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Some Factors Affecting the Potential of applying Egyptian Quartzitic Sandstone of Wadi El-Shona South Gebel Akheider as Ornamental Stones

M. L. Abd Ellatif[1], Ahmed A. Omar[2], Maged E. Elfakharany[3]

Department of Raw Building Materials and Processing Technology Research Institute, Housing and Building National Research Center (HBRC), Egypt.
Correspondence Author, Email: geomagedmg@yahoo.com

ABSTRACT

The application of Egyptian quartzitic sandstone as one of quartz-based dimension stone in different ornamentation and decoration purposes based on its own various properties mechanical, chemical, textural and also required physico-mechanical properties the recent research added its durability against salt and firing as affecting factors on its potential usage and almost appropriate application.

The aim of the research was achieved by using a variety of laboratory experiments and techniques includes X-ray diffraction (XRD), petrography (polarizing and stereo microscopes), Infrared (IR) and some physico-mechanical properties (Bulk density (BD), water absorption (Wa) and apparent porosity (AP)). In addition, durability tests (Salt crystallization test and firing) have been applied.

Regardless, the physico-mechanical average values matches the specified requirement for quartzitic sandstone as dimension stone specification the durability of it against salts and firing should be considered for more accuracy before its application under different surrounding and aggressive environments.

Egyptian quartzitic sandstone of Wadi El-Shona controlled by some factors that affected its usage as ornamental stone not only aesthetic feature and physico-mechanical properties but also its durability against salts and firing. So, in the recent study the results demonstrated that the investigated samples have ability to be used as ornamental stones and in other engineering applications such as marine barrier.

Keywords: Ornamental stones; Quartzitic sandstone; Wadi El-shona; Durability.

INTRODUCTION

Geologically, the term quartzite is a metamorphic rock that is originated when quartz-rich sandstone or chert has been exposed to high and intense temperatures and pressures, often during plate tectonic movements and characterized by its dense of interlocking mosaic quartz crystals [1] consequently, this transformation process led quartzite significantly harder and more durable than its quartz rich predecessor.

On the other hand, according to the origin quartzites are classified into two main groups' orthoquartzite and metaquartzite [2-3]. Orthoquartzite is derived from quartz-rich sandstone and may be of diagenetic or low-grade metamorphic origin, while metaquartzite is formed, under metamorphic conditions of upper greenschist to granulite grade, from orthoquartzite or chert protoliths [4]

For engineers and architects quartzite possesses some benefits such as its natural beauty, durability, heat and stain resistance and also its low maintenance compared to some other natural stones. All of the previous criteria which make it easily classified as ornamental or dimensional stones belongs to (quartz-based dimension stone group) according to standard terminology ASTM C-119 as quartzite in a complete agreement with definition of dimension stone in [5] by the following : is natural stone, can be selected and fabricated to specific sizes or shapes, with or without one or more mechanically dressed or finished surfaces, for use as building facing, curbing, paving stone, monuments and memorials, and various industrial products.

In Egypt, some ancient and recent quartzite quarries are well known and represented by some type localities involve: Aswan, across Eastern Desert and also near Cairo (Gabal El -Ahmar). It should be noticed that Egyptian quartzite not only have historical importance by its usage in some historical and monumental applications but also have some important modern engineering uses as building material for cladding, flooring and also as decorative objects for instance in sculptures and artwork.

The most of Egyptian geological studies and researches about quartzite [6-8] are deal with it only from the theoretical point of view as one of the rock unit forming different geological formations within different studied areas such as without detailed studies for its different characterizations and its compatibility for applying as decorative ornamental stones while the recent research is different by focusing on evaluate some of the main factors affecting usage Wadi El-Shona quartzitic sandstone as decorative and ornamental stones through engineering and applied point of view depending on its mineralogical composition, physico-mechanical properties and durability. Sandstones also as one of the quartz-based dimension stone has commonly been used in architecture and historical buildings [9]. Current conditions of buildings and structures reveals that they are vulnerable to several natural and anthropic agents, such as fire [10-13]. Fire is responsible for microstructural alterations in stone (e.g., open porosity, pore size distribution, cracks, and chemical- mineralogical modifications) that alter its strength and durability properties [14] Durability tests in the recent study can be divided into: Artificial weathering using exposing to salt and exposing the studied rock to elevated temperature (firing). Fires and high temperatures cause changes in the physical properties and mineralogical composition of sandstones that are commonly used in monuments. The knowledge of how properties and mineralogical composition of sandstones change with increasing temperature is fundamental for the conservation and restoration of fire damaged sandstone monuments [15]. There are two main categories of fires, according to their temperatures and development: (i) small, localized fires that in general do not generate much heat (temperatures below 800°C) and (ii) large, extensive fires that generate higher temperatures with maximum temperatures (around 1200°C) [16]. The samples have been exposed to the two main categories of fires.

