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Study Correlation between Physical-Mineralogical Properties of Sandstone Used in Ptolemaic Temples in Upper Egypt and Its Weathering Resistance

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Abstract

This article focuses on study of a relation between physical-mineralogical properties of sandstone used in Ptolemaic temples in Upper Egypt and its resistance of deterioration factors affecting it. In the present study, sandstone samples were collected from four sites; namely the temples of Dendera, Esna, Edfu and Kom Ombo which are located in Upper Egypt. Polarized light microscope (PLM), Scanning Electron Microscope (SEM), X-Ray diffraction (XRD) and energy-dispersive X-ray spectroscopy (EDX) were used to determine mineralogical properties, microstructure, and chemical compositions of the deteriorated sandstone samples, addition to physical properties tests; results of the study confirmed that sandstone samples containing a high percentage of salts, clay minerals and iron oxides have been significantly affected by deterioration factors. The deteriorated sandstone samples were treated by paraloid B72 3% enhanced with Nano silica 5% to improve the physical properties of stone. Results of the study indicated that the samples which were consolidated by Nanoparticles based on acrylic Copolymers (Paraloid B72 and its Nanocomposite with Nano silica) achieved the best results for improvement of its physical-mineralogical properties. This is the ultimate aim of the study for the purpose of conservation and sustainability of building materials of the temples.

Keywords

Sandstone, Ptolemaic Temples, Physical-Mineralogical Properties, Weathering Resistance of Sandstone, Consolidation Materials

1. Introduction

The majority of the ancient temples in Upper Egypt were built using sandstones from the Gebel el-Silsila region, and restoration work has been done on these monuments in the past and present. In the southwest of Egypt, the Gebel el-Silsila region is located between Aswan and Luxor, at a distance of 50 kilometers, where are sandstone quarries located over the west and east banks of the Nile [1] [2]. Sandstone is the main building material that was used in construction of most of the Ptolemaic temples located in Upper Egypt, such as Dandara temple (dedicated to god Hathor, it was completed late 2nd century BC), Esna temple (the temple dedicated to the ram-headed god Khnum, it completed construction during the Ptolemaic period and the Roman period between 40 and 250 AD), Edfu temple (the temple dedicated to the god hours, it is very complete, It was built during the Greco-Roman Period), Kom Ombo temple (It was built by Ptolemy VI (180 - 145 BC) and added to by subsequent Ptolemys). Sandstones' petrophysical characteristics and material behaviour during deterioration are controlled by the rock fabric. Rock fabric is the product of geological processes such as sedimentation, compaction, diagenesis, and post-diagenetic modification, and it provides information about grain size, sorting, roundness of detrital grains, grain contacts, and cementing material qualities [3]. Sandstone's strength and hardness are influenced by the quantity and type of cementing agent that holds the sand grains together. In Egyptian sandstones, quartz, iron oxides (limonite and hematite), calcite, and clay minerals are the most frequent cements. The rock is friable and readily broken down when these cements are sparse, but it is well-indurated and robust when they are abundant and fill all of the intergranular pore spaces. As one of the most significant aesthetic and functional stones used in ancient Egypt, sandstone containing a lot of quartz cement is the hardest of all and is referred to as "silicified sandstone" [4] [5]. The most important feature of sandstone is their good workability and comparatively high weathering resistance, but numerous writers stress the significance of rock porosity and pore size distribution as determinants of rock weathering in their writings. Additionally, the mechanical properties of rocks are mostly determined by their porosity and cementation level [6] [7] [8] [9]. The texture and composition of the rock play a major role in how it degrades, not just the environment in which it is found, since there is a direct correlation between the bonding materials for mineral crystals and the strength of their bearing pressure stresses, the stone's ability to withstand pressures on it increases whenever there is a strong correlation between the mineral crystals and the bonding materials which play a significant role in the ability of the stone used in the archaeological buildings to bear the stresses on it [10] [11] [12]. The mineral and chemical composition of the stones used in the construction of archaeological buildings is an important factor in determining the degree of weathering and the extent of their resistance to the factors of damage that may affect them, and the strength of the bearing pressures placed on a stone is directly correlated with the mineral composition of the stone, since increasing as the proportion of hard minerals increases. The mineral composition of the stone may include both stable and alterable (unstable) forms of minerals. There are minerals such as halite, clay minerals and iron oxides, found within the components of sandstone, where these minerals are subjected to change when interacting with various damage factors [13] [14]. Wet and dry cycles cause complex mechanical damage in particular when salts are found in the pores of the stone; because it is characterized by high porosity, so it has ability to absorb moisture from air or ground, thus facilitating penetration of salts spray into its components causing physiochemical damage, especially when the dissolved salts turn to different crystalline sizes, causing cracks in internal structure of the stone [15], because sodium chloride salt is hygroscopic and tends to absorb water, the presence of water causes the salt crystal to expand, creating pressures and tensions inside the stone that cause disintegration of the binding material of sandstone; the stone's containment of iron compounds makes it vulnerable to oxidation, such as the transformation of ferrous compounds into ferric compounds, where iron compounds change the color of the stone, and ferric compounds increase in size when they acquire water of crystallization, causing stresses in the stone's structure, which accelerates the process of damage, and this phenomenon is known stone disease [16] [17]. Most sandstone has clays in the cement that binds the grains together. They are extremely prone to deterioration due to this type of cementing phase, especially in situations of cyclic wetness and drying that cause the clay minerals to swell and shrink. Numerous studies that point to this as a durability issue for sedimentary stones may be found in the literature on stone conservation [18] [19]. There is a study revealed the presence of clay minerals, minerals salts and iron oxides, causing accelerated stone damage, due to the soluble chloride and sulphate addition to clay minerals much damage to the porous materials. Because these components absorb moisture easily from the atmosphere and thus increase the moisture content within the stone, which dissolves the salts in the pores, and when evaporation of water occurs crystallization and recrystallization of salts cause mechanical damage to the stones [20]. Nanomaterials and synthetic nanocomposites have recently gained popularity in the consolidation and improvement of properties of archaeological building materials [21], which is what this study aims at improving the properties of sandstone that have been damaged. This research agrees with previous studies that the mineral and physical properties of the stone have a role in its resistance to various damage factors. The current study highlights correlation between physical-mineralogical properties and weathering resistance of sandstone used in Ptolemaic temples in Upper Egypt and the use of composite nanomaterials to improve its properties.

