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Effect of Petrographical Characteristics on the Engineering Properties of Some Egyptian Ornamental Stones

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Abstract— Ornamental stones have a wide variety in their mineralogical, petrographic and engineering properties.Five different types of Egyptian ornamental stones have been chosen to be analyzed chemically and petro-graphically for studying their engineering properties as a function of their petrographic characteristics. These types of studied ornamental stones including; Aswan red granite, Aswan granodiorite (grey granite), Minya, Red Sea and South Sinai marble were prepared for mechanical and physical tests. The mechanical and physical properties included; uniaxial compression, abrasion resistance, apparent porosity, water absorption, and dry density. The results indicated that the engineering properties of samples of the same type are generally a function of a wide range of petrographic parameters including; appearance, texture, grain size, mineralogical composition, degree of metamorphism, diagenesis, rate of strength minerals, pores, micro-cracks and fossils that will affect the stone selection for different uses.

Index words—Ornamental stones, petrographic characteristics, engineering properties.

1 Introduction

The term ornamental stones are namely used commercially as a result of its resistance to external factors, strength , texture diversity and aesthetic appearance in additional to their physical and mechanical properties. It is the most preferred hard natural stone type for uses in internal and external façade as cladding, flooring, roofing and, tiles. In historical and modern architecture ornamental stones have been a symbol of prestige for protecting buildings, requiring minimum periodic maintenance and keeping its initial appearance for years. [1].

Commercially the term marble is extended to include any rocks consisting of calcium and/or magnesium carbonate which could be polished easily, including ordinary limestone are termed as marble.The term is further extended to include stones such as alabaster, serpentine and other soft rocks. Marble is a durable stone in dry atmosphere only when protected from rain. The surface of marble crumbles readily when exposed to moist or acidic environment. Purest form of marble is statuary marble, which is white with visible crystalline structure. The engineering properties of a rock depends on the following characteristics; hardness of its constituent minerals, grain size and crystal form. Quartz is one of the commonest very hard 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 dependent 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. In magmatic rocks that strength evidently decreases when the grain size increases and they emphasize a linear relation between these two variables [4]. Relations between uniaxial compressive strength of limestone and their physical properties were studied [5, 6].

A number of investigations have studied the relationship between petrographic and mechanical properties of granites. The results of these investigations indicated that the mechanical strength of granites as a function of a wide range of petrographic parameters including grain size, mineral composition and weathering [7-15]. Although the relationships between the mechanical properties and petrographic characteristics of granitic rocks are well known, the effect of mineralogical characteristics on the engineering properties of granite types is different.

Classification of rocks depends on their texture coefficient values as igneous, metamorphic and sedimentary. Igneous rocks showed a high texture coefficient value and strength and small drillability property, whereas sandstones showed small texture coefficient value and strength. Marbles are situated between these two rocks. High texture coefficient of rocks is resulted from the increment in the number of grains, complexity of grain, random grain orientation and high grain concentration [16].

The aim of this study is to quantify the relationships between the petrographic characteristics, and engineering properties of selected granitic and marble rocks from five different quarries in Egypt, which have widely used in building or as ornamen-

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tal stone. The results of this study will be used to predict the engineering properties of these rocks based on mineralogical andpetrographic characteristics.

2. MATERIALS AND METHOD.

2.1. Raw Materials.

Granitic samples were collected from two different quarries in Egypt (El Shellal andAbo Marwa-Aswan) on the other hand; Marble samples were collected from three different quarries (El Sheikh Fadl - Minya, Zaafarana- Red Sea and Wadi Wata-South Sinai) as shown in (fig.1). Also, these types of the selected ornamental stones are listed in Table1.