MATERIALS AND METHODS

Three studied representative quartzite samples were collected from recent quarry facade which belongs to (Magnom mining company) and located in the area South of Gebel Akheider (Wadi El-Shona) and bounded between longitude 32° 04، 52،، with latitude 29° 39، 27،، (Fig.1). The study area of (Wadi El-Shona) is considered as one of the Wadi Ghoweiba tributaries which lies in the easternmost part of the northern Eastern Desert of Egypt, bordering the northwestern tip of the Gulf of Suez [17]

Generally, the study area of (South Gebel Akheider) occupies by several lithological units with different ages from Jurassic to Quaternary (Fig.2) but particularly, the studied quartzite are stratigraphically belong to Oligocene rocks which recorded with patchy Gabal El-Ahmar Formation (Fig.3) in the central part of the study region which contains vividly colored sand, quartzite, and gravels [7] including many conglomerate lenses and beds (Fig4).

Stratigraphically, the studied quartzite as quarry facade represents a cap rock for Gabal El-Ahmar Formation described as dark gray to reddish brown, very hard, quartizitic sandstone bed (1.0–2.0 m thick) [6]

Methods

Mineralogical composition

The X-ray diffraction technique (XRD) has been utilized to determine the mineralogical composition. Subsequently, the analyzed samples were examined using a polarizing microscope (Olympus BX50, Japan) in accordance with the specifications outlined in ASTM C-1721 [19]. The objective of this examination was to identify the texture of the samples under investigation and categorize the rocks being evaluated. Additionally, a stereomicroscope (Olympus GX71, Japan) was utilized to assess the impact of fire on the examined samples.

