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Testing and Assessment of some Egyptian Marble Types

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Abstract

Marble is one of the most important materials in the field of interior design for houses and buildings. Marble is a natural material with aesthetic values that may vary from one type to another depending on its mineral compositions and its properties. In this research, the necessary tests were done for six types of Egyptian marble to (The main aims of this research) are: To compare the differences between geological, chemical, physical, and mechanical properties of the same marble type in the different areas and to quantify the different characteristics and uses of selected marble types. The tests were physical, mechanical (according to ASTM standards), chemical, as well as petrography analysis. It was found that: South Sinai Teriesta marble samples had the highest values of major oxides, as SiO_2 1.03%, MgO 0.638%, Al_2O_3 0.355%, Fe_2O_3 0.339%, and the lowest value of CaO 54.6%, compared with other studied marble types. Zaafarana marble samples had the lowest values of water absorption with average of 0.356% and the apparent porosity with average of 0.894%, the highest average values of: bulk density 2.729 gm/cm3, abrasion resistance 2.345, and compressive strength 100.29 MPa compared with other studied marble types. Elminya Selvia marble samples had the highest values of water absorption with average of 1.488% and the apparent porosity with average of 3.770%., the lowest average values of: bulk density with 2.468 gm/cm3, abrasion resistance 1.145, and compressive strength 41.37 MPa. Modulus of rupture ranged from 7.2 to 13.8 MPa, for dry and wet conditions and the flexural strength ranged from 6.4 to 12.25 MPa, for dry and wet conditions. It was cleared that Red Sea Zaafarana marble is the strongest type and Elminya Selvia marble is the weakest one.

1. Introduction

Marble is one of the most important natural stones used in many fields during different ages due to its high gorgeous value as a natural material. Marble consists mainly of limestone (pure crystallized calcium carbonate), or dolomite transformed under the influence of heat and pressure. Some of

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other compounds such as magnesium carbonate, iron, and aluminium oxides, etc. are included in the composition. These compounds differ from one place to another hence they affect the colour and other properties of marble. There may appear some negatives that must be addressed, such as the presence of gaps [1]. The Egyptian marble and ornamental stones have been subjected to many geological investigations regarding their origin, mode of formation, appearance, mineralogical constitution, microstructure such as voids or pores, micro-cracks, and micro-cavities, etc. So, it is important to determine the suitability of different types for applied purposes [2]. Presence of superficial cracks in marble increase the absorption, porosity, and colour spots. The marble industry is one of the most important national income sources. Knowledge of marble properties, specifications and composition are the most important means of developing and marketing as strategic goals of the country. Commercially the term marble is extended to include any rock composed of calcium carbonate that requires polish, including ordinary limestone. 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 distinctive lustre of statuary marble is caused by the reflection of penetrated light from the surfaces of inner crystals [3]. Marble quarries are found in different locations all over the country; along the coast of the Red Sea (Zaafarana), Sinai, Elminya, Assiut, Aswan and the Eastern Desert [4]. In Egypt, there are many types of marble that are presented in both local and global markets such as Zaafarana Sunny and Selvia; Teriesta Gray, Bronze, and brownish; Galala white, Lenses (Fas), and Biege; Elsheikh Fadl Sunny and Selvia; Elminya Sunny and Selvia; Imprador; Khatmeya; Batchino; and Samaha. Table 1 and Fig. 1 present the different locations of marble quarries in Egypt.

This paper consists of eight sections: introduction in section one, importance of Egyptian marble in section tow, market study in section three, areas of study and raw materials in section four, experimental work and methodology in section five, results in section six, discussions in section seven, and conclusion in section eight.

Table 1: Location of marble quarries in Egypt [4]

Type	Location	Commercial Name	Specifications
White Marble	Wady Elalaky, Wady Elmiyah	White Carrara	White with black and red veins
Black Marble	Wady Elalaky, North Albaramia, Wadi Elmiyah	Black Carrara	Black with white veins
Calcic Stone (Marble substitute)	Assiut and Kharga, Zaafarana, East of Sohag	Berlato	White and dark beige, yellowish beige
Calcic Stone (Marble substitute)	Wadi Fyran, Sinai, Zaafarana, Elkoraymat, Elgalala	Botshino	Reddish pink
Green Serabantin	Wady Atallah Alkoser, Om Hassan Mountain	Green Marble	Dark green with veins
Calcic Stone (Marble substitute)	Balk upper Egypt, Alhasna	Fleto Rosso	Beige with brownish veins
Green Brishia Ferdy	Wady Elhamamat, Gabal Eldokhan	Green Brishia	Dark and light green
Red Brishia	Assiut, Sohag	Red Brishia	Dark and light red
Alalbastar	Elminya, Assiut, Beni Suife	Alalbastar	Golden yellow and white
Gray	Edfo, West of Elminya	Teriesta	Gray and smoked

Fig. 1: Locations of marble and ornamental stone quarries in Egypt [4]

▭= marble and marbleized limestone, Δ = marble and granite factories, ○ = alabaster

2. Importance of Egyptian Marble and Ornamental Stones

The Ancient Egyptians, more than five hundred years ago, knew about forty different kind of ornamental stones and worked chiefly with granite and some types of marble such as alabaster. Some historians asserted that the Greek and the Romans acquired the skills of quarrying and processing of marble from the Ancient Egyptians [5]. The Egyptian ornamental stones were used historically in Egypt. During the Age of Ancient Egyptians, the granite was extracted from Upper Egypt and used in the construction of buildings, as well as temples. In addition, other cultures learnt from the Egyptian methods of extracting and cutting of stones like the Ancient Romans in 3rd century B.C [6]. Moreover, when the Romans took the knowhow of quarrying from Egypt, they transferred it to other places. Italy acquired the knowhow from the Romans and concentrated on developing the industry which currently is among the most leading suppliers' marble in the world.

There were no significant uses of marble and granite after the Age of Ancient Egyptians. However, during the Islamic Civilization, the marble was imported from abroad to be used in the construction of mosques. For instance, Bianco Carrara marble was imported from Italy and used in the construction of El Zaher Bibars mosque in old Cairo. Afterwards, the production of marble was present locally but on a small scale mainly used in flooring of villas, as well as palaces [7]. In the early 1950s, there were two companies operating in the market for extraction: Egyptian Company for the Exploitation of Mines and Quarries, as well as Egypt's Company for Mines and Quarries [5]. In 1960s and 1970s, the imports of marble started to decline accompanied by the expansion of the marble local industry in which new marble processing firms opened like Aswan Company for Marble and Granite [7]. During the 1980s, the local market started to be more specialized and looked for the best techniques of stone production. The factories worked on enlarging the capacity of cutting and processing of stone to increase their production capacity. The ornamental stones industry started operating largely in 1990s, until now several factories and workshops opened in Shaq Althoaban near Elmaadi district in Cairo and many industrial regions [6].

