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Original article

DURABILITY OF DECORATIVE STONES AND OTHER CONSTRUCTION MATERIALS OF AL-TANBOGHA AL-MARDANY MOSQUE (1340 A.D) 14TH CENTURY IN CAIRO

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Abstract

The present research deals with the most important devises and various techniques used to identify the different types of stones, decorative stones and mortars used for construction of Al-Tanbugha El-Merdani mosque at el-Darb Alhmar in Cairo. Different examination and analysis techniques were used to identify the various types and composition of rocks, decorative stones which adorn the lower parts of mosque walls, as well as building materials and mortars. Polarizing microscope was used to identify the minerals and rocks. Beside to scanning electron microscope equipped with energy dispersive X-Ray spectrometry. X-Ray fluorescence XRF was also aid detecting the elements. Laser induced Breakdown Spectroscopy LIBS was also employed. The obtained results were gathered in an attached table .

Keywords: *Decorative stones, Mortars, Construction, Analysis*

1. Introduction

Monuments are commonly damaging due to the deterioration effects of natural weathering and air pollution [1]. Therefore the development of new materials or novel methodologies to consolidate and protect the decayed stones from physical, chemical and biological damage are considered of vast importance [2]. To be aware of the previous treatment of archaeological materials and their consequence becomes more and more important in the conservation. In recent decades many projects in the field of conservation require examination and analysis to make the optimal use of the collected data [3]. There are methods, often newer and less well known in the field of analysis and examination are used to collect data for characterization of stones components. In Islamic architecture any surface may be regarded as worthy of receiving. Elaborate decoration were one of the greatest achievement of Cairo's mediaeval artisans. All these achievements were evidenced in myriads of minarets, domes and interiors of historical buildings .This study will address the deferent types of stones used to adorn the lower parts of walls in historical islamic buildings located in Cairo. Natural stones are classified according to their presses formation into sedimentary stone (i.e. limestone), metaphoric stone (i.e. marble), and igneous stone (i.e. granite) [4]. In order to be suitable as building material, stones should have specific characteristics. Most important of which is their ability to resist the deterioration by time and weathering mechanism [5, 6]. Different stones were used to decorate the walls of Islamic architecture in several decorative elements such as geometric, calligraphic, arabesque, and floral shapes. Mamluk Artisans in Cairo produced remarkable decorative stonework which is considered unique and artistically perfect. In this research; some types of building materials used in Al-Tanbugha El-Merdani mosque at El-Darb Alhmar, fig. (1-a, b, c, d) will be studied through different examination and analytical techniques for evaluating their durability states.

Figure (1) Decorative stones in the lower parts of the walls (El Tanbagha El Maradany Mosque).

2. Materials and Methods

Various techniques were used to illustrate the causes of decorative stone deterioration of Al Tanbagha El Maradany mosque. Most notably technique included photographic, recording, petrographic analysis of decorative stones and mortars as well as sophisticated techniques which provide additional information on particular aspects of decorative stone deterioration. These techniques include polarizing microscope, X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM) coupled with EDX probing, in addition to Laser–Induced Breakdown Spectroscopy (LIBS) analysis. Furthermore, physical and mechanical laboratory testing were done to evaluate stone strength (Compressive strength). Samples selection and initial preparation were done after visual examination and photographic docum-entation depending on the sample size or volume. This step is an important step for choosing single or multiple small samples represent-ative portion of the original ones to prepare appropriate sub-samples for various mode of examinations.

2.1. *Petrographic study*

Prepared thin-sections were examined by papetrographic microscope model Nikon Labphot2-pol, Olympus BX40 and Olympus BHSP trinocular equipped with digital 35-mm cameras. This investigations were done at magnifications up to 1000-X and they were documented at various mode by image analysis software. The information obtained from petrographic study is numerous and includes: detailed texture, microstructure, and mineralogy of the material; type, composition, and condition of the original masonry unit. evidence of chemical and physical deterioration in the samples; and the exact type of stone used in the decorative stone [7].