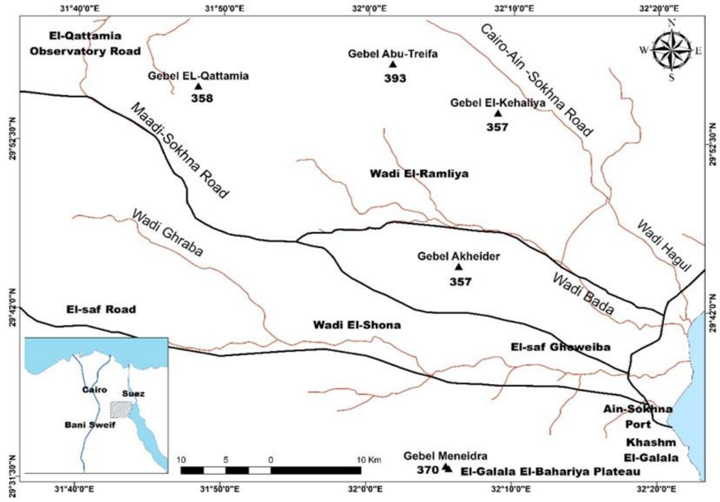


***Figure 1**: Location map of the study area [17]*

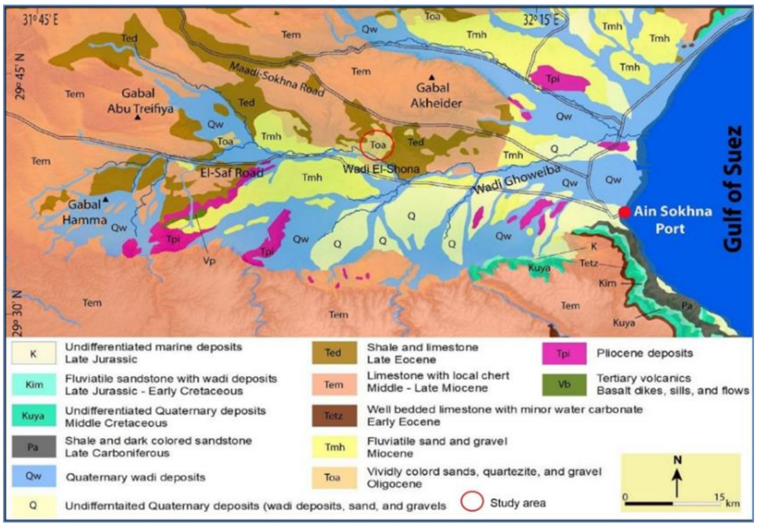


Figure 2: *Geological map of the present study region, modified after [18]*

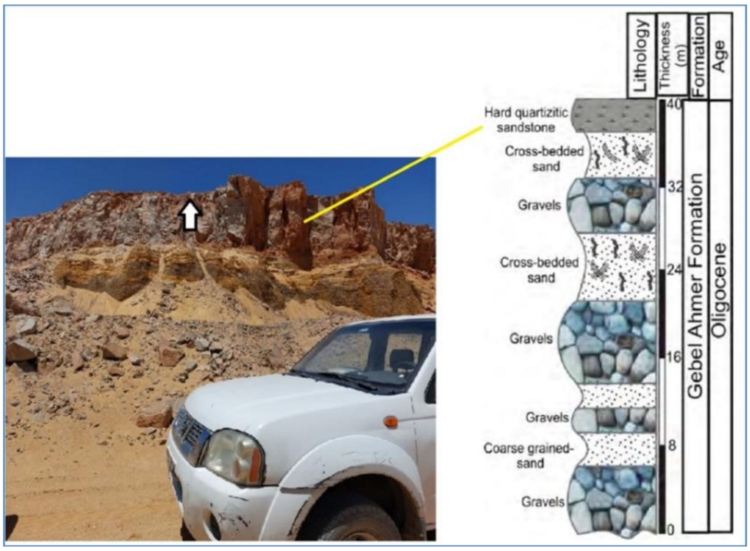


Figure 3: *Stratigraphic columnar section of the Oligocene Gebel Ahmer Formation, south of Gebel Akheider [6] associated with own field photo for studied quartzite quarry façade*

Figure 4: *One of the studied quartzitic sandstone blocks in study area*

Chemical composition

The representative examined samples were tested for chemical analysis using an X-ray fluorescence (XRF) model (Phillips PW 1400 Spectrometer, Holland) at HBRC to detect the predominant oxides, chlorides, sulphate, and loss of ignition (L.O.I.) contents.

Physico-mechanical Properties:

Firstly, three physical properties were measured for the studied quartzitic sandstone samples including Bulk density (BD), water absorption (Wa) and apparent porosity (AP). All of the three measured previous physical properties were carried out and calculated according to the recommended standard test methods ASTM C-20 and ASTM C-97 [20-21]. Secondly, the measured mechanical properties involve compressive strength, Modulus of rupture and abrasion resistance also calculated for the selected samples based on ASTM C-170, ASTM C-99 and ASTM C241respectively [22-24]. The measured average physico-mechanical values were compared to the requirements of the standard specifications ASTM C-616 for quartz-based dimension stone [25].

All of the previous measured physico-mechanical properties were carried out in the Housing and Building National Research Center laboratories.

Durability tests

In the recent research two main durability tests or artificial weathering or ageing tests were carried out for measuring durability of the studied rock against damage by artificial weathering cycles using salts and heating by firing.

In the case of salt crystallization the test is conducted in accordance with the specifications stated in the BS EN 12370 standard [26]. Three cubic samples of rocks were thoroughly cleaned and dried until a consistent weight was achieved at a temperature of 75 oC. The initial weight after drying was recorded. The cubes were completely submerged in two beakers containing solutions of 14% Na2SO4.10H2O for a duration of two hours. Subsequently, the cubes were subjected to a drying process in an oven set at a temperature of 75 °C for duration of 22 hours. The specimens were allowed to reach ambient temperature, and their mass was recorded. The cubes underwent 45 cycles.

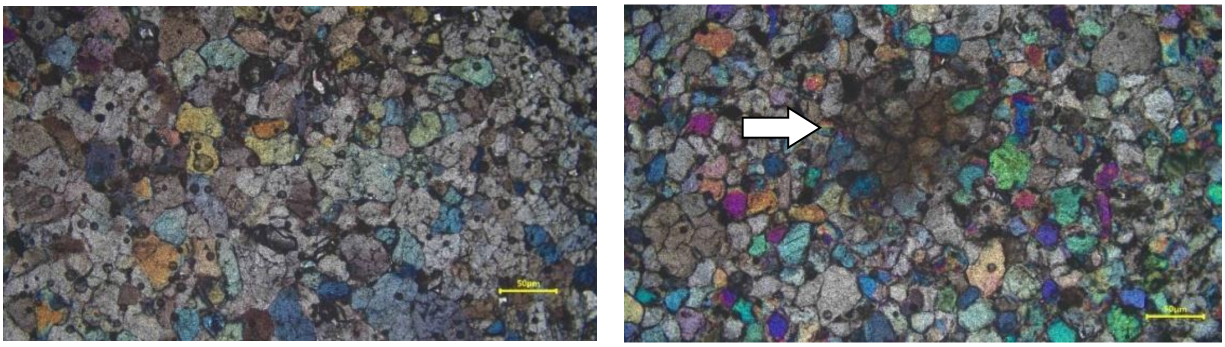
Concurrently, the impact of firing on the examined samples has been analyzed after exposing to different elevated temperature. To evaluate the effect of thermally heating on the studied sandstone rocks, cubic rock specimens (2.5 cm* 2.5 cm *2.5 cm) have been exposed to elevated temperature in an oven from room temperature 20 °C up to 800°C and 1000 °C. Temperature was controlled with a digital programmable temperature controller. The rate of heating was set at 6 °C/ min and each temperature threshold was maintained for 3 h. After this, the specimens were left to cool down unforced to room temperature and were visually examined and tested by methods described below. Thin sections for polarizing microscope analysis were made from samples after each heating experiment in order to detect the impact of firing on the interior texture, optical properties of minerals as well as mineralogical alterations using a stereomicroscope for polished slabs of fired studied samples as well as FTIR spectroscopy. The infrared spectra (IR spectra) were recorded on FTIR spectrometer, measured in the 4000 - 400 cm-1 spectral range in the transmission mode for unfired samples, 800°C and 1000 °C.