2. Materials and Methods

2.1. Sandstone Samples of Case Studies

Sixteen samples were collected from case studies; four samples (S1 - S4) represents

Dandara temple which is situated on the west bank of the Nile, about 5 kilometers south of Qena, four samples (S5 - S8) represents Esna temple which located in Esna city on the west bank of the Nile in Luxor (776 km south of Cairo), four samples (S9 - S12) represents Edfu temple which is located on the west bank of the Nile River between Esna and Aswan, four samples (S13 - S16) represents Kom ombo temple, which is situated on the East side of the Nile, 45 kilometers to the north of the city of Aswan and about 800 kilometers to the south of Cairo. These samples are representative of the different symptoms of deterioration, such as granular disintegration, weathering out of stone components and multiple scaling, efflorescence salts, granular disintegration into powder, separation of crusts or thin sheets of stone surface, loss of stone material, exfoliation, bleeding of stone, fissures, cracks and chipping off pieces (Figure 1 and Table 1).

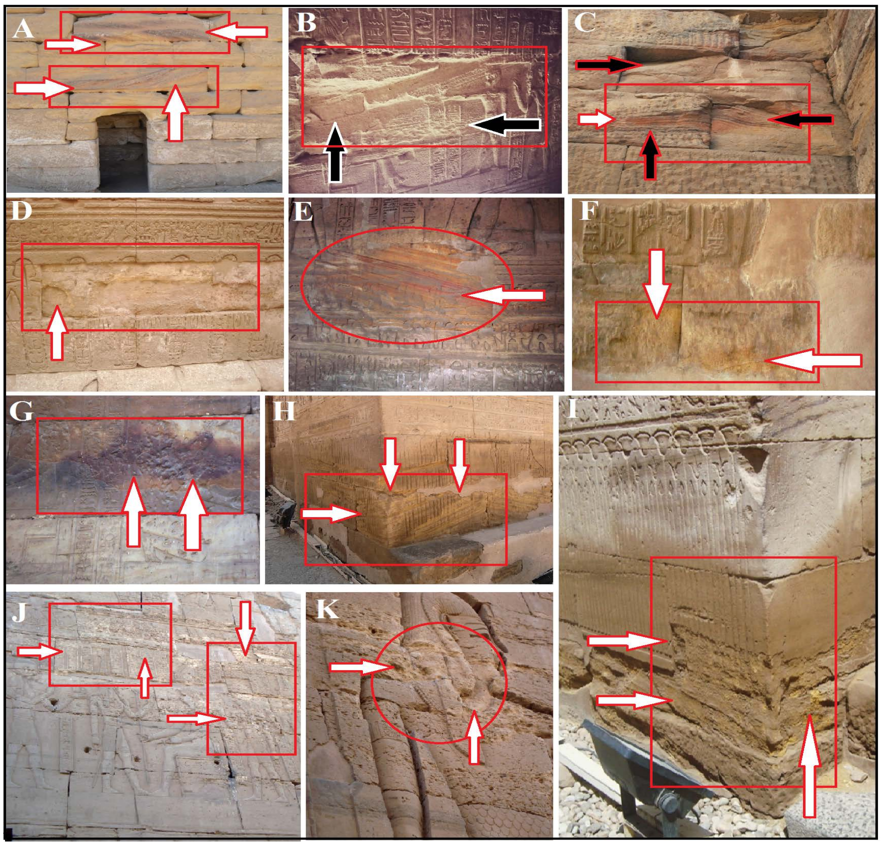


Figure 1. (A, B, C) shows different deterioration symptoms of Dandara temple; (A) coloration due to migration of iron oxids (the sacred lake), (B) weathering out of stone components (Crypt behind Holy of Holies), (C) the upper part of photo shows weathering out of stone components and the rectangular shape shows coloration due to migration of iron oxids. (D, E, F) shows different deterioration symptoms of Esna temple; (D, F) weathering out of stone components, (E) coloration due to migration of iron oxids (Hypostyle Hall). (G, H, I) shows different deterioration symptoms of Edfu temple; (G) coloration due to migration of iron oxids, (H, I) weathering out dependent on stone structure (The main gate). (J, K) shows different deterioration symptoms of Kom ombo temple; (J, K) alveolar weathering due to lose of stone material (The upper part of the eastern wall of the courtyard surrounding).

Table 1. Location of the deteriorated samples were taken from case studies.

Samples cod	The location of the samples
S1 - S4	The upper parts of the eastern wall, the sacred lake and Crypt behind Holy of Holies.
S5 - S8	The lower parts of the eastern wall of hypostyle hall.
S9 - S12	The lower stones of the main gate of the temple.
S13 - S16	The upper part of the eastern wall of the courtyard surrounding the temple.