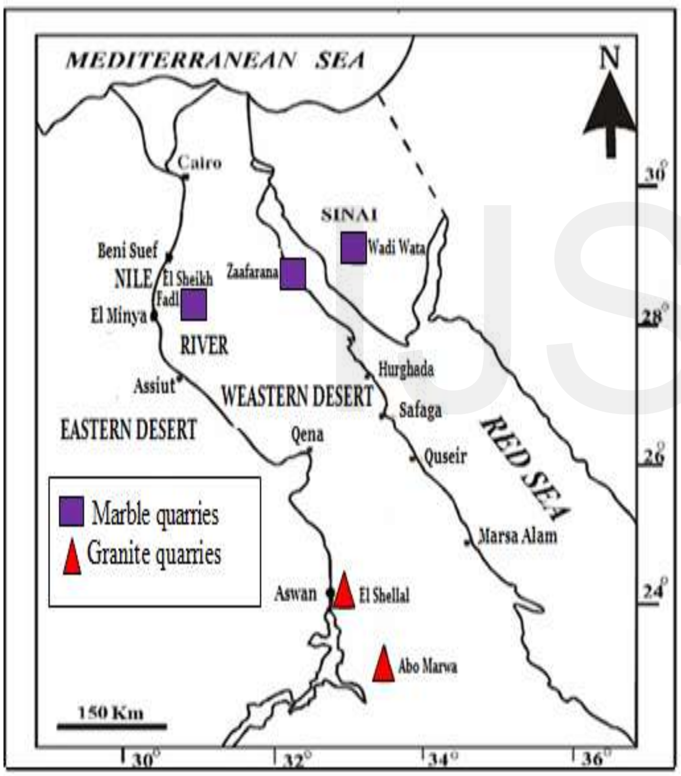


Fig. 1. Location map of the studied areas.

TABLE 1

TYPES OF THE SELECTED SAMPLES OF ORNAMENTAL STONES.

Rock type	Location	Commercial name
Granite	El Shellal – Aswan	Red Granite
Granodiorite	Abo Marwa – Aswan	Grey Granite
Marble	El sheikh Fadl – Minya	Sunny Marble
Marble	Zaafarana- Red Sea	Botchino Marble
Marble	Wadi Wata - South Sinai	Teriesta Marble

2.2 METHODS AND TESTS

2.2.1 Petrographic analysis

The petrographic studies are carried out by the Central Laboratories Sector at The Egyptian Mineral Resources Authority. A thin section was prepared for each sample for Polarizing microscopic investigation. The petrographic analysis of the studied granitic samples revealed that; grey granite samples (Fig 2.a) composed mainly of plagioclase feldspars (represents about 35-40%), quartz (represents about 25-30%), potash feldspars (represents about 15-20%), biotite& hornblende (represents about 10-12%) as essential minerals associated with rare opaque minerals (represents about1%). Sericite, chlorite, carbonate, titanite, iron oxides and clay minerals are secondary minerals (alteration products). Plagioclase feldspars (mainly oligoclase and albite) which occur as medium-grained subhedral to euhedral crystals sometimes zoned and partially altered to sericite and carbonate minerals.

Quartz occurs as medium to fine-grained, anhedral to subhedral crystals intercalated with other minerals constituents. Potash feldspars represented mainly by microcline and orthoclase which occur as medium-grained, anhedral to subhedral crystals and partially altered to clay minerals. Potash feldspars are intergrowth with plagioclase to form microperthitic and antiperthitic textures. Mafic minerals represented by biotite which presents as medium to fine flakes, subhedral crystals and partially altered to chlorite, titanite and iron oxides. Opaque minerals occur as fine to medium-grains disseminated in the rock.

Also, Red Granite (Fig 2.b) sample composed mainly of potash feldspars (about 50-55%), quartz (about 15-20%), plagioclase (about 15-20%) and mafic minerals (as biotite& hornblende 7-10%) with rare amounts of muscovite and opaque minerals.
Potash feldspars is the main mineral constituent in the rock and represented mainly by orthoclase and microcline perthite which occur as coarse-sized, subhedral to anhedral crystals and partially altered to kaolinite. Potash feldspars intergrowth with plagioclase feldspar (mainly albite) to form perthitic texture and sometimes encloses fine grains of quartz and show poikiltic texture.

Quartz occurs as coarse to medium grained, anhedral crystals, display wavy extinction and sutured boundaries. Quartz slightly deformed and cracked in some parts. Plagioclase occurs as medium to coarse–sized, subhedral to anhedral crystals and partially altered to sericite, carbonate and clay minerals. Biotite is the main mafic mineral, occurs as fine to medium-grained aggregates of flaky crystals and shows partial alteration to chlorite, and iron oxides. Hornblende occurs as medium-grained, prismatic crystals and partially altered to chlorite and iron oxides. Opaque minerals occur as rare, fine grains and scattered in the rock. The mineral composition of the studied granitic rock samples are summarized in (table.2).