2.2. *X-Ray fluorescence analysis*

XRF analysis was carried out for powder sampling using X-Ray Fluorescence equipment PW 2404 with six analyzing crystals. The samples were prepared by pressing the powder of the sample in Aluminum Cup using Herzog presser and 10 ton pressure [8]. Where, crystals (Lif-200), (Lif-220) were used for estimating Ca, Fe, K, Mn and other trace elements while crystal (TIAP) was used for determining Mg and Na. In addition, crystal (Ge) was used for estimating P and crystal (PET) for determining Sodium and Magnesium. The concentration of the analyzed elements is determined by using software Super Q Semi Q programs with accuracy 99.99 % and confidence limit 96.7 %. The estimation of the major and trace elements was done by powder pellets (pellets methods)

2.3. *X-Ray diffraction analysis*

A Philips X-ray diffraction equipment model PW/1710 with Monochromator, CuK_{α} radiation (1.542 Å) at 40 K.V., 35 m.A. and scanning speed 0.02 θ/sec. were used. The reflection peaks between 2θ ranging between 2θ and 60 θ, corresponding spacing (d, Å) and relative intensities (I/Io) were obtained.

2.4. *SEM and EDX analysis*

SEM examination not only provide the detailed microstructure and 3D morphology of investigated samples at a very high magnification but also provide the elemental composition of an area of interest. Furthermore, EDX spectroscopy determined the elemental composition of the stone components, cement hydration products, stain producing material, efflorescence deposits, or secondary deposits in mortar. In our research, a Cambridge Scanning Electron Microscope (Camscan Series 11 SEM) equipped with Robinson backscatter electron detector and Kevex energy dispersive x-ray spectrometer with 4Pi Revolution software (2001) was used for determining different characteristics. These characteristics such as physio-chemical weathering attack strongly decorative stones blocks , starting from surface and continuing inward thus disfiguring the mineral fabric [9].

2.5. *Laser-induced breakdown spectroscopy analysis (LIBS)*

Laser-induced breakdown spectroscopy (LIBS) has emerged in the past ten years as a promising technique for analysis and characterization of the composition of abroad variety of objects of culture heritage [10]. These objects include painted artworks, icons; polychromes, pottery, sculpture, metal, glass, stone artifacts, building stone and other construction material. Moreover, the pigmented materials can be identified by taking into account detected and non-detected elements [11]. In this part of the study, LIBS technique was used for detecting the characteristic of chemical elements of decorative stone using chemometrics device models (SIMCA and PLS-DA) to stone and mortars. These analysis was done based on spectral lines identification and reference database. Moreover, to reach at reliable values for compressive strength, suitable number of samples should were prepared and properly tested. The test results are then analyzed to establish the investigated stone properties. The testing processes include 9 cubes from the decorative stone taken from the lower parts of the mosque walls to determine the stones compressive strength and modulus of elasticity. Three samples were equipped with 10 mm long electric strain gauges. One strain gauge was fixed to the cube parallel to its vertical axis to measure the longitudinal compressive strain corresponding to the applied compressive stress. The vertical compressive stress was increased until failure.