2.2. Examination and Mineralogical Composition

Thin sections of deteriorated sandstone samples were examined using Polarized Light Microscopy (PLM) LEITZ WETZLAR (GERMANY), with an LEICA Cam Max. 100 W (307-148.002-514,687). The samples (S1 - S4) were taken according to the representativeness of the degradation processes of Dandara Temple, the examination of the sandstone samples under polarized microscope shows sandstone is composed of quartz (main component), rock fragments, carbonate minerals (calcite and dolomite), clay minerals (kaolinite), opaque matter, feldspar (microcline, al-bite), iron oxides. It shows the lowest contents of quartz and rock fragments, but the highest contents of clay minerals and opaque matter. Color banding and alignment of mica and longish quartz grains are characteristic. The samples (S5 - S8) were taken according to the representativeness of the degradation processes of Esna Temple; Light optical microscope reveals that sandstone is composed of quartz (main component), feldspar (microcline, albite), carbonate minerals (calcite and dolomite), clay minerals (kaolinite) and iron oxides (magnetite, hematite). These components are cemented by carbonate minerals (calcite and dolomite) admixed with gypsum, clay minerals and iron oxides. Quartz grains are very fine to fine-grained with rounded to sub angular outlines. The samples (S9 - S12) were taken according to the representativeness of the degradation processes of Edfu Temple, the petrographic study of sandstone samples shows fine-grained, the highest contents of rock fragments, clay minerals and iron oxides. It shows the lowest contents of quartz and rock fragments, but the highest contents of clay minerals and opaque matter, color banding and alignment of mica and longish quartz grains are characteristic. By examining the samples (S13 - S16) representing the phenomena of damage to Kom Ombo Temple, it was found that they are similar to the visual characteristics of the sandstone taken from the Temple of Edfu (Figure 2). Mineralogical study using X-Ray diffraction patterns, using a Philips X-ray PW 1840 diffractometer with Cu-Kα radiation generated at 40 kV and 40 mA. It covers 2θ from 5˚ to 50˚. The sandstone samples were investigated by XRD showed all samples are mainly composed of quartz (SiO_2), Albite ($NaAlSi_3O_8$), Magnetite (Fe_3O_4), Hematite (Fe_2O_3), Calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), kaolinite ($Al_2Si_2O_5(OH)_4$), and halite (NaCl) (Figure 3 and Figure 4). Microstructure and chemical compositions of the deteriorated sandstone samples were determined by Scanning Electron Microscope (SEM) Model Quanta 250 (FEG) Field Emission Gun (Accelerating voltage 200 V - 30 kV Operating Voltage 5 - 30 kV, Magnification:

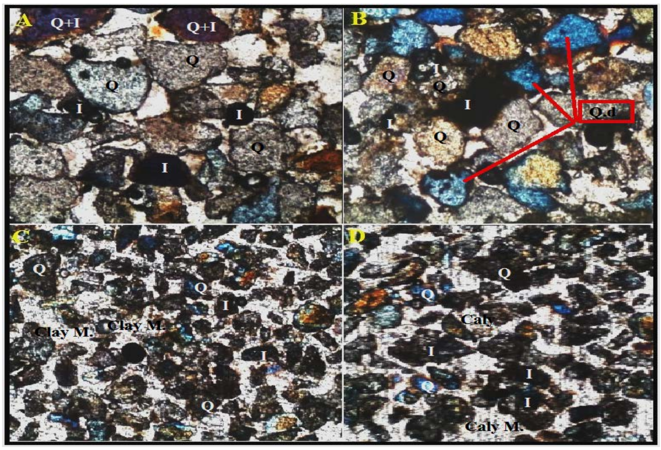


Figure 2. Thin section photomicrographs of all sandstones. (A) A thin section of sandstone representing the Temple of Dendera; showing quartz grains that are medium to coarse-grained, rounded to subrounded, and presence iron oxides cement, addition to heavy minerals. (B) A thin section of sandstone representing the Temple of Esna; photomicrograph shows erosion and dissolution in quartz crystals, iron oxids and clay minerals were found. (C, D) A thin section of sandstone representing the Temples of Edfu and Kom Obo; photomicrograph shows abundance of clay minerals compared to samples A, B. addition to iron oxids and heavy minerals were found.