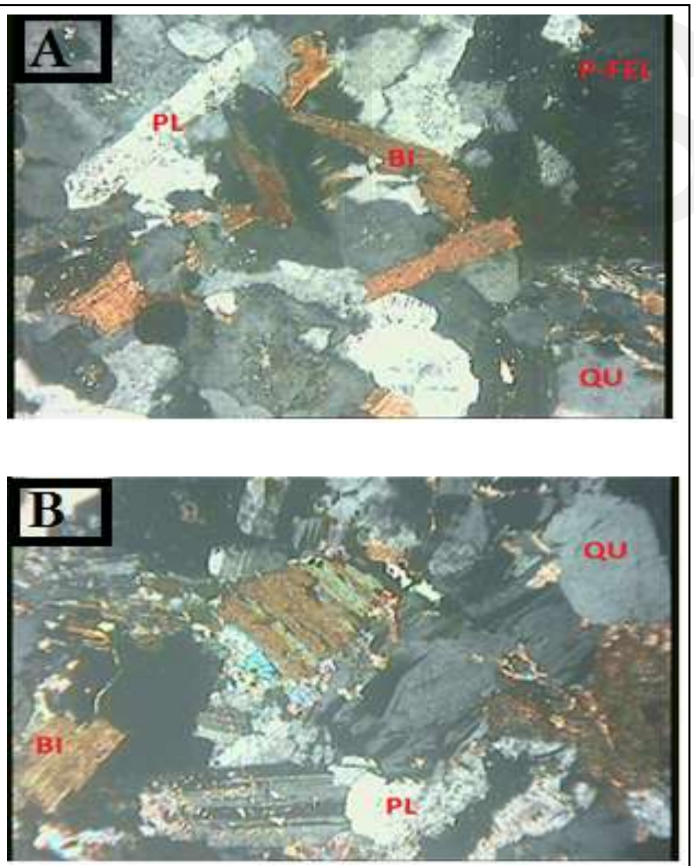


Fig. 2. Photomicrograph of (A) grey granite and (B) red granite samples showing the occurrences of slightly deformed and cracked in some quartz crystals.

TABLE 2
MINERALOGICAL COMPOSITION FOR STUDIED LOCALITIES OF GRANITIC ROCKS.

Minerals	El Shellal – Aswan	Abo Marwa– Aswan
Quartz	15 – 20 %	25 – 30 %
Potash feldspars	50 – 55 %	15 – 20 %
Plagioclase feldspars	15 – 20 %	35 – 40 %
Biotite& Hornblende	7 – 10 %	10 – 12 %

The petrographic analysis of marble samples revealed that; Sunny marble samples (Fig.3.A) are composed of calcite as major constituent associated with traces of iron oxides and opaque minerals. The matrix of the rock composed of very fine-grained calcite (micrite) admixed with small and crushed fossil fragments and admixed with traces of iron oxides and opaque minerals.

Microfossils and shell fragments present as large to medium sized (reach to 3 cm in length) and embedded in the matrix of very fine grained calcite. Microfossils composed mainly of sparite (recrystallized calcite) and/or micrite in some parts due to not complete recrystallization and embedded in the matrix of micrite. Microfossils are detected as elongated and rounded shapes and sometimes show medium to coarse sparitic calcite in the core. Some pores are detected in the rock where some microfossils possess intraparticle pore spaces, while other pores are detected in the rock and scattered in calcite matrix (interparticle pores).

Botchino marble samples (Fig.3.B) are composed of calcite as major mineral constituent associated with minor amounts of dolomite and traces of quartz, iron oxides and opaqueminerals. Calcite occurs in two forms, as micrite (very fine-grained matrix of calcite) and/or sparite (fine to medium- grained, recrystallized calcite). Microfossils and shell fragments present in considerable amounts as very fine sized of different shapes of recrystallized calcite. Pores are detected in the rock as fine pore spaces (interparticle pores). Quartz is present as fine grains of subangular to subrounded outlines in rare amount. Dolomite occurs as fine to medium subhedral crystals and associated with calcite.

Teriesta marble samples (Fig.3.C) are composed of calcite as major mineral constituent associated with minor amounts of dolomite, 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 and shell fragments present in great amounts as medium to fine sized of rounded to sub-rounded outlines and sometimes elongated. Microfossils are composed mainly of micrite and sometimes sparite (recrystallized calcite) and embedded in the matrix of micrite. Few pores are detected in the rock where some microfossils possess intraparticle pore spaces, while other pores are detected in the rock.