3. Market Study

The consumption of natural resources has been increased due to the increasing demand for their uses in recent building decoration. Humankind has consumed more aluminum, copper, iron and steel, phosphate rock, diamonds, sulfur, coal, oil, natural gas, and even sand and gravel over the past century than over all earlier centuries so that today the world annually produces and consumes nearly all mineral commodities at record rates [8]. Egyptian production during (2006 – 2009) was highly significant and increased from 3.3 Mt in 2006 to 3.6 Mt in 2009 with average share of about 3.29% [9, 10]. Figs. 2, 3, and 4 show the marble and ornamental stones global production, production rate of change, and the top ten producing countries.

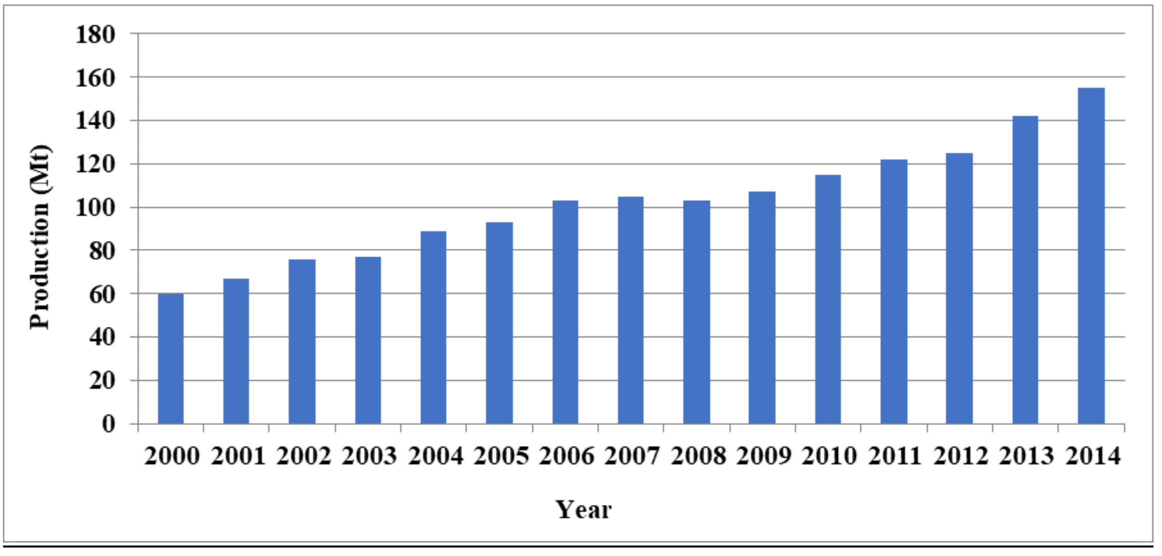


Fig. 2: Global marble and ornamental stones production [10]

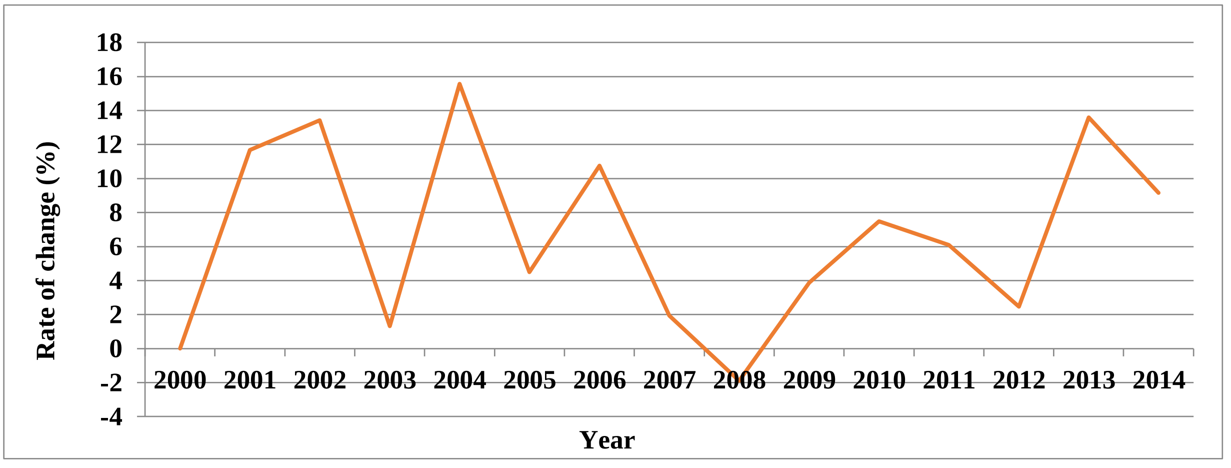


Fig. 3: Global marble and ornamental stones production rate of change [10]

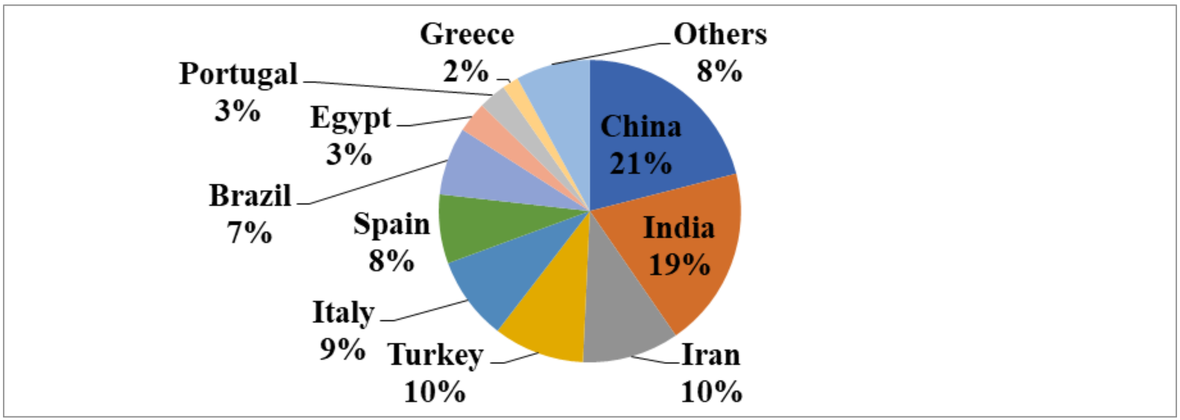


Fig. 4: The top ten Global marble and ornamental stones producers [9]

Global exports of marble ornamental stones have risen by 28.56% from 2001 with 16.63 Mt till 2005 reaching 21.38 Mt. In 2010 the exports were estimated to be about 21.07 Mt with a decrease of about 31 Mt compared with that in 2005. In 2015 the exports were estimated to be about 18.21 Mt, with a decrease of about 13.57% compared with that in 2010. And the Global exports of ornamental stones in 2020 were estimated to be about 17.04 Mt with a decrease of about 6.43% compared with that in 2015 [11] as illustrated in Figs. 5 and 6.