3. Results

3.1. *Petrographic study*

Petrographical studies revealed that each of the investigated samples are characterized by specific characte-ristics as follow: **Marly limestone** is fine-grained, composed of calcite and clay minerals as major constitutes (about 50 %) with rare amounts of quartz, feldspar, muscovite, biotite, iron oxides and opaque minerals. Calcite occurs as fine to very fine-grained, anhedral crystals inter-calated with other constituents, either as fine sparite and the majority show micrite as very fine grained. Clay minerals are also present as very fine grains and represent the matrix of the rock. Quartz and feldspar occur as fine grains (slit size) and scattered in the very fine matrix. Micas (biotite and muscovite) are very fine-grained, as flaky crystals and partially altered to chlorite and nearly oriented in parallel direction. Iron oxides and opaque minerals occur as fine to very fine-grained disseminated in the rock. **Sandy blood dolomite** has very fine to fine-grained texture, composed of dolomite and calcite as essential minerals with minor amounts of quartz, iron oxides and rare amount of feldspars and other opaque minerals. Microfossils and shell fragments are scattered in the rock in considerable amount. Dolomite constitutes the fine matrix of the rock and it occurs as fine to very fine grained euhedral to subhedral crystal and stained by iron oxides and sometimes shows zoning. Calcite occurs as medium to very fine grained, anhedral crystal either as sparite which composed the microfossil shells or intercalated with dolomite in the matrix of the rock. Quartz occurs as fine grains scattered in carbonate matrix. **Artificial stone**, the petrographical study revealed that the this sample is composed of amorphous substance and represented by two layers, the first layer (dark blue colour with light brown under P.P.L.) has a thickness about 0.5 mm. The 2nd layer (blue colour with brown under P.P.L.) has a thickness about 3.5 mm. and light. **Phyllite** is fine to very fine-grained, showing slightly schistose texture. It is composed of quartz, muscovite and chlorite with minor amounts of iron oxides, plagioclase, epidote and opaque minerals. Muscovite occurs as fine to very fine flakes and arranged nearly in parallel orientation to the schistosity. Quartz presents as anhedral crystals and sometimes polycrystalline. Chlorite occurs as irregular grains intercalate with the other constituents. Iron oxides and opaque minerals are present in considerable amounts scattered in the rock. Plagioclase and epidote occur as fine-grained in rare amount. **White marble** is composed of carbonate materials (dolomite & calcite) with other rare opaque minerals. These materials occur as medium to fine-grained, anhedral to subhedral, compacted and interlocked crystals. Carbonate materials shows perfect cleavage and mosaic texture. **Shell stone**, the petrographical study revealed that the sample is composed of three layers, the 1st one (yellow colour under P.P.L) had a thickness about 1.5 mm. The 2nd layer (in the middle, of brown colour under P.P.L.) had a thickness about 2.5 mm. and the 3rd layer (yellow colour under P.P.L.) is about 1 mm. Further-more, the first and third layers are composed mainly of carbonate mineral, with minor amounts of silica (fine grains of quartz and opaque minerals). Where, the 2nd layer were mainly composed of carbonate mineral. Finally, the petrographic study of **mortar** sample revealed that these sample were composed of two layers, the 1[st] layer (white color) mainly consisted of carbonate minerals with little amounts of quartz, gypsum and iron oxides. All components of this layer are very fine-grained and admixed with each others to form a homogenous mixture. The 2[nd] one (grey color) composed of a cement material and quartz (sand grains) with minor amounts of carbonate minerals that characterized by a nearly homogenous mixture, all of these features are shown in fig. (2-a, b, c, d, e, f, g).

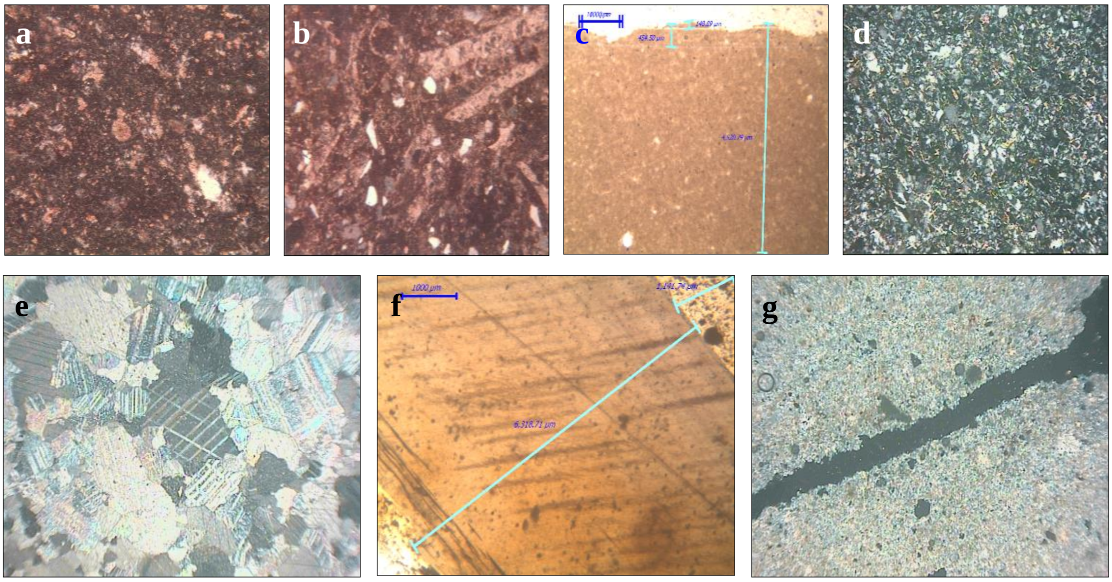

Figure (2) Thin section investigations showing **a.** marly limestone (*quartz*, *feldspars* & *hematite*), **b.** sandy blood dolomite (*quartz*, *feldspars* & *calcite*), **c.** artificial stone (*different sizes of quartz*), **d.** phyllite (*quartz* & *feldspars*), **e.** white marble (*calcite*), **f.** shell stone, **g.** mortar (*quartz*, *lime* & *gypsum*)

3.2. *X-Ray fluorescence analytical results*

XRF analysis revealed that the decorative stones materials samples are composed of the several elements in a decreasing order of their abundance as shown in tab. (1).