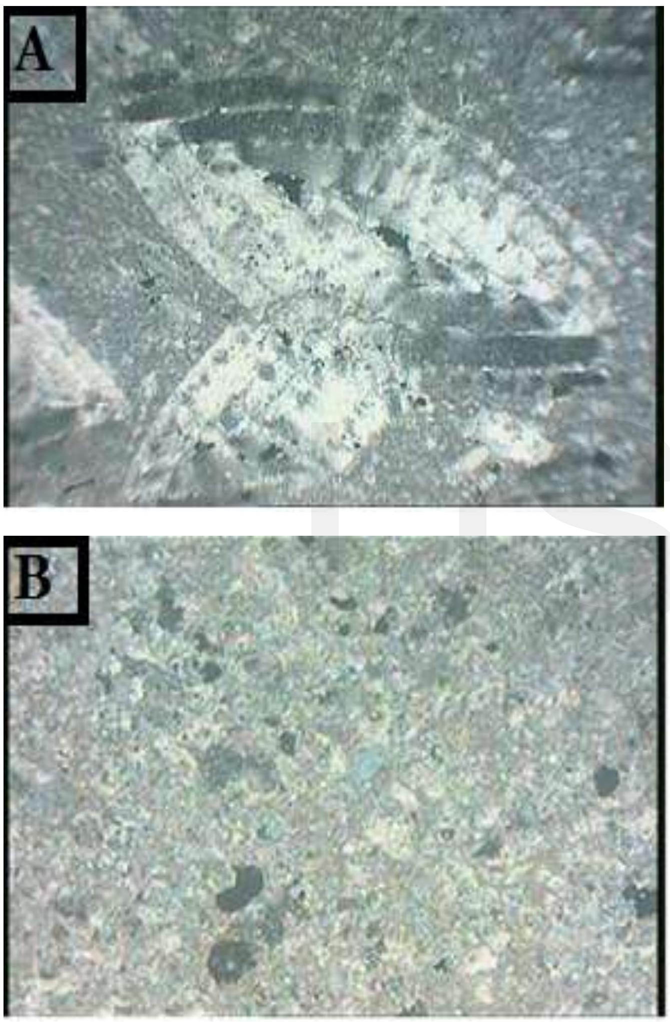
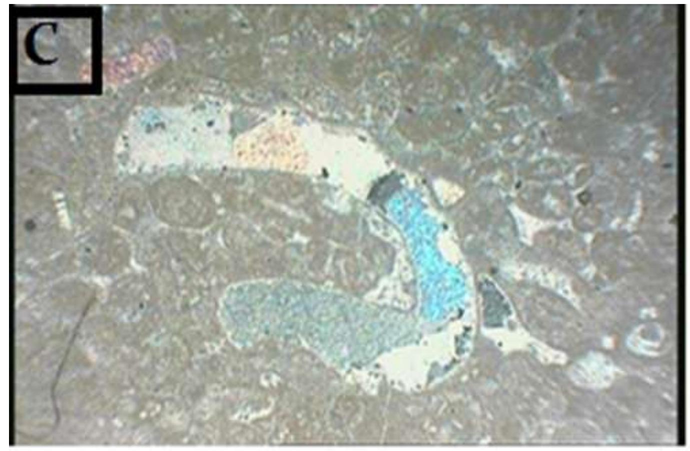


Fig.3. Photomicrograph of: (A) Sunny marble showing the occurrences of large sized microfossil and pores
(B) Botchino marble showing the occurrences of very fine pores.



(C) Teriesta marble showing the occurrences of medium to fine sized microfossil.

2.2.2 Chemical analysis

A complete chemical analysis was carried out by the Central Laboratories Sector at The Egyptian Mineral Resources Authority. A selected sample of ornamental stones is geochemically analyzed. The major oxides of the selected samples are determined by using XRF. Chemical analysis of major oxides of the studied marble rocks are given in Table (3.A) while the studied granitic rocks are listed in Table (3.B).

TABLE 3.A

CHEMICAL ANALYSIS OF MAJOR OXIDES FOR STUDIED LOCALITIES OF MARBLE ROCKS.

Major oxides	El sheikh Fadl-Minya	Zaafarana-Red Sea	WadiWatta-South Sinai
Sio_2	Traces	0.33	0.72
Fe_2o_3	0.07	0.12	0.38
Cao	55.47	55.20	54.94
Mgo	0.39	0.34	0.01
Al_2o_3	0.06	0.06	0.13
L.O.I	43.68	43.14	43.17
In.R	0.13	0.55	0.42
Total	99.80	99.74	99.77

TABLE 3.B:
CHEMICAL ANALYSIS OF MAJOR OXIDES FOR STUDIED LOCALITIES OF GRANITIC ROCKS.