RESULTS & DISCUSSION

Petrographic investigation and mineralogical composition

It is essential to examine the initial texture and mineralogy of the stone firstly, to investigate the mineralogical changes that may occur with firing. Petrographically, the representative studied thin sections (for unfired samples) consist mainly of medium to coarse angular to sub angular mature quartz grains with mostly sutured boundaries. The studied quartzite has two types of quartz grains the first is monocrystalline which represents more than 90% of total quartz content while rest called polycrystalline which represented the second type. Most quartz grains of the studied sample forming highly packed and interlocking framework that reflected granoblastic mosaic texture. The studied quartzitic sandstone most likely to be classified mineralogically as quartz arenites with moderately sorting [27]. In addition to quartz the associated minerals within the studied thin-section can be classified into feldspars which represented by (k-feldspar and plagioclase) with some heavy minerals including biotite, tourmaline and rare zircon.

Mineralogically, X-ray diffraction patterns of the three representative samples are agreed with their petrographical investigation by polarizing microscope as it showed that the sample is mainly composed of quartz (Fig 6) and detected by its main peak at 2θ theta= 26.65.



(A) (B)

Figure 5: *A) Photomicrograph of Highly packed and interlocking quartz framework, B) Some of the forming quartz grains associated with heavy minerals mostly iron oxide.*

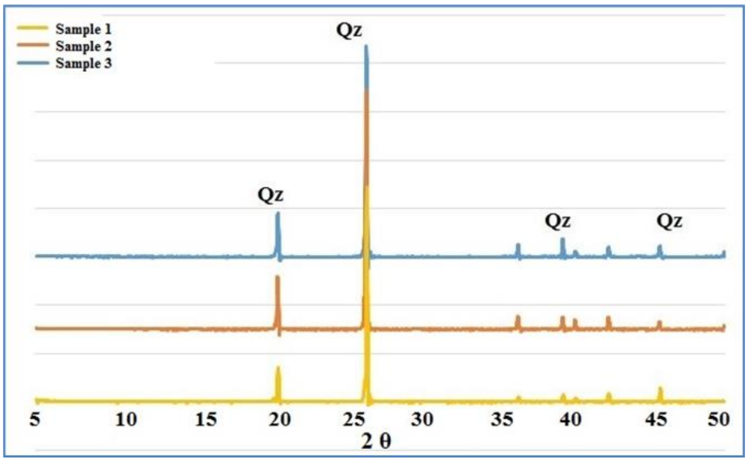


Figure 6: *XRD pattern of studied samples*

Chemical composition

The obtained chemical composition of the three representative quartzitic sandstone studied samples and its average were given in table 1 expressed by wt%. It includes the different forming oxides (major, minor, and trace) associated with chloride and sulphates content and also Loss of Ignition (L.O.I). The chemical composition gained data reveals that SiO2 is the main major oxide as its presence with very content with narrow range from (97.67 to 98.20 wt. %) with an average 97.99 wt. %. The excess of SiO2% in the recent studied quartzite samples is due to the presence of quartz as the major rock forming minerals which mean a complete agreement between both of the mineralogical and chemical composition of the studied quartzite samples. On the other hand, some other oxides (Al2O3 , CaO, Fe2O3, and TiO2 with sulphates (SO3) and (L.O.I) are present in a minor wt. % as all of the previous not exceeds 1 wt. %. Moreover, all of the other remaining oxides (Cr2O3, Na2O, K2O, MgO, SrO), in addition chloride are present as traces not exceeds 0.1 wt. %. Some chemical parameters can be used as guide for geochemical classification of studied quartzite as the following binary diagrams Figs (7) for log (SiO2/Al2O3) versus Log (Na2O/K2O) and also versus log (Fe2O3/ K2O) with boundaries suggested by [28] and [29] respectively which exhibited that the studied quartzite are occupied the quartz arenite zones in both suggested binary diagrams.