Table (1). XRF results for decorative stones and other contraction materials.

Analytical Results %								
D.N	***Marl Limestone***	***Sandy Dolomite***	***Artificial stone***	***Phyllite***	***Marble***	***Shells***	***Mortar***	***Limestone blocks***
SiO_2	56.5	1.35	31.25	55.6	0.29	0.11	38.14	16.55
TiO_2	15.1	1.15	0.03	0.62	0.01	0.01	0.13	0.05
Al_2O_3	0.55	0.02	1.23	14.45	0.03	0.02	1.3	0.82
Fe_2O_3	5.45	1.02	0.01	612	0.07	0.51	0.97	0.32
MnO	0.08	0.07	0.18	0.1	0.01	0.03	0.01	0.01
MgO	2.9	0.56	0.3	7.16	22.5	0.08	224	1.21
CaO	5.66	54.3	0.78	2.88	35.95	48.25	17.82	38.22
Na_2O	4.35	<0.01	7.59	3.67	0.01	1.39	5.05	1.66
K_2O	2.69	0.07	0.41	1.93	0.02	0.01	1.54	1.08
P_2O_5	0.2	<0.01	0.18	0.22	0.03	0.09	0.64	1.65
Cl	0.15	0.75	0.37	0.83	0.34	0.52	10.78	2.8
SO_3	0.25	<0.01	0.33	0.49	0.33	0.89	10.21	1.4
L.O.I	6.01	40.3	2.36	5.8	40.32	47.85	10.95	34.12

3.3. *X-Ray diffraction analytical results*

After evaluating diffraction charts and their relative intensities which are obtained through the XRD analyses and compared with ICDD files [12], it could be said that the decorative stone samples are mainly composed of the compunds listed in tab. (2) & shown in fig. (3-a, b, c, d, e, f, g)

Table (2) XRD results for decorative stones and other contraction materials (Some investigated samples).

Sample	*Major const.*	*Minor const.*	*Trace const*
Marl	Quartz	Albite, Illite	Clinochlore
Sandy Dolomite	Calcite	--	Quartz
Artificial Stone		Amorphous	
Phyllite	Quartz, Clinochlore, Albite	Muscovite, Hematite	Calcite
White Marble	Dolomite	Calcite, Brucite	--
Shell	Aragonite	--	Calcite
Mortar sample	Quartz	Gypsum, Halite Calcite	Dolomite, Pyrite
Limestone Brick	Calcite	Quartz	--

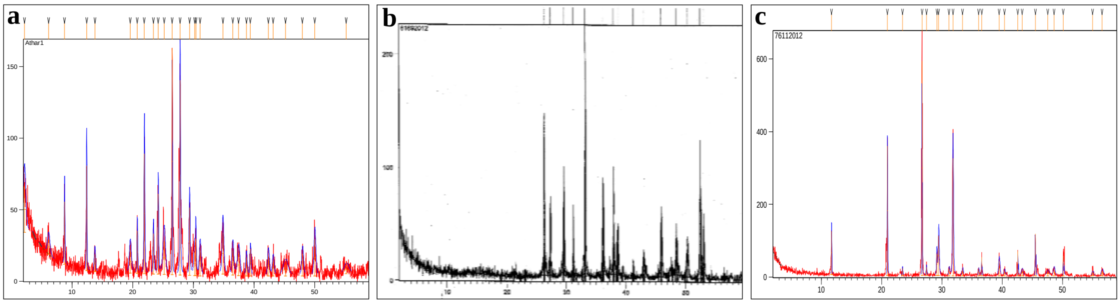

Figure (3) Some XRD pattern of different types of stone **a**. marly limestone**, b**., shell, **c**. mortar