Major oxides	El shellal-Aswan	Abo Marwa-Aswan
Sio_2	69.42	74.5
Fe_2o_3	3.78	2.27
Cao	2.47	2.13
Mgo	0.78	0.65
Al_2o_3	13.09	13.22
Tio_2	0.65	0.35
Mno	0.13	0.10
Na_2o	4.08	3.28
K_2o	4.63	2.61
L.O.I	0.95	0.80
Total	99.98	99.91

2.2.3 Uniaxial compression test

Twenty-five samples, including five of each type of studied ornamental stones were tested under uniaxial compression. These samples were in the form of prismatic samples withdimensions of of 10 x 10 x 20 cm^3, corresponding to a height to length ratio of two. It was carried out in the Concrete Laboratory, Civil Engineering Dept, Al-Azhar University.The uniaxial compression test was carried out by using A Computerized Compression Machine. The compressive strength was obtained from the recorded value of the force divided by the cross sectional area of the specimen as following [17].

$$Cs = P / A$$

Where,

Cs = Compressive strength.
P = Applied load at failure.
A = Cross sectional area of the specimen.

The results of uniaxial compression test for studied ornamental stones are summarized in Table 4.

2.2.4 Abrasion test

Abrasion resistance was investigated in Housing& Building National Research Center (HBRC). The cross sectional area of the test specimen 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 specimen was placed under a pressure of 600 gm/cm^2 using sand (25-36 mesh) as abrasive material.The loss in thickness (abrasion) was determined according to [18] by using the following formula:

$$\text{Abrasion (Loss of thickness)} = \frac{W1 - W2}{A \times \rho}$$

Where,

W1 = Weight of specimen before abrasion.
W2 = Weight of specimen after abrasion.
ρ = Sample density.
A = Cross sectional area of the specimen.

The results of Abrasion test of studied ornamental stones as shownin Table 4.

2.2.5 Physical Properties

The physical properties of studied ornamental stones include; apparent porosity, bulk density and water absorption .These tests were carried out in the Mineral Processing Laboratory, Faculty of Engineering, Al-Azhar University.The results of the physical properties of studied ornamental stones are summarized in Table 4.

TABLE.4

AVERAGE PHYSICAL AND MECHANICAL PROPERTIES OF THE STUDIED ORNAMENTAL STONES.

Rock type	Locality	Porosity (%)	Water absorption (%)	Dry density (gm/cm3)	Abrasion resistance (mm)	Compressive strength (Mpa)
Grey granite	Abo Marwa -Aswan	0.55	0.19	2.62	0.17	162.9
Red granite	El Shellal -Aswan	0.65	0.22	2.61	0.11	116.56
Botchino marble	Zaafarana-Red Sea	2.33	1.01	2.57	1.61	85.42
Teriesta marble	WadiWata-South Sinai	2.05	0.8	2.58	0.72	79.82
Sunny marble	El Sheikh Fadl-Minya	5.46	2.12	2.53	2.46	52.74

3. Discussions

It can be seen that from (table.4) grey granite samples exhibit the best physical and mechanical properties, where it gained the highest value of compressive strength (162.9 Mpa). This explained by that the high mineralogical composition of quartz ranging from 25% to 30%and also, due to fine grained texture in additional to the presence of micro-cracks are very little and the lowest value of porosity (0.55) hence water absorption is the least (0.19%) due to strong interlocking crystalline texture. Also, the high resistance to abrasion (0.19 mm) gives this grey granite the priority for use as building and decorative stone (indoor and outdoor). This priority could be supported by accepted appearance architecturally and highly polished finish.

While, red granite samples have a lower compressive strength value (116.56 Mpa) than grey granite samples because it has a low pecentage of quartz in the range of (15-20%) besides it has coarse grained texture in additional to quartz crystals slightly deformed and cracked in some parts and this due to the tectonic movements. Also, these samples have a lower value of porosity (0.65) hence water absorption is less (0.224%) due to interlocking crystalline texture.