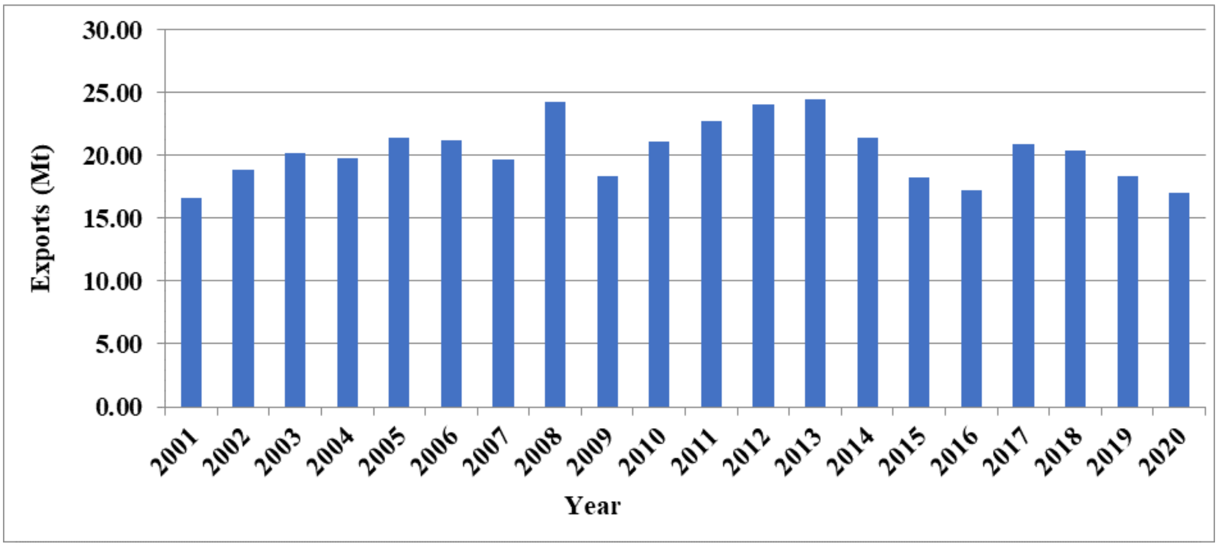


Fig. 5: Global ornamental stones exports [11]

Fig. 6: Global marble and ornamental stones exports rate of change [11]

The Egyptian marble and ornamental stones exports have rose by 15.16% from 2015 with 1.847 Mt till 2020 reaching 2.127 Mt. The top ten countries imported the Egyptian marble and ornamental stones in (2015-2020) were, in descending order by tonnage, China, Libya, Lebanon, Saudi Arabia, Algeria, North Korea, Kuwait, Jordon, United Arab Emirates, and Morocco, and these countries accounted for about 87% of the Egyptian exports [12]. Table 2 and Fig. 7 show the Egyptian marble and ornamental stones exports and the top ten importers respectively. Table 3 represents the average prices of some Egyptian marble types [13, 14]

Table 2: Egyptian marble and ornamental stones exports [12]

Year	Exports (Mt)	Rate of Change (%)
2015	1.847	-
2016	1.955	5.85
2017	2.080	6.39
2018	2.227	7.07
2019	2.466	10.73
2020	2.127	- 13.75

Mt: Million tons

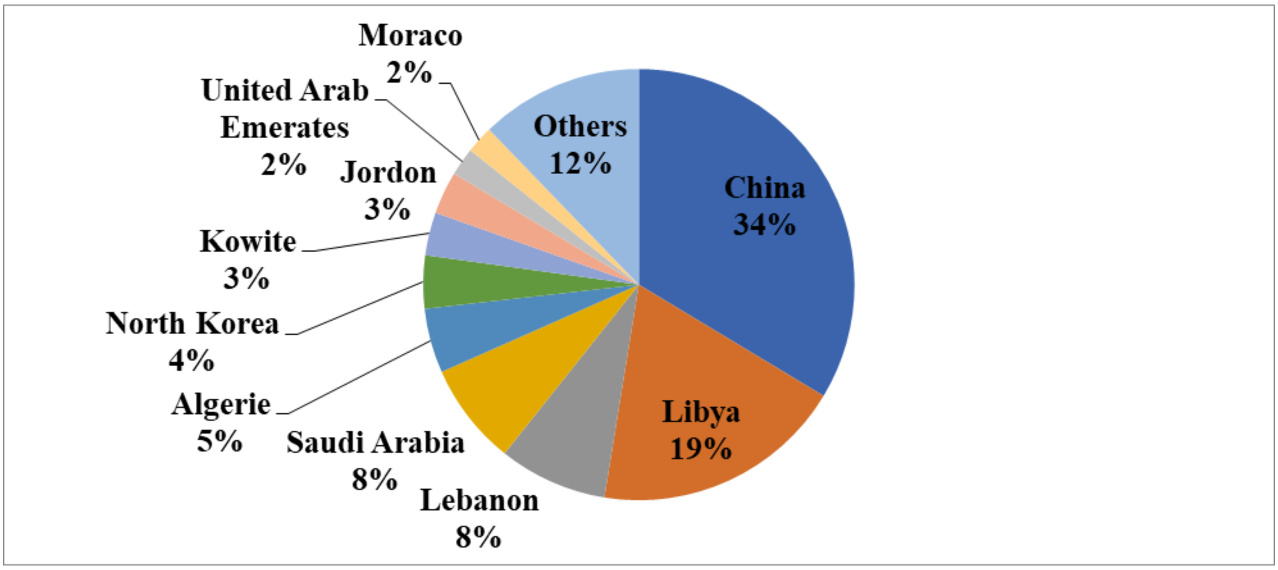


Fig. 7: The top ten importers of Egyptian marble and ornamental stones [12]