Table 1: Chemical composition of the investigated samples

Sample	SiO_2	Al_2O_3	CaO	Fe_2O_3	Cr_2O_3	Na_2O	K_2O	MgO	SO_3	P_2O_5	SrO	TiO_2	Cl	L.O.I	O T
	Weight percentage %														
Q1	97.67	0.33	0.36	0.63	0.12	0.04	0.03	0.09	0.15	0.07	0.04	0.23	0.03	0.20	99.99
Q2	98.20	0.14	0.29	0.65	0.12	0.05	0.02	0.11	0.10	0.02	0.02	0.05	0.03	0.18	99.98
Q3	98.10	0.14	0.32	0.48	0.05	0.05	0.02	0.16	0.08	0.03	0.02	0.19	0.04	0.26	99.96
Ave:	97.99*	0.20**	0.32**	0.58**	0.09***	0.04***	0.02***	0.01***	0.11**	0.04***	0.02***	0.15**	0.03***	0.21**	99.97

* Major oxide by weight % ** Minor by weight % *** Trace by weight %

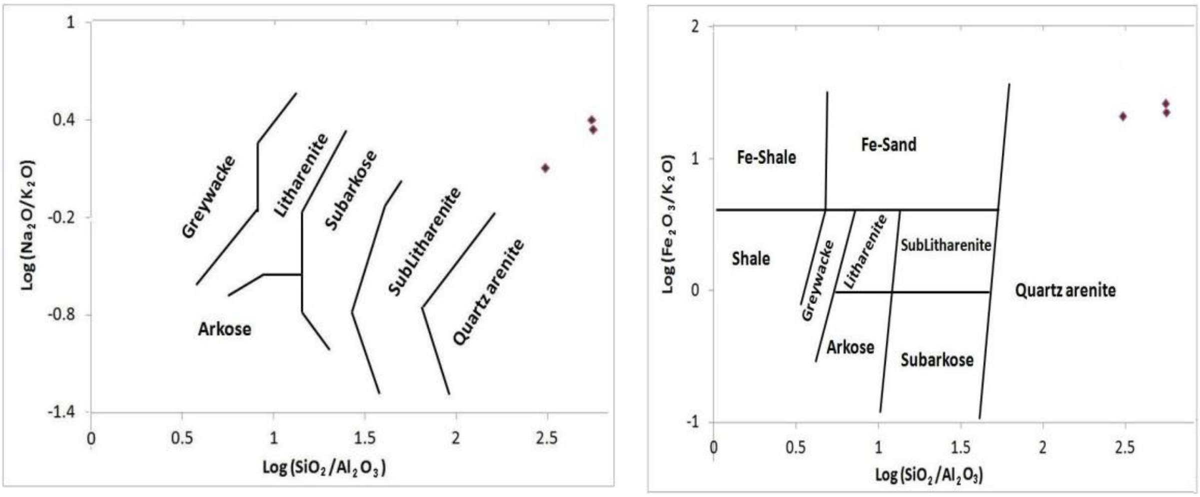


Figure 7: *Geochemical classification of the studied quartzitic sandstone samples.*

Physico-mechanical properties of the studied samples

The obtained average values for the different studied physico-mechanical properties of the studied 3 samples listed in Table (2) show:

Physico-mechaical properties	Average value	Specification requirements	
Bulk density (gm/cm^3)	2.6	1.5(gm/cm^3)	Min
Water absorption%	0.19	3 %	Max
Apparent porosity%	0.49	4.5%	Max
Compressive strength (MPa)	121	68.9 (MPa)	Min
Modulus of rupture (MPa)	11.9	6.9 (MPa)	Min
Abrasion resistance, Ha	13	8	Min

Their average bulk density (B.D) is of 2.6 gm/cm3 and they are characterized by low water absorption (WA%) values with an average of 0.19 % and consequently, the average apparent porosity of the studied samples is 0.49%. On the hand, the obtained an average dry compressive strength (C.STR) is 121 MPa and also their average modulus of rupture (M.RUP) is 11.9 MPa for the studied 3 samples. It can be also noticed that the abrasion resistance (AB.H) for the studied samples with an average 13.

Finally, all of the obtained average values for the different studied physico-mechanical properties for the studied samples are agreed with (quartzitic sandstone class II) based on the standard specification for quartz-based dimension stone number ASTM C-616 [26] and its requirements.

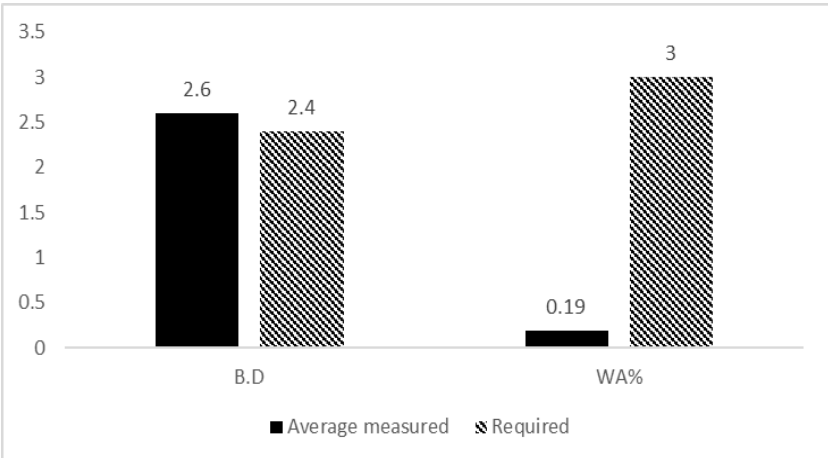


Figure 8: *the comparison between measured and required average values of studied physical properties based on standard specification*