Also, red granite samples exhibit the highest resistance to abrasion (0.11mm) as compared to grey granite. This might be due to the fact that when these rock aggregates abrade during abrasion test, the larger mineral grains of this rock within the aggregates have a lager surface area to abrade compared with the smaller mineral grains [9]. Although this type is relatively low in compressive strength as compared to the grey granite, it is considered regarding to its colours to be one of the most valuable ornamental stones in the world and it is preferable to use these rocks. It can be seen that red granite is preferably to be used for stairs as a result of its high resistance to abrasion.

On the other hand, from the results of the studied marble rocks; it is observed that sunny marble samples exhibit lower physical and mechanical properties. It has the lowest compressive strength value (52.7 Mpa) and also, these samples have the highest value of porosity (5.46) hence water absorption is the most (2.12%). This is explained by presence of fossils and shell fragments are detected in this rock in great amounts as large to medium sized (reach to 3 cm in length) in additional to that some pores are detected in the rock where some microfossils possess intraparticle pore spaces, while other pores are detected in the rock and scattered in calcite matrix (interparticle pores) besides presence of micro-discontinuities in these samples makes it easier for the grains to be removed by the abrasive and these defects represent a weakness areas in these rocks hence these samples have a lowest resistance to abrasion and may be used for slaps only.

Botchino marble samples exhibit good physical and mechanical Properties. It has the highest compressive strength value (85.42 Mpa) besides it is a lower value of porosity (2.33) hence water absorption is less (1.01%). This due to that this rock has a very fine grained texture besides presence of traces of quartz grains in this rock as fine grains which lead to increasing in compressive strength in additional to some Pores are detected in the rock as fine pore spaces (interparticle pores) and scattered in calcite matrix. These samples have a good resistance to abrasion (1.61 mm). This kind of rock may be used as isolating material in some electric appliance because it has rarepercentages of metal oxides such as iron and aluminum oxides besides the other decoration purposes (indoor applications).

Teriesta marble samples exhibit good physical and mechanical Properties. It has a higher compressive strength value (79.8 Mpa) besides it is a lowest value of porosity (2.05) hence water absorption is the least (0.8%). This due to that this rock has a very fine grained texture besides it has few pores are detected in the rock but this rock contains microfossils and shell fragments present in great amounts as medium to fine sized and embedded in the matrix of very fine grained calcite which may be affect the strength of these rocks. Also, these samples exhibit the highest resistance to abrasion and this due to the presence of higher ratio of silica in this rock (0.72%). However these higher silica ratios render the cutting and polishing of these rocks very difficult. This kind of rocks can be used for appliance subjected to friction because of high resistance to abrasion in additional to the other decoration purposes.

Granite samples of El shellal and Abo Marwa are classified as high strength rocks while marble samples of El Zaafarana and Wadiwata are classified as medium strength except El Sehikh Fadl marble samples are classified as low strength [19].

CONCLUSION

From the above results, we can be concluded that:

1. Most of the rock samples show high to medium strength values, which is favorable for the use of these rocks as building or decorative stones except of rock samples of El Sheikh Fadl show low strength values.

2. Grain size and geological microstructure are important factors on which the strength of rocks depends. The strength increases as the mean grain size decreases.

3. Mineralogical composition is one of the main properties controlling the rock strength. The increase of quartz in rock material would increase the strength of rock material.

4. The presence of higher ratios of silica in limestone leads to an increasing in its resistance to abrasion. However these higher silica ratios render the cutting and polishing. This clear in WadiWatalimestone samples.

5. Abo Marwa granodiorit samples possesses the highest compressive strength as well as the lowest porosity while, El Shellal red granite samples exhibit the highest resistance to abrasion. Meanwhile, El Sheikh Fadl marble samples exhibit the lowest physical and mechanical properties.

6. The results indicate that rocks of the same type in different areas have different physical and mechanical values. This is because of difference in geological setting and other physical properties. Thusit can be concluded that change in texture and mineralogical characteristics of rocks due to crystallization, diagenesis and the effects of tectonism appear to affect the engineering properties of same rocks in different areas.

7. Texture of marble samples is variable but in general show interlocking crystalline texture. It is observed that calcite grains occurs in two forms, as micrite (very fine-grained matrix of calcite) and/or sparite (medium to coarse grained, recrystallized calcite) and this means that grain size varies from aphanitic to coarse grained texture hence strength properties may be reduced and this shows effect of high degree of metamorphism and diagenesis and this clearly in El Minya Sunny marble samples.

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