Table 3: Prices of some Egyptian marble types (2021) [13, 14]

Marble Type	(LE/m^3)	(LE/m^2)	(LE/m^2)	(LE/m^2)	(LE/m^2)
S. Sinai - Treista	6000	196-263	271-338	229-303	316-390
Suize - Galala	10000	307-374	425-492	351-425	486-559
R.S. Elsheikh Fadl Sunny	3000	99-166	136-203	123-196	168-241
Elminya Sunny	2200	56-123	77-144	75-149	103-176
Elminya Selvia	2400	62-129	86-153	82-156	113-186
R.S. Zaafarana	5900	193-260	267-334	226-300	312-385
Thickness	Blocks	Slabs (2 cm)	Slabs (3 cm)	Tiles (2cm)	Tiles (3 cm)

S: South R.S: Red Sea, and LE: Egyptian pound

4. Areas of Study and Raw Materials

In this study, samples of six types of Egyptian marble were taken according to ASTM standards (number of samples and dimensions are illustrated in experimental work section) including: South Sinai-Teriesta, Suize-Galala, Red Sea-Elsheikh Fadl Sunny, Elminya Sunny and Selvia, and Red Sea- Zaafarana. Table 4 and Fig. 8 show the studied marble types of locations and coordinates.

Table 4: locations and coordinates of the studied marble types

Marble Name	Location	Governorate	Latitude N	Longitude E
Teriesta	Abo Gaada - Ras Sudr	South Sinai	29° 33' 30.54"	33° 16' 07.00"
Galala	Wadi Elkhafouri -Elgalala Elbahariya	Suize	29° 31' 17.90"	31° 56' 51.70"
Elsheikh Fadl Sunny	Khashm Elrakaba	Red Sea	28° 27' 25.00"	31° 52' 13.00"
Elminya Sunny	Wadi Tihna - Beni Hasan	Elminya	28° 04' 33.90"	31° 10' 56.00"
Elminya Selvia	Wadi Tihna - Beni Hasan	Elminya	28° 02' 50.90"	31° 11' 06.71"
Zaafarana	Gebel Thilmet - El Zaafarana	Red Sea	28° 52' 58.06"	32° 33' 17.84"

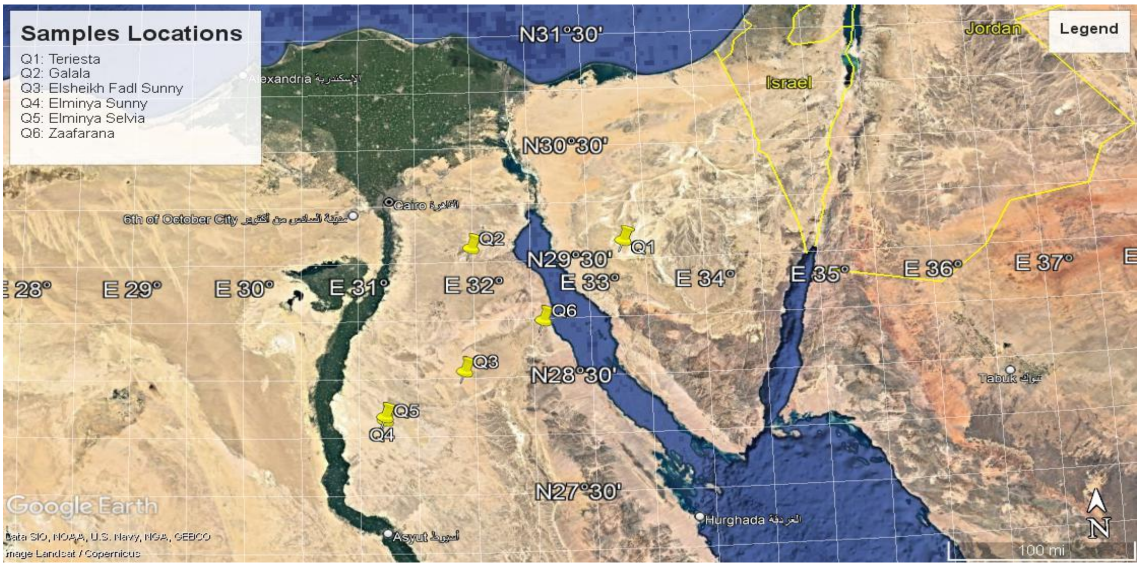


Fig. 8: Locations and coordinates of the studied marble types of quarries

5. Experimental Work (Methodology)

The experimental work of this study included the determination of the chemical analysis (XRF), the mineralogical analysis (XRD), the petrographical study, and physic mechanical properties: the absorption by weight, the apparent porosity, the bulk density, the abrasion resistance, the compressive strength, the modulus of rupture, and the flexural strength for all studied marble types.
All physical and mechanical tests were carried out according to ASTM standard codes. For dry conditions, the specimens were dried for 48 hours in a ventilated oven at a temperature of 60 C^o, and then cooling for 30 minutes. For wet conditions, the specimens were completely immersed for 48 hours in distilled water at a temperature of 22 C^o, and then the surfaces were dried with a damp cloth.

5.1 Chemical analysis (XRF)

A complete chemical analysis was carried out by the Center of the Evaluation and Upgrading Ores Quality in South Valley - Faculty of Engineering - Assiut University. Representative samples of studied marble types were geochemically analyzed.

5.2 Petro graphical study

The petrographically studies were carried out according to ASTM – C1721 [15] by the Central Laboratories of The Egyptian Mineral Resources Authority. A thin section was prepared for each sample for polarizing microscopic investigation

5.3 Physical properties

Physical tests were carried out according to ASTM - C97 [16]. The specimens are cubes of length (60 mm). The different properties can be calculated as follows:

$$\text{Absorption weight } \% = ((W_w – W_d) / W_d) *100 \quad (1)$$

$$\text{Apparent porosity } \% = ((W_w – W_d) / (\rho_w \times V_s)) *100 \quad (2)$$

$$\text{Bulk density } (gm/cm^3) = W_d / V_s \quad (3)$$

Where:
W_d: is the weight of oven-dry specimen (gm)
W_w: is the weight of saturated specimen (gm)
ρ_w: is the density of water (1 gm/ cm^3) V_s: is the total volume of the specimen (cm^3)