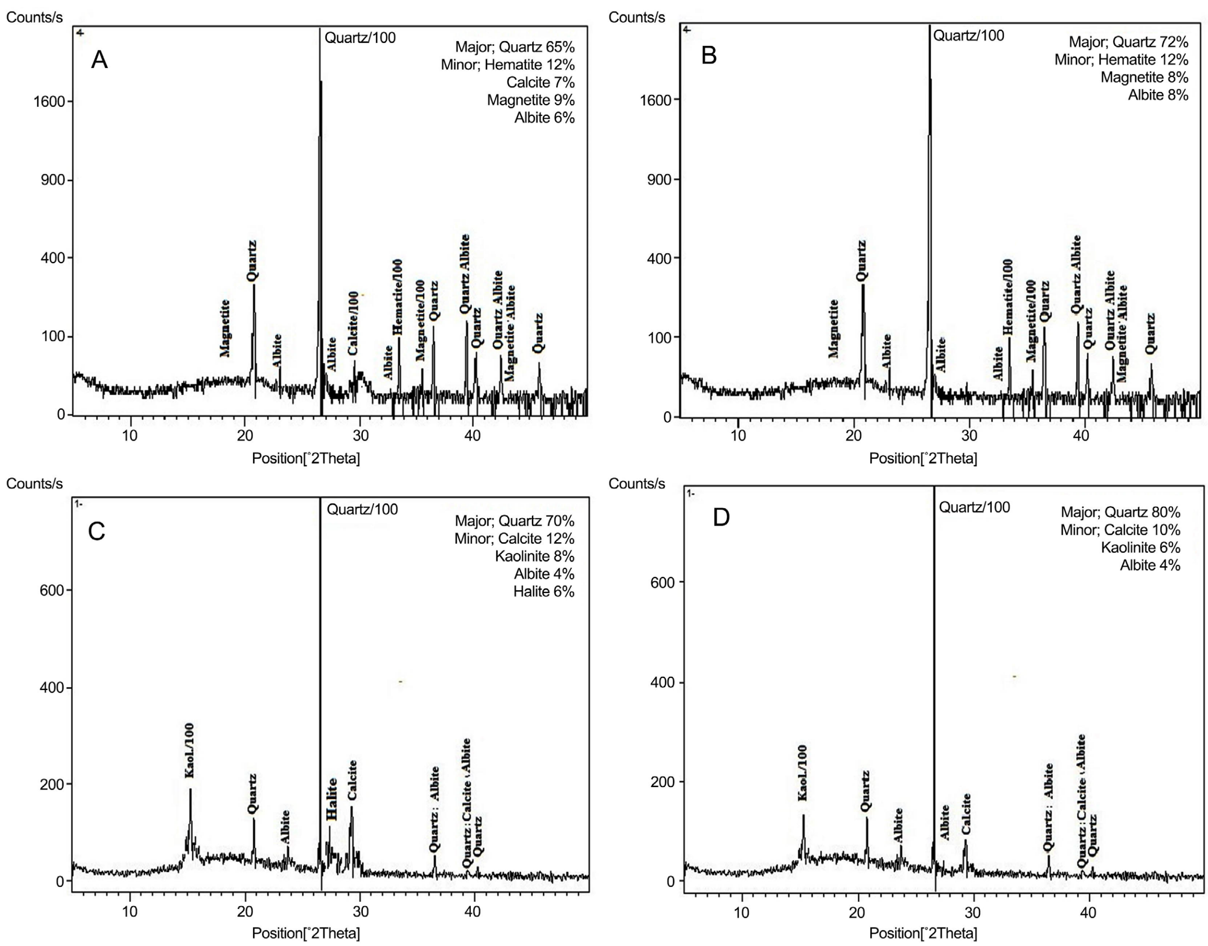
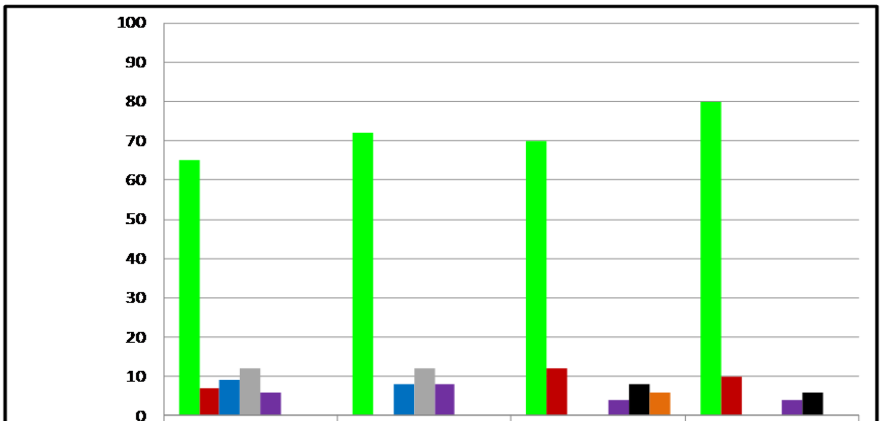


Figure 3. XRD pattern of deteriorated sandstone samples of case studies; (A) Sandstone samples of Dandara Temple. (B) Sandstone samples of Esna Temple. (C) Sandstone samples of Edfu Temple. (D) Sandstone samples of Kom Ombo Temple.



	A	B	C	D
Quartz	65	72	70	80
Calcit	7	0	12	10
Magntite	9	8	0	0
Hematite	12	12	0	0
Albit	6	8	4	4
Kaolinite	0	0	8	6
Halite	0	0	6	0

Figure 4. Chart shows X-ray diffraction analysis results of sandstone samples that represent case studies.

30 X - 300 kX) coupled with X-ray energy dispersive system (EDS) with accelerating voltage 30 kV, Magnification 14× up to 1,000,000 and resolution for Gun, in K550X Sputter Coater, England. The scanning electron microscope of the same deteriorated sandstone samples from Case studies revealed, the samples consists mainly of quartz grains cemented with Calcite and iron oxides. the examination of samples were taken according to the representativeness of the degradation processes of Dandara and Esna Temples, revealed that the samples consist of abundance of iron oxides (Magnetite, Hematite) and the highest contents of rock fragments, feldspar and mica. The examination of the sandstone samples showed abundance of clay minerals soluble salts and small contents of calcite and gypsum were found in the samples of Edfu Temple, by investigation of samples of sandstone that taken from Kom Ombo Temple, it was found that dissolution of cements occurred of the sandstone led to an increasing in porosity, disintegration and loss of cohesion of the stone causing the sandstone and decrease of strength qualities (Figure 5). EDX microanalysis of the sandstone samples showed that Si, Mg, Fe, Ca, Al, Ti, K, S and Na. The results of microanalysis confirmed the presence of Mg, Fe, Ca, and Al elements in high percentages in the sandstone samples representing the temples of Dendera and Esna As a result of the presence of iron oxids. Microanalysis of sandstone samples taken from the temples of Edfu and Kom Ombo, they confirmed the presence of Na, Ca, and Al elements in high percentages compared to the sandstone samples representing the temples of Dendera and Esna, As a result of the presence of clay minerals (Figure 5 and Figure 6).