3.4. *SEM and EDX investigation results*

SEM photomicrographs of the investigated samples are characterized by the presence of specific features and occurring of some degradation forms affected the stones crystals'. Furthermore, presence of some salt species such as Gypsum and Halite. On the other hand, EDX micro analysis indicated that each of the investigated samples are characterized by specific characteristics as follow: **Marl stone** is composed of (Si, Al, O, Ti, Mg, Na, K, Ca, C, Fe, S), where, **Sandy blood dolomite** is composed of (Ca, Mg, S, Si, C, Au, Na). In addition it could be noticed that **Artificial stone** is composed of amorphous substance (Si, Al, O, Pb, Ti, Ca, Fe, Mg, Al, K, Sn, Cl), and **Phyllite** sample is composed of (Ca, Cl, K, O, S, Na, Mg, P, Si, C Ti, Mn). Furthermore, **White Marble** is composed of (Ca, S, C, O, Mg, Na, Al, Cl) and **Shell stone** is composed of (Ca, C, Cl, O, Na). Finally, **Mortar sample** is composed essentially of (Ca, Cl, Na, O, Al, Si, Mg, Fe), some of these features are shown in fig. (4-a, b, c).

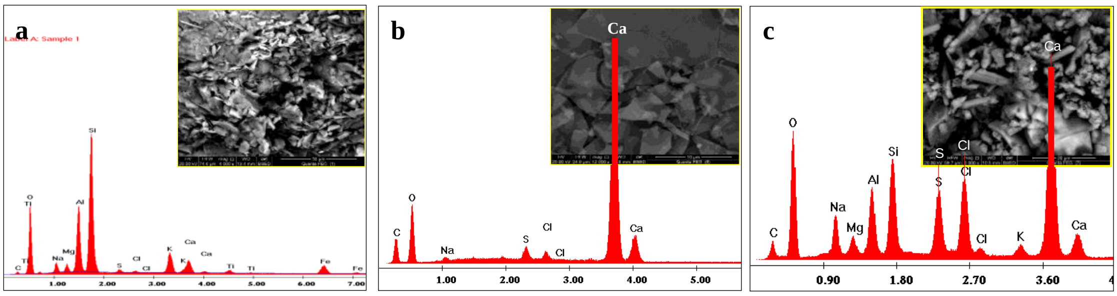

Figure (4) XRF patterns and SEM photomicrographs showing **a.** marly limestone **b.** shell stone, **c.** mortar

3.5. *LIBS analytical results*

Laser-induced breakdown spectroscopy (LIBS) proved that the analyzed samples have different chemical components vary according to their origin as listed in tab. (3) & fig. (5).

Table (3) LIBS results for decorative stones and other contraction materials (Some investigated samples).

Analytical Results %						
Marl Limestone	***Sandy Dolomite***	***Artificial stone***	***Phyllite***	***Marble***	***Shells***	***Mortar***
Mg	Ca	Al	Ca	Ca	Na	Na
Ca	Mg	Ca	NA	Na	C	Ca
Au	Si	Na	Al	Hg	Ca	Al
Fe	Fe	Si	Mg	Al	Al	Hg