5.4 Abrasion resistance

Abrasion resistance test was carried out according to ASTM - C241 [17]. The specimens' dimensions were (60mm*60mm*30mm). The samples were placed into the holding device of the abrasion testing machine. The rotating disk was then set for 45 revolutions per minute and a normal load of 20 N was applied. The face of the sample which was in touch with the rotating disc was abraded by an abrasive material under the standard conditions, Fig. 9(a). The abrasive material used for testing was white fused alumina having grit size of 80. The abrasive material was stored in a hopper fixed over a top plate to feed abrasives through the delivery pipe. The abrasive material was fed continuously into the abrasion path so that it can remain uniformly distributed. The sample was subjected to 225 revolutions, after which the machine is stopped automatically. The abrasion resistance was measured from the weight difference of each sample of the same marble before and after the 225 revolutions. Then the loss of thickness and the abrasion resistance can be calculated as follows:

$$\text{Abrasion resistance} = 10\ G\ (2000 + W_{av}) / 2000\ W_L \quad (4)$$

$$\text{Loss of thickness (cm)} = (Wd – Wa) / (\rho s*A)\ [2] \quad (5)$$

Where:
G: is the bulk specific gravity (gm/ cm^3)
W_{av}: is the specimen average weight = (W_d + W_a)/2 (gm)
W_L: is the specimen loss of weight = (W_d – W_a) (gm)
Wd = is the weight of oven-dry specimen before abrasion (gm)
Wa = is the weight of specimen after abrasion (gm)
ρs = is the density of water (1 gm/ cm3), A = is the cross-sectional area of the sample (cm^2)

5.5 Compressive strength

This test was carried out according to according to ASTM - C170 [18]. The specimens were cubes of length (60 mm). Centre the specimens in the testing machine and apply the initial load at a rate that will permit hand adjustment of the contact plate on the specimen. Rotate the plate back and forth through an angle of about 30° under a small load to properly seat the spherical block but take care not to move the specimen out of the central position, Fig. 9(b). Preferably, the rate of loading should not exceed 100 psi (690 KPa/s), but this requirement may be considered as being met if the speed of the loading head is not more than 0.05 in. (1.3 mm)/min. The compressive strength was calculated as follows:

$$\text{Compressive strength (MPa)} = F/A \quad (6)$$

Where:
F: is the total load on the specimen at failure (N)
A: is the calculated area of the bearing surface (mm^2)

5.6 Modulus of rupture

Modulus of rupture test was carried out according to ASTM - C99 [19]. The specimens' dimensions were (200mm*100mm*60mm). Lay the specimen flat wise on the support blocks, spaced 7 in. (180 mm) apart and equidistant from the load application block, with all three application loads and parallel support blocks. When a load of 10 lbf (50 N) has been applied, stop the loading, and make all application loads and support blocks coincide with the marks on the specimen by centring the specimen under the application loads block and moving the support blocks under the span marks. Apply the loading at a rate not exceeding of 1000 lbf/min (5000 N/min) until failure of the specimen. Fig. 9(c). The modulus of rupture was calculated as follows:

$$\text{Modulus of rupture (MPa)} = 3WL/2bd^2 \quad (7)$$

Where:
W: is the breaking load (N)
L: is the length of span (mm)
b: is the width of specimen (mm)
d: is the thickness of specimen (mm)

5.7 Flexural strength

In this test, ASTM - C880 standard code [20] was applied where the specimens' dimensions were (350mm*100mm*30mm). Assemble the apparatus and place the specimen on the span supports and adjust the quarter point loading blocks into contact with the specimen. Apply the load at a uniform stress rate of 4.14 MPa (600 psi/min) to failure, Fig. 9(d). The flexural strength was calculated as follows:

$$\text{Flexural strength (MPa)} = 3WL/4bd^2 \quad (8)$$

Where:
W: is the breaking load (N)
L: is the length of span (mm)
b: is the width of specimen (mm)
d: is the thickness of specimen (mm)

a: Abrasion machine

b: Compressive strength machine

c: Modulus of rupture machine

d: Flexural strength machine

Fig. 9: Tests machines

6. Results

After conducting the necessary tests for various studied types of Egyptian marble, including physical, mechanical, chemical, and petrographical study; the results and discussions were drawn in the following sections.

6.1 Chemical analysis (XRF)

The chemical composition greatly affected the physical and mechanical properties of marble, especially SiO_2%. Although the presence of colored oxides (Fe_2O_3, MgO, and Al_2O_3) give a beautiful feature, the presence of a high ratio of these oxides makes the cutting process very difficult. Also, these oxides limit the use of marble in many connections in the industry such as electrical insulators which react with moisture in the atmosphere and in turn results fainter color. The different oxides of the selected samples were determined by using XRF as listed in Table 5. As shown, Teriesta marble had the highest value of magnesium, aluminum, iron, and silicon oxides and the lowest value of calcium oxide compared with other marble types. Those showed the fantastic gray color of this type, and the highest value of abrasion resistance among the other marble types. Galala and Elminya Selvia marble types had the lowest values of these oxides, but they had the highest values of calcium oxide. The percent of CaO ranged from 54.6% for Teriesta to 57.2% for Galala marble types; SiO_2 ranged from 0.138% for Galala to 1.03% for Teriesta types; and MgO ranged from 0.096% for Elminya Selvia to .0638% for Teriesta types.