2.3. Physical Properties of the Studied Sandstone Samples

The physical properties tests were carried out according to American society for testing and material (ASTM C97-18) [22] to determine the physical (bulk density, water absorption, porosity). The deteriorated sandstone samples were cut into cubes 4 × 4 × 4 cm. Then, its physical properties were measured according to the following equations;

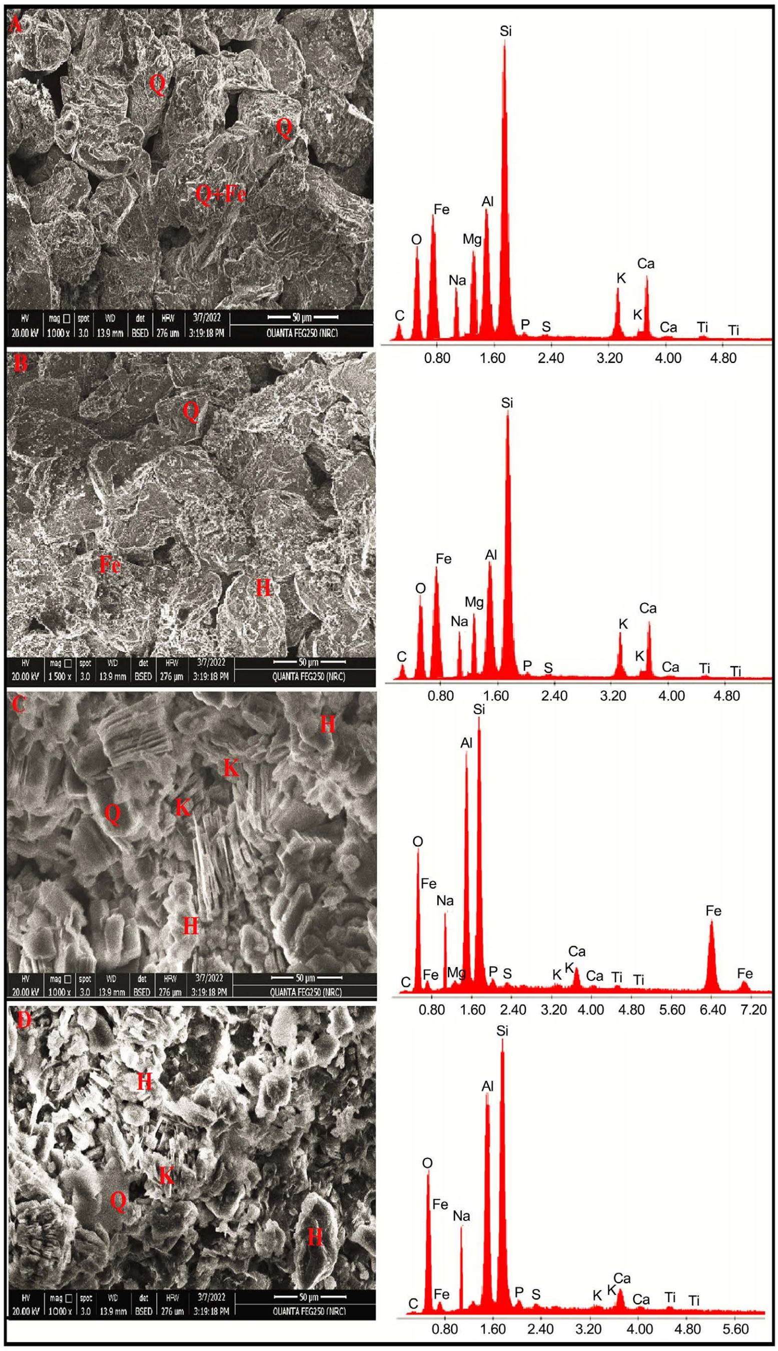
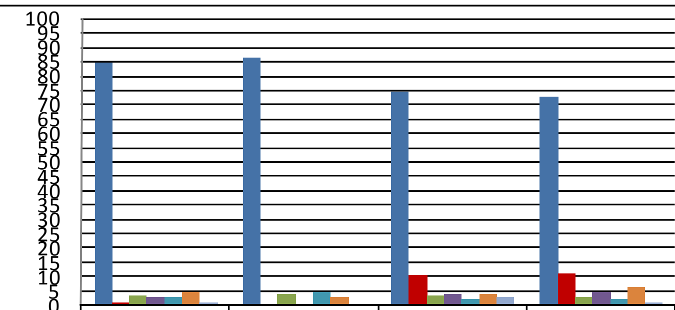


Figure 5. SEM micrographs of the studied sandstone samples and their corresponding EDS analysis. (A) Samples of Dandara Temple, (B) Samples of Esna Temple, (C) Samples of Edfu Temple, and (D) Samples of Kom Ombo Temple.



	A	B	C	D
SiO	84.89	86.73	74.57	72.7
Al2O3	1.08	0.15	10.2	11.3
Fe2O3	3.2	4.02	3.4	2.8
CaO	3.02	0.03	3.9	4.5
MgO	2.91	4.6	2.03	2.3
Na2O	4.3	3.03	4.07	6.2
TiO	0.7	0.07	2.7	1.2

Figure 6. Chart shows major element concentrations (wt.%) of sandstone samples that represent case studies.

To calculate the bulk density (ASTM C97/C97M-15):

$$\rho_{\text{dry}} = \frac{m_{\text{solid}}}{V_{\text{total}}}$$

where ρ = density, m = mass, V = volume

To calculate the apparent porosity (ASTM C97-83):

$$n = \frac{V_{\text{pore space}}}{V_{\text{total}}}$$

Capillary Water Absorption (ASTM C97/C97M-15) = $W_2 - W_1 / W_1 \times 100$.

Where (W_1) dry weight, (W_2) wet weight.

The physical properties of sandstone samples are given in Table 2, the results obtained from the physical properties tests demonstrate that the sandstone specimens were taken from case studies exhibit the average porosity values are between 10% and 17%, average of density values are between 2.1 gm/cm^3 and 2.7 gm/cm^3. Average of capillarity water absorption values are between 15% and 27%.

3. Consolidation of Deteriorated Samples of Case Studies

When particle size is reduced to the nanoscale, materials with the same chemical composition have better characteristics than those with larger grain sizes. The nanoparticles dispersed in polymers used in consolidation and protection procedures enhance the effectiveness of materials used to extend the life of stone monuments [23] [24] [25] [26] [27], So, it was chosen paraloid B72 3% enhanced with Nano silica 5% to improve the physical properties of deteriorated sandstone samples that were taken from case studies.

