-Minya marble (55.7, 53.7 and 40.3 GPa) respectively (table 5). In case of Plastic region (stage III), it is observed that Red Sea have the higher value of crack damage stress followed by South Sinai and El-Minya marble (70, 66 and 37 MPa) respectively (table 4). This explained by that, Red Sea marble have fine grained and well sorted texture while El-Minya marble has a lot of micro-defects and a wide range of grain size of sparite and micrite.

3.3. Effect of mineralogy, microstructure and fossils on the physical properties and mechanical behavior of limestone.

Comparing the mechanical properties of limestone, it is observed that El-Minya limestone has lower values of uniaxial compressive strength than Helwan limestone (16.3 and 22.2 MPa) respectively (table 4 and fig. 5). Also it has the high value of apparent porosity (22.792%) and the water absorption (9.1%) (table 3). This due to, El-Minya limestone is composed mainly of calcite, which it has medium to coarse grains and huge amount of microfossils, pores and pockets scattered in the matrix of calcite (fig. 3-A), so this type of limestone exhibit the lowest resistance to abrasion (2.586 mm.) (table 6) although it tested under pressure 300 gm/cm^2. The most suitable application for El-Minya limestone is as a raw material in cement manufacturing and chemical industries because the presence of high content of calcium carbonate.

Similarly slake durability test for limestone samples (table 7) presents that, Helwan limestone exhibit higher values of the retaining percentages as compared to El-Minya limestone samples adversely its apparent porosity and water absorption values (table 3).

Helwan limestone has better values of mechanical properties, such as uniaxial compressive strength and abrasion resistance, than El-Minya limestone (22.20 MPa and 2.390 mm.) respectively (table 4 and 6), this due to; it has a very fine grained texture, the trace presence of microfossils and pores, the presented pockets are filled with calcite and the high ratio of silica and iron oxides comparing with El-Minya limestone (4.95% - 0.25% of silica) and (0.27% - 0.08% of iron oxides) respectively (table 2).

The failure behavior of studied limestone types, El-Minya, and Helwan limestone samples (table 4-5) indicated that, both of them are considerably differ. In crack closure region (stage I), Helwan limestone consumed ($^{2.6}/_{22.2} \times 100 = 11.71\%$) of its failure stress as compared to El-Minya limestone ($^{2.05}/_{16.3} \times 100 = 12.58\%$), this due to El-Minya limestone contains more pores and pockets. In case of perfect elastic region (stage II), Helwan limestone exhibits longer elastic region (2.6-9.2 MPa) as compared to El-Minya limestone (2.1-6.5 MPa) hence it has the higher value of the elastic modulus (7 GPa) (table 5). In case of plastic deformation (stage III), Helwan limestone possesses the higher value of the crack damage stress (13.5 MPa) as compared to El-Minya limestone (9 MPa) (table 4). This can be explained by that, Helwan limestone has fine grained texture and high amount of silica as explained previous.

4. CONCLUSIONS

From the above results and discussions, we can be concluded that:

1. The most of studied stones are suitable for use as building or decorative stones. And it can classified as; Granite is high strength, marble is medium strength except El-Minya marble considers a low strength while limestone is very low strength stone.
2. The mineralogical compositions, recrystallizations and diagenesis have a direct effect on the physical and mechanical properties of all stones.
3. The mechanical properties of marble and limestone enhancing by the presence of silica and iron oxides. However the high silica content render the cutting and polishing and this is clear in South Sinai marble and Helwan limestone samples.
4. Microstructure of stones plays a major role in its mechanical behavior. Microfossils, pores and pockets have adversely effect on the physical and mechanical properties.
5. Grain size has adversely proportional with both of crack damage stress and modulus of elasticity. This mean that, increasing in grain boundaries due to coarse grain size, provided more continuous paths of weakness for growing cracks to propagate and promoting more rapid degradation of rock grains.
6. Marble has a wide variety in texture, but in general it shows interlocking crystalline texture because calcite grains found in two forms, as micrite (very fine grained calcite) and sparite (medium to coarse grained of recrystallized calcite). This followed by a variation in the mechanical properties such as strength and abrasion resistance.
7. The studied limestone, especially El-Minya limestone, is most suitable for the cement manufacturing and chemical industries due to high containing of calcium carbonate.

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