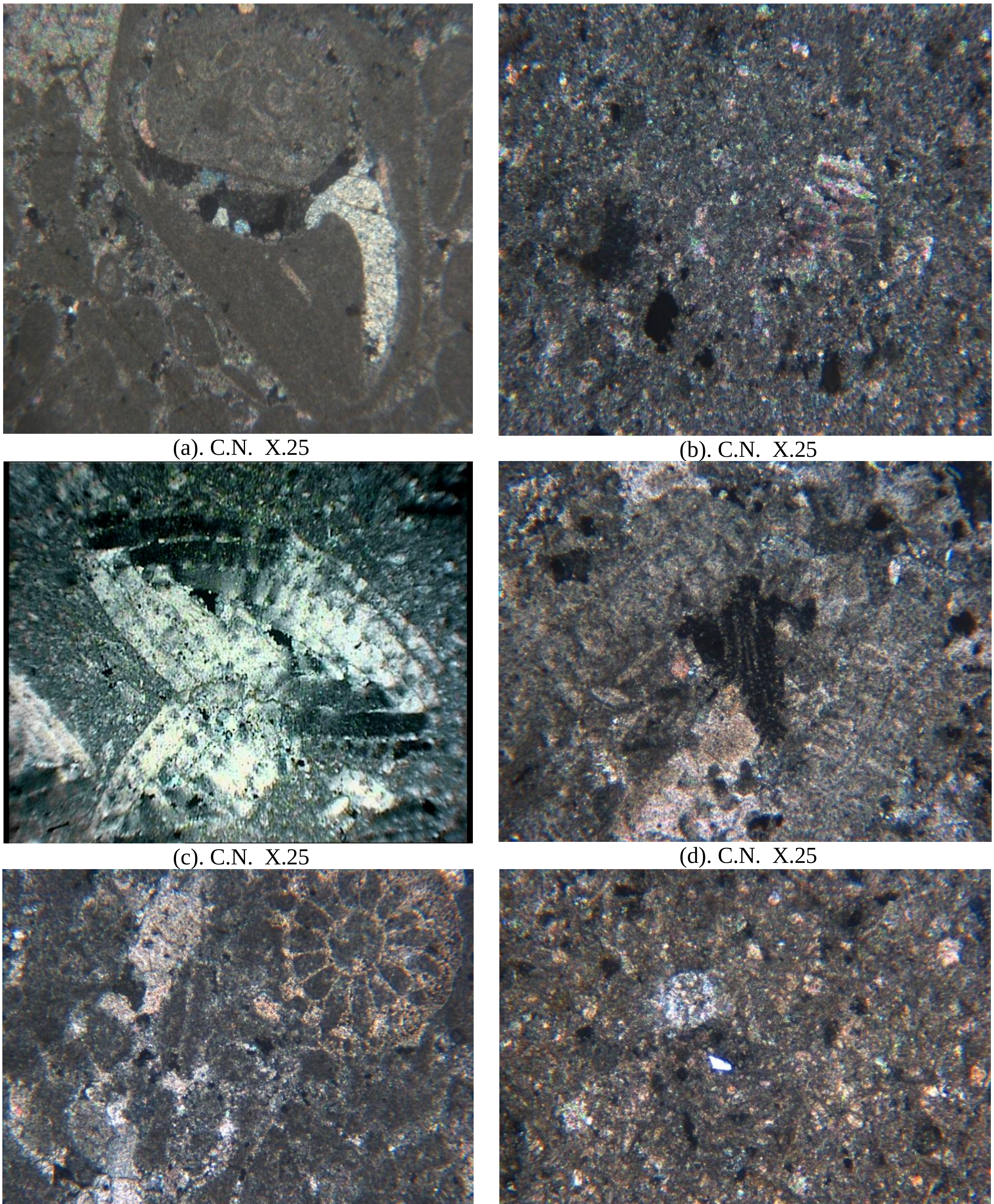
Table 5: Chemical analysis of all studied marble types

Marble Type	**S. Sinai - Teriesta**	**Suize - Galala**	**R.S. Elsheikh Fadl Sunny**	**Elminya Sunny**	**Elminya Selvia**	**R.S. Zaafarana**
%	Q1	Q2	Q3	Q4	Q5	Q6
MgO	0.638	0.146	0.250	0.324	0.096	0.281
Al_2O_3	0.355	0.038	0.323	0.269	0.049	0.200
SiO_2	1.030	0.138	1.020	0.875	0.188	0.564
P_2O_5	0.115	0.092	0.149	0.103	0.158	0.096
SO_3	0.118	0.027	0.040	0.065	0.046	0.047
Cl	0.028	0.006	0.016	0.019	0.005	0.020
K_2O	0.131	0.035	0.093	0.084	0.038	0.039
CaO	54.600	57.200	55.100	55.600	57.500	55.900
Fe_2O_3	0.339	0.037	0.207	0.157	0.041	0.092
SrO	0.031	0.037	0.046	0.012	0.023	0.037
Rh_2O_3	0.202	0.000	0.000	0.000	0.000	0.000
LOI	42.400	42.300	42.800	42.500	41.900	42.700

6.2 Petro graphical study

Petrographic examination of the rocks to be used as ornamental stone can yield important information about the type, size, shape, proportions of mineral grains, their interlocking nature, the amount and interconnectedness of pores, micro-fractures, and microfossils, etc.

Fig. 10(a) shows a photomicrograph of South Sinai - Teriesta marble where the rock is composed mainly of calcite as the major mineral constituent associated with minor amount of dolomite and traces of iron oxides and opaque minerals. Calcite occurs as very fine-grained (micrite), some microfossils are filled by re-crystallized carbonate minerals. Pelloids and ooids are observed in the matrix of the sample and are composed mainly of calcite. For Galala marble as illustrated in Fig. 10(b); the rock is composed mainly of calcite as the essential component associated with traces of dolomite, quartz, collophane, iron oxides, and opaque minerals. Calcite occurs as very fine-grained (essentially of micrite), some microfossils are scattered in the matrix of the sample. The microfossils are filled by re-crystallized fine-grained calcite, the matrix is partially re-crystallized to sparite (calcite). For Elsheikh Fadl Sunny marble as cleared in Fig. 10(c); the rock is 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, traces of iron oxides, and opaque minerals. Microfossils and shell fragments are present as large to medium sizes and embedded in the matrix of very fine-grained calcite. Microfossils composed mainly of sparite (re-crystallized calcite) and micrite in some parts due to not complete re-crystallization and are embedded in the matrix of micrite. Fig. 10(d) illustrates a photomicrograph for Elminya Sunny marble where the rock is composed mainly of calcite as the essential component associated with traces of quartz, dolomite, glauconite, iron oxides, and opaque minerals. Calcite occurs as very fine to medium-grained (sparite), significant number of microfossils and fossil shell fragments of different sizes and shapes are scattered in the matrix of the sample. The microfossils are large to very fine in size and filled by micrite and some of them filled by re-crystallized calcite. Elminya Selvia marble as shown in Fig. 10(e) is composed mainly of calcite as the essential component associated with minor amount of dolomite, traces of iron oxides, opaque minerals, cellphone, and quartz. Calcite occurs as very fine to medium-grained (sparite), significant number of collars, microfossils and fossil shell fragments of different sizes and shapes are scattered in the matrix of sparite calcite. The microfossils are filled by re-crystallized coarse-grained calcite. Zaafarana marble as illustrated in Fig. 10(f) is composed mainly of calcite as the essential component associated with minor amount of dolomite, traces of quartz, collophane, iron oxides and opaque minerals. Iron oxides and opaque minerals occur as very fine-grained crystals scattered in the rock matrix. Some microfossils are scattered in the matrix. Few fine pore spaces and irregular micro-fractures are present in the sample.