Considerations and rationale for choosing of paraloid B72 enhanced with Nano silica were for the following reasons:

1) The ability of Nano silica to produce siloxane linkages (Si-O-Si) utilizing a process of hydrolysis, condensation, and polymerization allows them to restore the inter-granular cohesiveness in stone. These molecules react with moisture, particularly that held in the stone's pores, to form hydrolysis. The hydrolysis process produces silanol, which is subsequently polymerized through condensation to form a "gel" with the robust properties of the silicate minerals found naturally in stone, such as lightfastness, oxidative stability, and binding strength.

2) Paraloid B72 is considered one of the acrylic resins most frequently used in the consolidation of stones due to its characteristic mechanical properties and ease of use, there for, it doesn't cause discoloration for the surface, also increases the water-resistance of stone surfaces and thus it is considered acceptable material for monumental stones preservation.

The consolidation was applied to the samples by immersion method, after consolidation of the samples; they were subjected to examination with SEM and measurement of their physical properties according to (ASTM C97-18). The examination results showed the consolited samples by Nano silica 5% with paraloid B72 3% achieved the best result in coating of mineral granules, filling voids and good diffusion of polymer, in addition to the growth of degraded quartz crystals (Figure 7). The values of density and apparent porosity of consolidated and treated samples refers to the ability of paraloid B72 3% enhanced with Nano silica 5% to make positive change and improvement in physical properties of consolidated samples. The density of all sample increased after consolidation process, it was found that there was a significant decrease in the porosity of the consolited samples, as well as a decrease in the percentage of capillarity water absorption (Table 3).

Table 2. Physical properties results of the deteriorated samples of case studies.

Average values of physical properties			
Samples cod	**Bulk Density** gm/cm^3	**Porosity** %	**Capillarity water absorption** %
S1 - S4	2.3	14	18
S5 - S8	2.3	15	19
S9 - S12	2.1	17	23
S13 - S16	2.2	16	22

Table 3. Physical properties results of the deteriorated samples before and after consolidation.

Average values of physical properties (After consolidation)			
Samples cod	**Bulk Density** gm/cm^3	**Porosity** %	**Capillarity water absorption** %
S1 - S4	2.6	8	12
S5 - S8	2.4	9	13
S9 - S12	2.4	11	15
S13 - S16	2.5	10	14