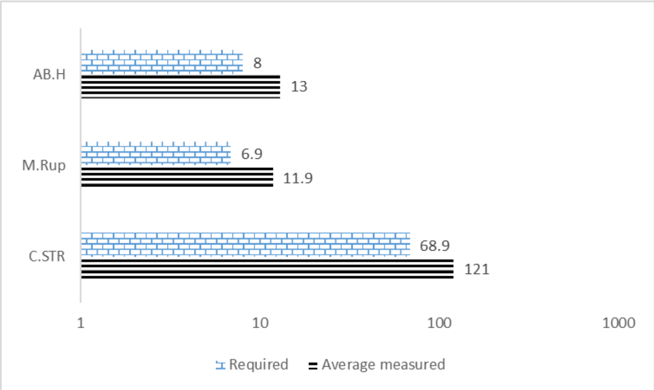


Figure 9: *the comparison between measured and required average values of studied mechanical properties based on standard specification*

Salt crystallization test

Salt crystallization test were conduct for three representative studied samples Q1, Q2 and Q3. The obtained results listed in Table (3) and represented graphically in (Fig.10) reflected the change in weight of the studied samples over 45 cycles from W0 to W45 and also average weight loss Avg ΔM%. As shown in table (3) approximately neglicable weight loss ΔM% for all three studied samples over 45 salt crystallization cycles moves within narrow range from 0 to -0.039 % with an average (ΔM%. - 0.034%) that means it belongs to Class A durability class based on Barry diagram as shown in (Fig.11).

On the other hand, for some of the studied sample surficial efflorescence were observed as visual observation associated with damage by salt crystallization as observed in figure and investigated by stereomicroscope as in photomicrograph (12).

Table 3: The weight loss (ΔM %) for the studied samples over 45 salt crystallization cycles from W0 to W45

Sample	initial weight (gm) W0	Final weight, (gm) W45	ΔM %	Avg ΔM%
Q1	170.87	170.82	-0.029	
Q2	174.7	174.7	0	- 0.034
Q3	176.38	176.31	-0.039	

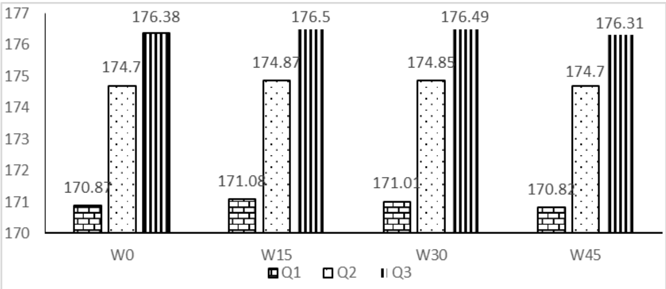


Figure 10*: The weight loss (ΔM %) studied samples over 45cycles of salt weathering*

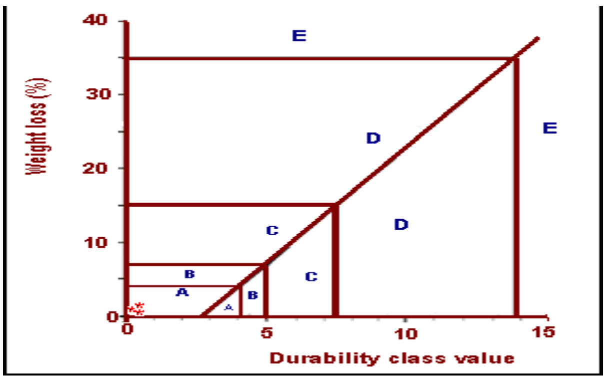


Figure 11: *Barry diagram presenting durability class and value based on weight loss percentage of the studied samples.*