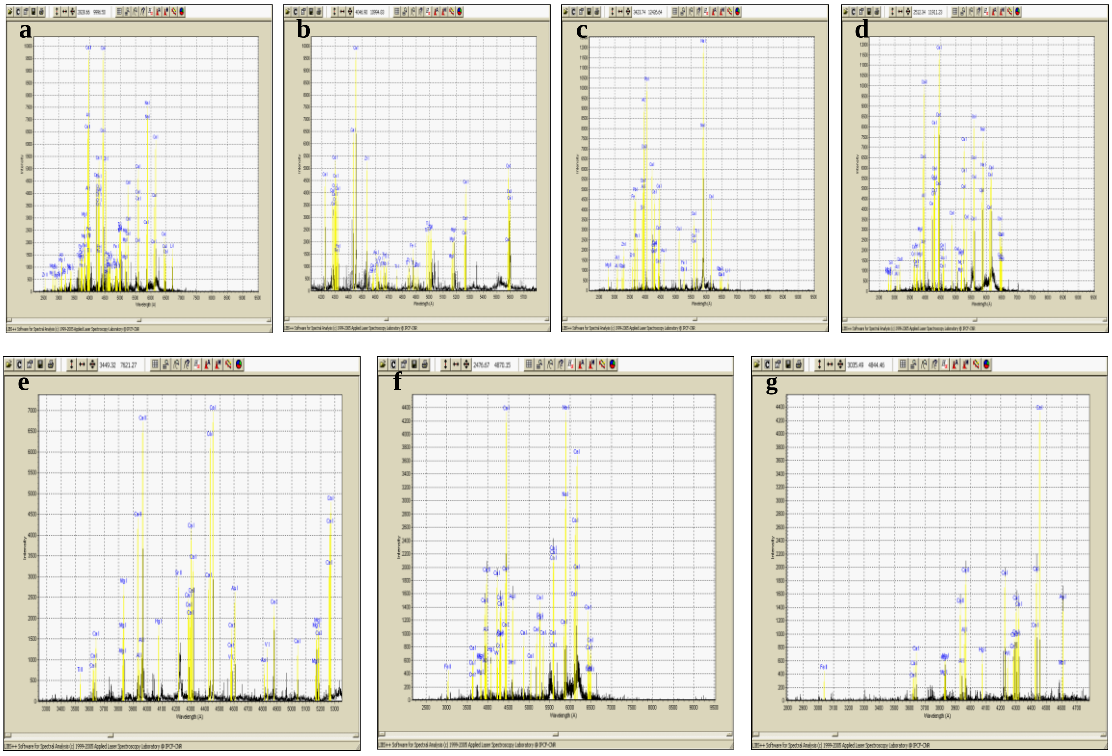

Figure (5) LIBS spectrum showing **a.** marly limestone **b.** sandy blood dolomite, **c.** artificial stone, **d.** phyllite, **e.** white marble, **f.** shell stone, **g.** mortar

3.6. *Compressive strength results*

The testing results of compressive strength of each core samples reveled that there are some variation were recorded as listed in tab. (4) & shown in fig. (6).

Table (4) shows the results of the compressive strength of the nine cubes LIBS results for decorative stones

Analytical Results of Mechanical Properties					
No.	***Weight (g)***	***Dimensions Average (mm)***	***Failure Load (N)***	***Compressive strength (N/mm^2)***	***Remark***
1	3.3	11.0 * 10.0 * 11.0	5905	53.7	
2	3.6	11.4 * 10.0 * 11.2	2125	18.6	Marl Stone
3	3.6	10.5 * 10.6 * 11.0	2365	21.2	
4	2.4	9.3 * 10.0 * . 10.0	5685	61.1	White
5	2.7	10.0 * 10.0 * 10.0	5710	57.1	Marble
6	2.1	9.4 * 9.6 * 8.8	5630	62.4	Stone
7	3.4	10.9 * 9.0 * 14.6	5360	54.6	
8	3.7	8.8 * 10.5 * 14.2	8345	90.3	Phyllite
9	4.1	10.6 * 9.9 * 15.0	4480	42.7	Stone

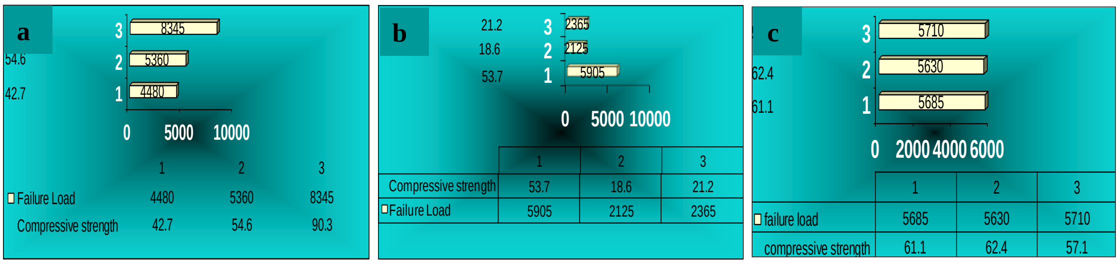

Figure (5) Compressive strength & failure load of **a.** marly limestone **b.** sandy blood dolomite, **c.** white marble

4. Conclusion

Various techniques were used to determine the basic structure/composition and mechanical properties and to establish the causes of the decorative stone deterioration in Al- Mardany mosque. The results confirmed that decorative stone were exposed to several factors of deterioration such as ground water, polluted atmosphere, temperature variations and overload. These factors affected the different building materials used in our case study through many deterioration mechanisms that led finally to the presence of many deterioration appearances. The appearances that include salt crystallization, cracks, missing parts noticed on decorative stones particularly in the lower part of Qablah wall in Al-Mardany mosque. Moreover, it could be claimed that both of blood dolomite, phyllite and marl stone were highly effected by the previous deterioration factors, however the marble were less effected by these deterioration mechanisms. Finally, it could be said that seriously durability decreasing of decorative stones used in Al- Mardany mosque are essentially owed to the synergetic effects between all these deterioration and environmental factors dominated in the study area.

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