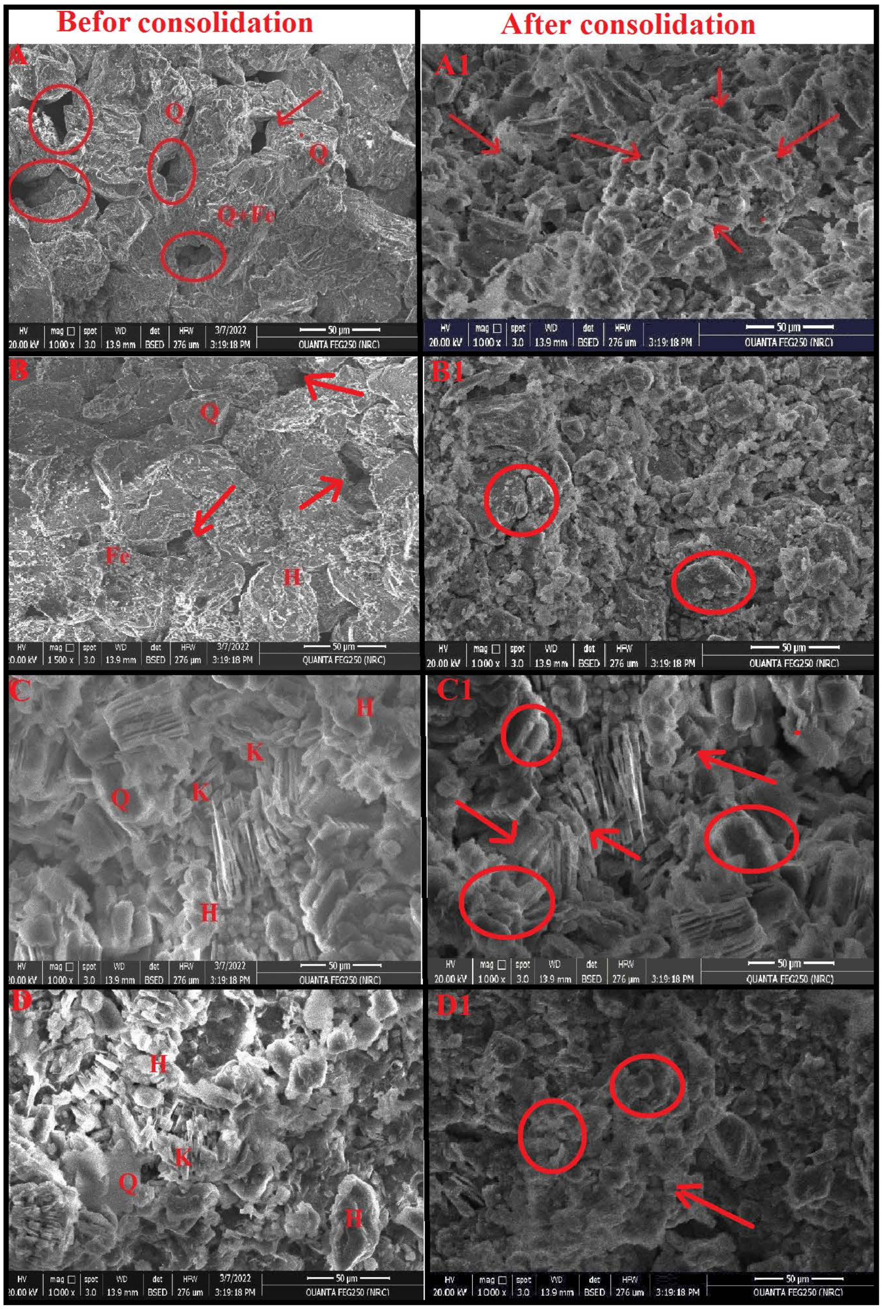


Figure 7. SEM micrographs of the studied sandstone samples befor and after consolidation. (A-A1) Samples of Dandara Temple, (A) the deteriorated sample befor consolidation, (A1) the deteriorated sample after consolidation show coating of mineral grains and filling voids (B-B1) Samples of Esna Temple, (B) the deteriorated sample befor consolidation, (B1) the deteriorated sample after consolidation, show a good diffusion of polymer, coating of mineral grains and filling voids (C-C1) Samples of Edfu Temple, and (D-D1) Samples of Kom Ombo Temple. (C, D) the deteriorated sample befor consolidation, (C1, D1) the deteriorated sample after consolidation, show a good diffusion of polymer Arrows and circles indicate the growth of quartz crystals.

4. Conclusions

This study deals with relation between physical-mineralogical properties of sandstone used in Ptolemaic temples in Upper Egypt and its resistance of weathering factors affecting it.

The deteriorated sandstone samples were taken from case studies; the investigations of samples were performed by polarized light microscope (PLM), scanning electron microscope (SEM), EDX analytical, X-ray diffraction (XRD), and physical properties tests.

According to petrographic examination, the sandstone is composed of three different components: structure grains, cementing materials, and pores. The sandstones taken from Dandara Temple are mainly composed of quartz as framework grains (65 % of stone volume), feldspar (Albite 6%). The quartz grains are fine medium to coarse, rounded to subrounded, iron oxides (Hematite 12% and Magnetite 9% of stone volume) as cement material. The samples taken from Esna Temple are mainly composed of quartz (72% of stone volume), feldspar (Albite 8%), and iron oxides (Hematite 12% and Magnetite 8% of stone volume) as cement material.

Low concentration of feldspars in most samples is observed; it indicates that sandstone samples taken from Temples of Dandra and Esna are chemically weathered and recycled. Change in sandstone colour is due to the oxidation of iron (confirmed by EDS and XRD analysis).

The sandstone samples taken from temples of Edfu and Kom Ombo are mainly composed of quartz (70% to 80%), feldspar (Albite 4%), carbonate (calcite 10% to 12%), clay (Kaolinite 6% to 8%), and salts (Halite 6%). Low concentration of feldspars and high of clay minerals in most samples indicate that sandstone samples taken from Temples of Edfu and Kom Ombo are chemically weathered due to effect of relative humidity, and high concentration of Halite is observed; This causes rise of the moisture content within the pores of the stone and thus the clay minerals will swell and facilitates weathering of the sandstone (confirmed by EDS, XRD analysis and SEM investigation).

The deteriorated sandstone samples were consolidated by Nanomaterials and synthetic nanocomposites (Nano silica 5% with paraloid B72 3%). According to SEM investigation, it was found that synthetic nanocomposites were distinguished by coating of mineral grains and filling voids of the stone, as well as good spread of polymer. Through a microscopic examination, the growth of decomposing quartz crystals is observed.

The study concluded that there is a strong correlation between physical-mineralogical properties of sandstone and its ability on counter to various damage factors, which was confirmed by examination and investigation conducted on the samples representing the damage. Where it was found that clay minerals helped decompose of sandstone samples were taken from Temples of Edfu and Kom Ombo when affected by moisture; on the other hand, an oxidation process occurred for the iron compounds present in the sandstone samples was taken from Temples of Dandara and Esna, which led to the occurrence of coloration of surface of the stone, in addition to the occurrence of decomposition and weathering as well.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Siegesmund, S., Weiss, T. and Vollbrecht, A. (2002) Natural Stone, Weathering Phenomena, Conservation Strategies and Case Studies: Introduction. *Geological Society*, *London*, *Special Publications*, **205**, 1-7. https://doi.org/10.1144/GSL.SP.2002.205.01.01

[2] Fitzner, B., Heinrichs, K. and La Bouchardiere, D. (2003) Weathering Damage on Pharaonic Sandstone Monuments in Luxor-Egypt. *Building and Environment*, **38**, 1089-1103. https://doi.org/10.1016/S0360-1323(03)00086-6

[3] Ruedrich, J., Bartelsen, T., Dohrmann, R. and Siegesmund, S. (2011) Moisture Expansion as a Deterioration Factor for Sandstone Used in Buildings. *Environmental Earth Sciences*, **63**, 1545-1564. https://doi.org/10.1007/s12665-010-0767-0

[4] Harrell, J.A. (2016) Varieties and Sources of Sandstone Used in Ancient Egyptian Temples. *Journal of Ancient Egyptian Architecture*, **1**, 11-37.