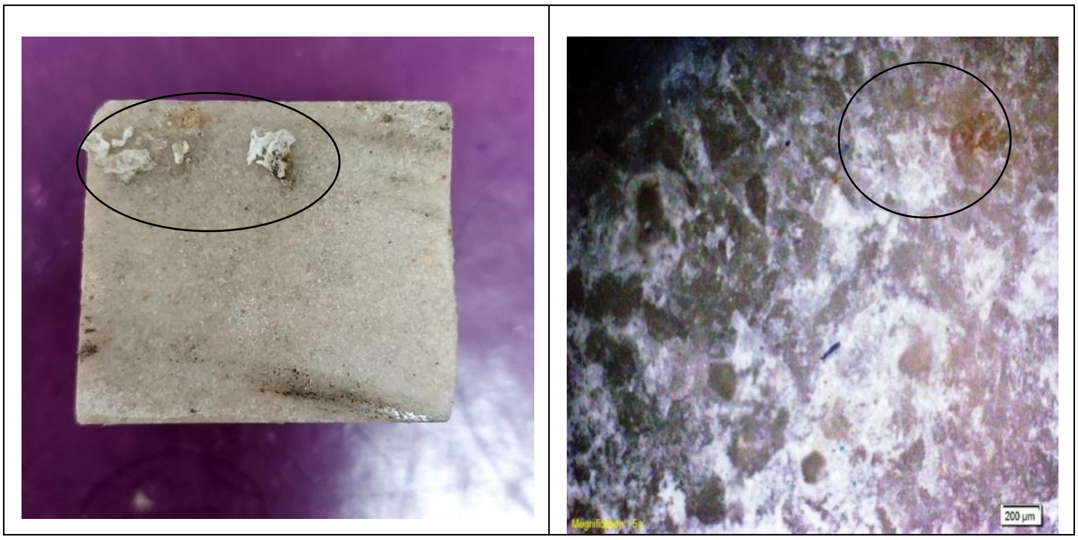


Figure 12: *Surficial efflorescence associated with salt crystallization test of the studied sample and illustrated by elliptical shape (left). Stereo-photomicrograph shows slight Surficial efflorescence crystals associated with salt crystallization and marked by circle (right).*

Firing

Petrography investigation of fired samples

For all analyzed quartzitic sandstones, the quartz grains show significant alteration at 850 °C and 1000 °C (Fig. 13). micro cracks have been clearly observed not only at the boundary of grains (transgranular cracks) but also, within the grains (intracracks). The formed microcracks have been developed due to the transformation of α-quartz to β-quartz at 580 °C – 595 °C (30), and this is associated with a volume increase. Another and visible change in the colour order of quartz grains which reflect changes in the internal quartz structure due to firing effect at 1100 °C. Moreover, Stereo microscope and visual detection of fired samples show the significant changes in colour for both degree of firing. Quartzitic sandstone sample changed from its original light grey colour to light pink at 850 °C then to reddish to light brown at 1100 °C (Fig. 14). Colour changes can be a perennial problem predominantly for decorative stones and can identify and reflect the lower quality and damage of the stone.

FTIR spectrum of unfired and fired studied samples.

Figure shows the spectra of sandstone samples before and after fire. The signals at 518 and 463 cm-1 are related to the SiO2 compound of quartzitic sandstone. The bands at 798.85 and 778.29 cm−1 are assigned to Si-O-Si bond bending motion in SiO2. The IR vibration at 1083 cm−1 is the asymmetric stretching motion of oxygen in a Si-O-Si bridging configuration. In the spectra of sandstone after firing (850 °C and 1000 °C), the signals are the same as un fired quartzitic sandstone except of signals one at the 1432.35 cm-1, that is related to oxidation of some impurities present scattering within the mineralogical composition as plotting in spectra Fig(15) .

As investigated quartzitic sandstone characterized by homogeneity in its mineralogical and chemical composition associated with highly packed and interlocking quartz framework microscopic texture it leads to increase the compactness between its quartz forming grains with decreasing the pore space consequently, the increase in the obtained average values of some measured physico-mechanical properties includes: bulk density, compressive strength, modulus of rupture and also increase its resistance to abrasion with decrease in obtained average values for others (water absorption and apparent porosity). On the other hand, another positive effect for the obtained textural, mineralogical, chemical composition as well as physico-mechanical results as it increase durability and resistance for studied quartzitic sandstone against two different studied ageing factors (salt crystallization and firing) which can be clearly observed through slight average of weight loss (ΔM% = - 0.034) over 45 salt crystallization cycles which means class A durability class based on Barry diagram.