(a). C.N. X.25 (b). C.N. X.25

(c). C.N. X.25 (d). C.N. X.25

(e). C.N. X.25 (f). C.N. X.25

Fig. 10: Photomicrograph of all studies marble types

6.3 Physic-mechanical properties

Table 6 shows all results of physic mechanical tests and Table 7 represents the tests requirements according to ASTM – C503 [21].

Table 6: Results summery of physic mechanical tests of all studied marble types

Marble Type	S. Sinai - Teriesta	Suize - Galala	R.S. Elsheikh Fadl Sunny	Elminya Sunny	Elminya Selvia	R.S. Zaafarana
Color	Gray	Milky White	Flower Beige	Light Beige	Light Beige	Light Pink/Beige
Grain Size* **	VF to F	VF	VF	VF to M	VF to M	VF to F
Absorption (%)	0.87	0.74	0.55	1.19	1.49	0.36
AP (%)	2.22	2.07	1.48	3.18	3.77	0.89
BD (gm/cm^3)	2.55	2.72	2.68	2.68	2.47	2.73
Abrasion Resistance	2.14	1.71	1.90	1.31	1.15	2.34
Loss of Thickness. (mm)	1.47	1.86	1.69	2.37	2.74	1.36
Dry CS (MPa)	89.51	58.33	67.00	54.21	41.37	100.29
Wet CS (MPa)	66.75	34.09	59.37	45.84	36.93	76.57
Dry MR (MPa)	10.83	8.71	13.80	9.86	8.10	10.84
Wet MR (MPa)	10.13	7.20	10.63	7.81	8.53	11.54
Dry FS (MPa)	9.90	8.69	10.53	9.52	8.48	10.22
Wet FS (MPa)	9.73	6.40	9.05	7.59	7.47	12.25

*** VF: Very fine (0.0625- 0.125) mm, F: Fine (0.125- 0.25) mm, M: Medium (0.25-0.5) mm, R.S.: Red Sea, S.: South, AP: Apparent porosity, BD: Bulk density, CS: Compressive strength, MR: Modulus of rupture, FS: Flexural strength, and MPa: Megapascal = 1 N/mm^2

Table 7: Tests requirements according to ASTM – C503 [21]

Property	Test Requirements	Test Method
Absorption by weight, max, %	0.2	ASTM - C97
Density, gm/cm3	2.305 - 2.800	ASTM - C97
Abrasion resistance, min	10	ASTM - C241
Compressive strength, min, Mpa	52	ASTM - C170
Modulus of rupture, min, Mpa	7	ASTM - C99
Flexural strength, min, Mpa	7	ASTM - C880

7. Discussions

The following discussions can be drawn from the above results in Table 6 compared with the tests requirements according to ASTM – 503 [21] in Table 7:

South Sinai - Teriesta marble: Is extracted from Abo Gaada, Ras Sudr, South Sinai Governorate. The chemical composition of this type is consisting of 54.6% calcium oxide, 0.638% magnesium oxide, 0.355% aluminium oxide, 0.339% iron oxide, 1.03% silicon oxide, and traces of other elements. The grain size of this type is very fine to fine grained, its colour is Gray. The average results of physic mechanical tests are water absorption is 0.87% of its volume, apparent porosity is 2.22%, bulk density is 2.55 gm/cm3, abrasion resistance is 2.14, loss of thickness is 1.47 mm, dry and wet compressive strength are 89.51 MPa and 66.75 MPa respectively, dry, and wet modulus of rupture are 10.83 MPa and 10.13 MPa respectively, and dry and wet flexural strength are 9.9 MPa and 9.73 MPa respectively. Therefore, this marble type exhibit very good physical and mechanical Properties (according to ASTM - C503 [21]) compared with other studied marble types. Due to that rock has a very fine to fine grained of calcite (micrite) and medium to fine grained of re-crystallized calcite (sparite) texture, then this type of marble shows a medium degree of metamorphism. It is also due to presence of higher ratio of silica, in additional to presence of pores and micro-fractures which are very little in these samples compared with samples of other studied marble types. So, this kind of marble can be used for applications subjected to friction because of high resistance to abrasion, in additional to the other decoration purposes (indoor applications).

Suize - Galala marble: Is extracted from Wadi Elkhafouri, Elgalala Elbahariya, Suize Governorate. The chemical composition of this type is consisting of 57.2% calcium oxide, 0.146% magnesium oxide, 0.038% aluminium oxide, 0.037% iron oxide, 0.138% silicon oxide, and traces of other elements. The grain size of this type is very fine grained, and its colour is milky white. The average values of physic-mechanical tests results are water absorption is 0.74% of its volume, apparent porosity is 2.07%, bulk density is 2.72 gm/cm3, abrasion resistance is 1.71, loss of thickness is 1.86 mm, dry and wet compressive strength are 58.33 MPa and 34.09 MPa respectively, dry, and wet modulus of rupture are 8.71 MPa and 7.2 MPa respectively, and dry and wet flexural strength are 8.69 MPa and 6.4 MPa respectively. Therefore, this marble type shows good physical and mechanical properties (according to ASTM - C503 [21]) compared with other studied marble types. Due to that rock has very fine grains of calcite (micrite) and very fine to fine grained of re-crystallized calcite (sparite) texture, then this type of marble shows a partial or medium degree of metamorphism besides it has few pores are detected in the rock. This rock contains microfossils filled by re-crystallized fine-grained calcite. Presence of quartz, dolomite, iron oxides and cellophane as very fine to fine grained caused a good physical and mechanical property. This kind of marble can be used in applications subjected to flooring or stairs, but it is better to be used in the other applications purposes like cladding of walls (indoor).

Red Sea - Elsheikh Fadl Sunny marble Is extracted from Khashm Elrakaba, Red Sea Governorate. The chemical composition of this type is consisting of 55.1% calcium oxide, 0.25% magnesium oxide, 0.323% aluminium oxide, 0.207% iron oxide, 1.02% silicon oxide, and traces of other elements. The grain size of this type is very fine grained, and its colour is flower beige. The average values of physic-mechanical tests results are water absorption is 0.55% of its volume, apparent porosity is 1.84%, bulk density is 2.68 gm/cm3, abrasion resistance is 1.9, loss of thickness is 1.69 mm, dry and wet compressive strength are 67 MPa and 59.37 MPa respectively, dry, and wet modulus of rupture are 13.8 MPa and 10.63 MPa respectively, and dry and wet flexural strength are 10.53 MPa and 9.05 MPa respectively. Therefore, this marble type represents good physical and mechanical Properties (according to ASTM - C503 [21]) compared with other studied marble types. Due to that rock has a very fine grained of calcite (micrite) and medium to coarse grained of re-crystallized calcite (sparite) texture, then this kind of marble shows the medium degree of metamorphism, besides it has some pores detected in the rock where some microfossils possess intraparticle pore spaces, while other pores detected in the rock scattered in calcite matrix (interparticle pores). Due to the presence of higher ratio of silica, in additional to presence of magnesium and iron oxides, this kind of marble Elsheikh Fadl Sunny can be used for applications subjected to friction because of high resistance to abrasion in additional to the other decoration purposes (indoor applications).