[5] Götze, J. and Siedel, H. (2004) Microscopic Scale Characterization of Ancient Building Sandstones from Saxony. *Materials Characterization*, **53**, 209-222. (In Germany) https://doi.org/10.1016/j.matchar.2004.08.016

[6] Benavente, D., Cueto, N., Martínez-Martínez, J., García del Cura, M.A. and Cañaveras, J.C. (2007) The Influence of Petrophysical Properties on the Salt Weathering of Porous Building Rocks. *Environmental Geology*, **52**, 215-224. https://doi.org/10.1007/s00254-006-0475-y

[7] Labus, M. and Bochen, J. (2012) Sandstone Degradation: An Experimental Study of Accelerated Weathering. *Environmental Earth Sciences*, **67**, 2027-2042. https://doi.org/10.1007/s12665-012-1642-y

[8] Schaffer, R.J. (2016) The Weathering of Natural Building Stones. Routledge, London. https://doi.org/10.4324/9781315793771

[9] Deprez, M., De Kock, T., De Schutter, G. and Cnudde, V. (2020) A Review on Freeze-Thaw Action and Weathering of Rocks. *Earth-Science Reviews*, **203**, Article ID: 103143. https://doi.org/10.1016/j.earscirev.2020.103143

[10] Alexandrowicz, Z., Marszałek, M. and Rzepa, G. (2014) Distribution of Secondary Minerals in Crusts Developed on Sandstone Exposures. *Earth Surface Processes and Landforms*, **39**, 320-335. https://doi.org/10.1002/esp.3449

[11] Adamovic, J., Mikulas, R., Schweigstillova, J. and Bohmova, V. (2011) Porosity Changes Induced by Salt Weathering of Sandstones, Bohemian Cretaceous Basin, Czech Republic. *Acta Geodynamica et Geromaterialia*, **8**, 29-46.

[12] Ameratunga, J., Sivakugan, N. and Das, B.M. (2016) Correlations of Soil and Rock Properties in Geotechnical Engineering. https://doi.org/10.1007/978-81-322-2629-1

[13] Ismael, H. (2015) The Climate and Its Impacts on Egyptian Civilized Heritage: Ei-Nadura Temple in El-Kharga Oasis, Western Desert of Egypt as a Case Study. *Present Environment and Sustainable Development*, **9**, 5-32. https://doi.org/10.1515/pesd-2015-0001

[14] El-Gohary, M.A. (2017) Environmental Impacts: Weathering Factors, Mechanism and Forms Affected the Stone Decaying in Petra. *Journal of African Earth Sciences*, **135**, 204-212. https://doi.org/10.1016/j.jafrearsci.2017.08.020

[15] Mohamed, E.H. (2019) Assessment of the Current State of Qanibay al-Rammah Complex (908 AH/1502 AD), as a Procedure Precedes the Restoration Process. *Open Journal of Geology*, **10**, 71-91. https://doi.org/10.4236/ojg.2020.101004

[16] Mohamed, E.H. (2014) The Conservation Methods of Archaeological Buildings Situated within Urban Surroundings in Cairo, with Application on Case Studies of the Archaeological, Islamic Buildings Located Saladin's Square. A Thesis for the Degree of Doctor of Philosophy, Archaeology Conservation Department, Faculty of Archaeology, SVU University, Tirupati.

[17] Radwan, A.E., Wood, D.A., Abudeif, A.M., Attia, M.M., Mahmoud, M., Kassem, A.A. and Kania, M. (2021) Reservoir Formation Damage; Reasons and Mitigation: A Case Study of the Cambrian-Ordovician Nubian "C" Sandstone Gas and Oil Reservoir from the Gulf of Suez Rift Basin. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-021-06005-8

[18] Sebastián, E., Cultrone, G., Benavente, D., Fernandez, L.L., Elert, K. and Rodriguez-Navarro, C. (2008) Swelling Damage in Clay-Rich Sandstones Used in the Church of San Mateo in Tarifa. *Journal of Cultural Heritage*, **9**, 66-76. (In Spain) https://doi.org/10.1016/j.culher.2007.09.002

[19] Jiménez-González, I., Rodríguez-Navarro, C. and Scherer, G.W. (2008) Role of Clay Minerals in the Physicomechanical Deterioration of Sandstone. *Journal of Geophysical Research*: *Earth Surface*, **113**, F02021. https://doi.org/10.1029/2007JF000845

[20] Mohamed, E.H. (2019) The Effect of the Reciprocal Relations of the Deterioration Symptoms in Different Building Materials in Some of Historic Cairo's Buildings. *Resourceedings*, **2**, 167-184. https://doi.org/10.21625/resourceedings.v2i2.612

[21] Hemeda, S., Khalil, M., Shoeb, A. and El Aziz, A.A. (2020) Nanostructured Materials for Strengthening and Preservation of Historic Structural Marble Columns. *International Journal of Conservation Science*, **11**, 485-498.

[22] American Society for Testing and Materials (ASTM C97-18) (2018) Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone.

[23] Alhilo, E.A., Kuba, S.A. and Dirweesh, A.F. (2021) Nanotechnology Use to Preserve the Durability of Archaeological Brick Buildings in Al-Najaf City. *IOP Conference Series*: *Materials Science and Engineering*, **1067**, Article ID: 012044. https://doi.org/10.1088/1757-899X/1067/1/012044

[24] El-Gohary, M. and El-Magd, M.A. (2018) Influence of Acrylic Coatings and Nanomaterials on the Interfacial, Physical, and Mechanical Properties of Limestone-Based Monuments. Case Study of "Amenemhat II Temple". *International Journal of Conservation Science*, **9**, 219-234.

[25] Badreddine, D., Beck, K., Brunetaud, X., Chaaba, A. and Al-Mukhtar, M. (2020) Nanolime Consolidation of the Main Building Stone of the Archaeological Site of Volubilis. *Journal of Cultural Heritage*, **43**, 98-107. (In Morocco) https://doi.org/10.1016/j.culher.2019.12.006

[26] Hassane, M., Ali, H.M. and Nazel, T. (2021) Consolidation of Archaeological Limestone and Improving Its Chemical and Physical Properties. *International Journal of Conservation Science*, **12**, 1231-1248.

[27] Barnoos, V., Shekofteh, A. and Oudbashi, O. (2022) Experimental Evaluation of the Consolidation Treatments of Low Porosity Limestone from the Historic Monument of the Anahita Temple of Kangavar, Iran. *Archaeological and Anthropological Sciences*, **14**, 1-21.