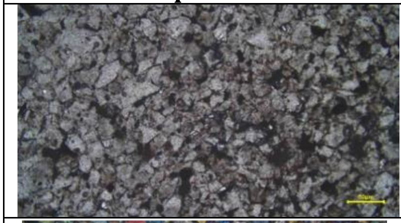
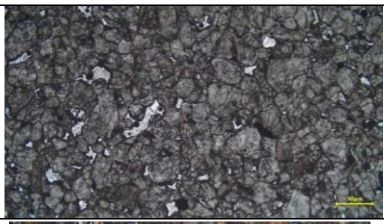
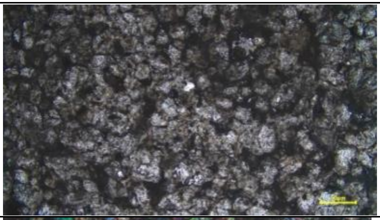
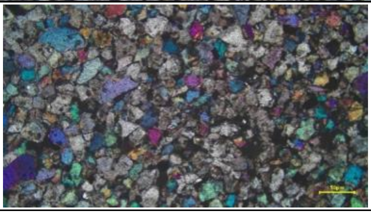
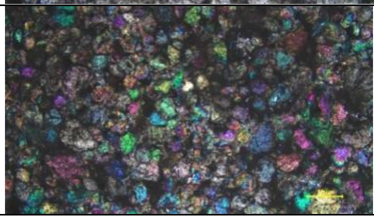
Studied sample at room temperature	Studied sample After firing A 850 ° C	Studied sample After firing A 1100 ° C	
			PPL
			XPL

Figure 13: *Photomicrographs show textural changes carried out by firing*

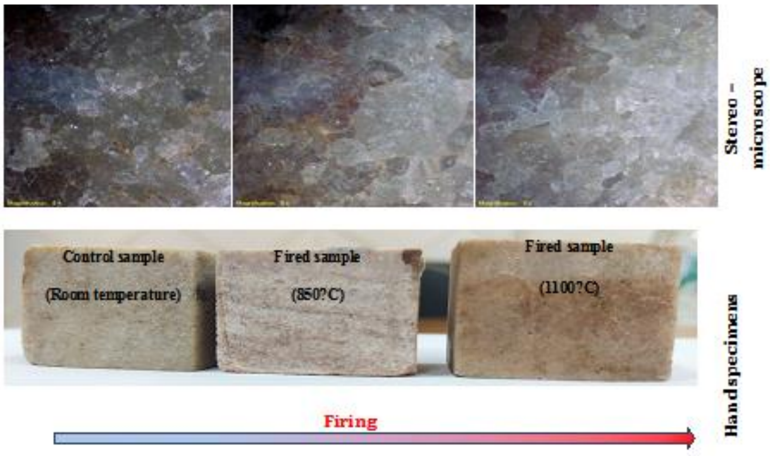


Figure 14*: Stereo micrographs and hand specimens show the difference between room temperature quartzitic sandstone and two fired samples.*

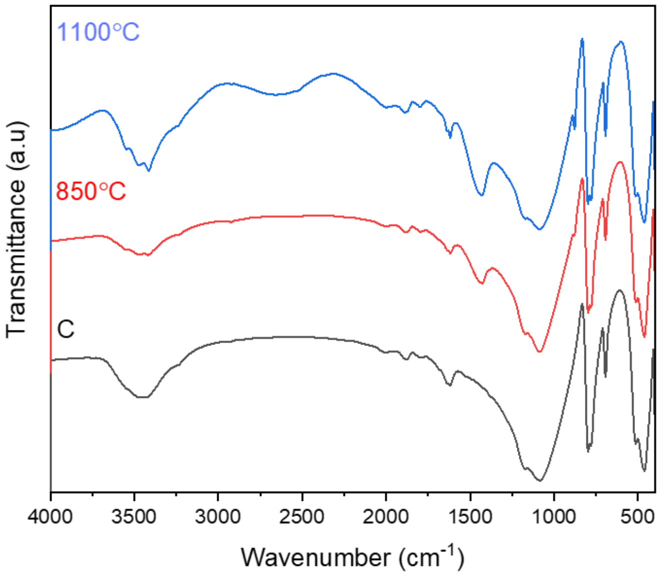


Figure 15: *FTIR charts for studied control and fired quartzitic sandstone samples.*

CONCLUSION & RECOMMENDATION

Quartizitic sand stone under investigation located geographically in the area called W. El Shona, South G. Ahmer, North weastern tip Gulf of suez and stratigraphically, represented a cap rock of G. El Ahmr Fm.

Mineralogically and chemically classification revealed that the investigated quartzitic sandstone originated from sedimentary origin (Quartz arenites).

As a result of highly packed and interlocking quartz framework structure for investigated (quartzitic sandstone) under polarizing microscope, it leads to increase compactness between quartz grains and consequently achievement average values of different physico-mechanical properties stated in (ASTM C616).

The effect of salt crystallization test through 45 cycles is almost negligible as (Δ m = - 0.034%) which means its durability follows (Class A) on Barry diagram and giving it an importance criteria added to its appearance and physico-mechanical properties to utilize as ornamental stones.

Silica cemented quartzitic sandstones also show minimal textural and mineralogical changes during the laboratory heating tests carried out. The changes are mainly observed at higher temperatures in the form of α-β-quartz transition at 575 °C. This volumetric increase generates thermal expansion cracks.

The various application of quartzitic sandstone not only involved for decoration and ornamental purposes but also it can be used in other engineering applications such as marine barrier.

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