Elminya - Sunny and Selvia marble types: Are extracted from Wadi Tina, Beni Hasan, Elminya Governorate. The type of Sunny contains 55.6% calcium oxide, 0.324% magnesium oxide, 0.269%

aluminium oxide, 0.157% iron oxide, 0.875% silicon oxide, and traces of other elements. The grain size of this type is very fine to medium grained, and its colour is light beige. The average values of physic-mechanical tests results are water absorption is 1.19 % of its volume, apparent porosity is 3.18%, bulk density is 2.68 gm/cm3, abrasion resistance is 1.31, loss of thickness is 2.37 mm, dry and wet compressive strength are 54.21 MPa and 45.84 MPa respectively, dry, and wet modulus of rupture are 9.86 MPa and 7.81 MPa respectively, and dry and wet flexural strength are 9.52 MPa and 7.59 MPa respectively. The type of salvia contains 57.5% calcium oxide, 0.096% magnesium oxide, 0.049% aluminium oxide, 0.041% iron oxide, 0.188% silicon oxide, and traces of other elements. The grain size of this type is very fine to medium grained, and its colour is light beige. The average values of physic mechanical tests results are water absorption is 1.49% of its volume, apparent porosity is 3.77%, bulk density is 2.47 gm/cm3, abrasion resistance is 1.15, loss of thickness is 2.74 mm, dry and wet compressive strength are 41.37 MPa and 36.93 MPa respectively, dry, and wet modulus of rupture are 8.1 MPa and 8.53 MPa respectively, and dry and wet flexural strength are 8.48 MPa and 7.47 MPa respectively. Therefore, these marble types show low physical and mechanical properties (according to ASTM - C503 [21]) compared with other studied marble types. This is explained by presence of fossils and shell fragments in great amounts as large to medium sized and embedded in the matrix of very fine to medium grained calcite (micrite). Micrite is converted to sparite (partial re-crystallized medium to coarse grained calcite) in some parts due to not complete re-crystallization which shows the high degree of metamorphism (diagenesis) that change the texture in these samples. In additional to some pores are detected in the rock where some microfossils possess intra-particle pore spaces, while other pores are detected in the rock and scattered in calcite matrix (inter-particle pores), besides presence of micro-discontinuities in these samples makes it easier for the grains to be removed by the abrasive and this makes it exhibit the least resistance to abrasion. These kinds of marble do not prefer to be used in applications subjected to flooring or stairs, but it may be used in the other applications purposes like cladding of walls (indoor).

Red Sea - Zaafarana marble: Is extracted from Gebel Thilmet, Elzaafarana, Red Sea Governorate. It contains 55.9% calcium carbonate, 0.281% magnesium oxide, 0.2% aluminium oxide, 0.092% iron oxide, 0.564% silicon oxide, and traces of other elements. The grain size of this type is very fine to fine grained, and its colour is light pink/beige. The average values of physic-mechanical tests results are water absorption is 0.36% of its volume, apparent porosity is 0.89%, bulk density is 2.73 gm/cm3, abrasion resistance is 2.34, loss of thickness is 1.36 mm, dry and wet compressive strength are 100.29 MPa and 76.57 MPa respectively, dry, and wet modulus of rupture are 10.84 MPa and 11.54 MPa respectively, and dry and wet flexural strength are 10.22 MPa and 12.25 MPa respectively. Therefore, this marble type exhibits very good physical and mechanical properties (according to ASTM-C503 [21]) compared with other studied marble types. Due to that rock has a very fine to fine grained of calcite (micrite) and fine grained of re-crystallized calcite (sprite) texture, then that type of marble shows the low degree of metamorphism, besides to the presence of traces of quartz grains in this rock leads to increasing in the strength properties. In additional to some few pores are detected in the rock as very fine pore spaces (inter-particle pores) scattered in calcite matrix and presence of microfossils which are very little and fine sized, besides to the lower degree of metamorphism. This kind of marble may be used as isolating material in some electric applications because it had rare percentages of metal oxides such as iron and aluminium oxides, besides to the other decoration purposes (indoor applications).

8. Conclusions

Regarding the discussed results and according to ASTM – C503 [21], the following can be concluded:

1. The results of tests (chemical, petrography, physical, and mechanical) on the studied marble types and according to ASTM standards showed that Red Sea - Zaafarana marble is the strongest type and Elminya Selvia marble is the weakest one.
2. All studied marble types need treatment because of high calcium oxide content, low degree of metamorphism, and so high apparent porosity and absorption according to ASTM - C503 [21].
3. High porosity and absorption of white and light beige marbles are considered advantages for manufacturing places that use high technology, especially in treatment and re-coloring stones by laser and other techniques.
4. Milky white Galala marble had the highest price of Egyptian marble types despite it isn't the strongest one and there are many types have better properties than it, that is due to its color, porosity, and absorption which enable it to be treated and re-colored easily.
5. Despite of poor quality of Elminya Sunny and Selvia marbles compared with other Egyptian marble types according to ASTM standards, these types are required because of their cheap prices and its light beige color which enable them to be treated and re-colored easily.
6. Zaafarana, Teriesta, and Elsheikh Fadl Sunny marbles have good properties compared with other studies marble types according to ASTM C-503 [21]. They almost need light treatment with polishing the surface for different uses keeping their fantastic colors without change.
7. Teriesta, Galala, Elsheikh Fadl Sunny, and Zaafarana marble types can be used in all indoor purposes like applications subjected to flooring or stairs, in addition to other decoration purposes after treatment and polishing according to different uses.
8. Elminya Sunny and Selvia marble types are not preferred to be used in applications subjected to flooring or stairs, but they can be used in other decoration purposes (indoor applications).
9. It is not preferred to use all studied marble types in outdoor purposes without treatment due to their abrasion resistance, porosity, and absorption.

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