Degradation of Limestone Buildings in Jordan: Working Effects and Conservation Problems "A Critical Study According to International Codes of Practice"

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Abstract: *This paper diagnoses scientifically the physical and chemical deterioration of some Jordanian monumental buildings as a result of using wrong conservation techniques and improper treatment materials. According to the scientific guidelines and international charters, conservation and treatment works followed in two of the most important archaeological sites in Jordan ("Aglun citadel and Jerash City") had been evaluated for assessing their validity and stability over the time. To achieve this objective, some of the scientific techniques and technical methods were followed such as evaluating the visual appearance changes by some special lenses, or magnifying glasses, and a Sony digital camera, defining some physical properties of ancient and modern samples of mortars and reinforced concrete through different scientific procedures; studying the micro-abrasion resistance of the samples by using Micro Tip I sand plasting instrument; defining the chemical and mineralogical composition by XRD technique, and studying the morphological features by SEM. Finally, the results proved that both sites are suffering severe forms of deterioration due to several factors and mechanisms such as increasing dampness of stone units and other building materials; surface crack patterns and pitting features; sulfation or salt-crustation and crystallization; breaking rocks surfaces down into smaller pieces, and corrosion of reinforcing steel bars.*

1- Introduction

Historic buildings and stone monuments form an important part of our cultural heritage, and are affected by many deterioration mechanisms (O'Brien, et al., 1995), that can be caused by several factors (Camuffo, 1995), either external (Hammecker, 1995) or internal (Rodrigues, 2001). Also, it is well known that one of the major problems facing stone conservation work is the treatment of highly disintegrated sculptures, when the deterioration reaches an advanced state, and the sculpture suffers decay of the matrix resulting in the deterioration of the surface layers and the loss of the carved detail (Hanna, 1984). Moreover, we can see that the quality of building materials and their protection against these different causes of deterioration had been taken into consideration since ancient times through using some traditional materials that were essentially based on the application of some natural components (Rodrigues and Charola, 1996) such as wax, oil, tallow and synthetic resins (De Witte, 1982). In addition, replacing some new materials as stone blocks, plaster layers or new mortars leads later to many deterioration aspects, especially with critical degrees of water saturation (Wessman, 1997), through the chemical reaction of replaced materials with original stone materials over time (Bucea and Sirivivatnanon, 2003), which requires some scientific work known as preservation and restoration interventions. Correct preservation, restoration and strengthening of historical buildings and monuments require the development of special techniques for decay diagnosis and safety assessment in terms of suitable intervention

Issue No. 16 July 2007
ISSN: 1319-8947 (pp.7-24)

(Righini, 2002). So, modern interventions, based on interdisciplinary scientific and empirical research and knowledge (Hammer, 1995), have been established through some scientific committees such as ICCROM, ICOMS, etc., depending essentially on some scientific tools called conservation and restoration procedures or codes of practice. The principal goals of these procedures aim to preserve the nature and condition of objects, to rectify or restore the different effects of poor manufacture, use and decay, and to prevent or minimize any future deterioration. However, any act of conservation should follow the codes of practice of professional conservation associations to achieve the authenticity and integrity of the conservation steps, and should clearly identify both added materials and original objects (Pini, et. al., 2000). (Drakaki, et. al., 2004).

From this point of view, we can argue that applying and developing conservation techniques demand not only a high degree of manual skill but also knowledge of material science, familiarity with earlier technology combined with an aesthetic sense (Koh, 2006). Thus, ICOM has presented a scientific document entitled 'the conservator-restorer: a definition of the profession' which underlines the fact that recognition and respect of the nature of individual objects are fundamental values in any conservation work (ICOM, 1984). Furthermore, these works should be made in accordance with UNESCO's operational guidelines and other international charters, which stipulate that the aim of modern restoration works is to reveal the original state within the limits of still existing material (International charters, 1964, 1979, 1984, 1987, 1994, 2002, 2004).

The goal of this study is to provide an overview of the causes for stone decay due to improper conservation work, mainly "unstable materials and wrong applications" –which is the case at several Jordanian monumental sites – and to show different temporal and spatial distribution of deterioration products found on the surface of these monuments.

1-1 Preservation State at Jordanian Sites

It is well known that all conservation works and interventions should be characterized by some scientific procedures whether in materials used or techniques applied (EHS, 2006). Also, the treatment materials should be characterized by several criteria such as lightness in substance and content (D'Avino, 1995), real stability, penetration to a sufficient depth (JMA, 2002), ability to improve the different physical, mechanical properties and chemical characteristics of treated surfaces (Brus and Kotlit, 1996), unchanging the visual appearance of these surfaces, and finally unsealing them or preventing future consolidation (Manaresi, et al., 1984). In addition, a new weathering resistant binder of mineralic nature should be formed (Ling, et al., 1993a). All criteria mentioned above should be carried out with largely improved methods and techniques.

In spite of the application of various approaches to maintain, repair and protect several archaeological sites in Jordan according to these procedures, there are many serious problems in these interventions which are essentially due to using some improper materials and wrong techniques that finally lead to variable phenomena of weathering.

To investigate these problems, two of the most important archaeological sites in Jordan "Ajlun Citadel and Jerash City" were selected after several scientific visits and field observations mainly because of several values that the sites reflected especially their aesthetic identity, political and educational significance.

The two sites lend themselves to a detailed examination and analysis to evaluate their restoration states according to the International Code of Practice. Through some scientific visits to these sites and evaluation of several technical reports of excavations, environmental situation and conservation works either published (Maria Cristina, 1986), (Rogan, 1988) (Abd Allah and Yahya, 1988), (Saffarini, 1989), (Abdel–Jalil 1989), (Al Kodah, 1993), (Palumbo, G, 1994) (Rizzi, and Volta, 1995) or un-published, many deterioration appearances have been noticed at many places in both sites, essentially due to the aggressive factors and mechanisms of deterioration resulting from using improper treatment materials and wrong application techniques, which can be explained as follows:

1-2 Improper Treatment Materials

Several types of improper treatment materials have been used such as some types of organic consolidants like calcium oxalate (Fassina, 2000); and the use of different types of mortars such as gypsum Gray Portland cement (Ostrasz, 1991). (Ostrasz, 1997), organic soot particles as a surface retouching and concrete reinforced by none galvanizing steel (Zayadine, 1985)

1-2-1 Gray portland cement

Gray Portland cement "GPC" used in the conservation works is a fine powder that was created in 1824 (NERC, 2005). It consists mainly of a mixture of hydraulic cement materials comprising primarily calcium silicates, aluminates and aluminoferrites derived from 30 raw materials that can be divided into four distinct categories: calcareous, siliceous, argillaceous, and ferruginous (Tennis, 1999). Also, it is very hard, strong and manufactured by calcining standard quantities of calcareous and clay materials at a very high temperature (Plenderleith, 1986). This material is used in conservation works in many archaeological sites in Jordan such as Petra, Desert castles, Kharrana Cara van sari, Amman citadel, Ajlun and Jerash. In the two present cases, it was used for conserving and strengthening some deteriorated parts "for renders or repointing" without abiding by a code of ethics or a code of practice which finally led to the creation of some aggressive stress, internal strain and presence of several harmful features and deterioration products as shown in Fig. 1 a, b.

1-2-2 Surface retouching

In the past, restoration works were performed

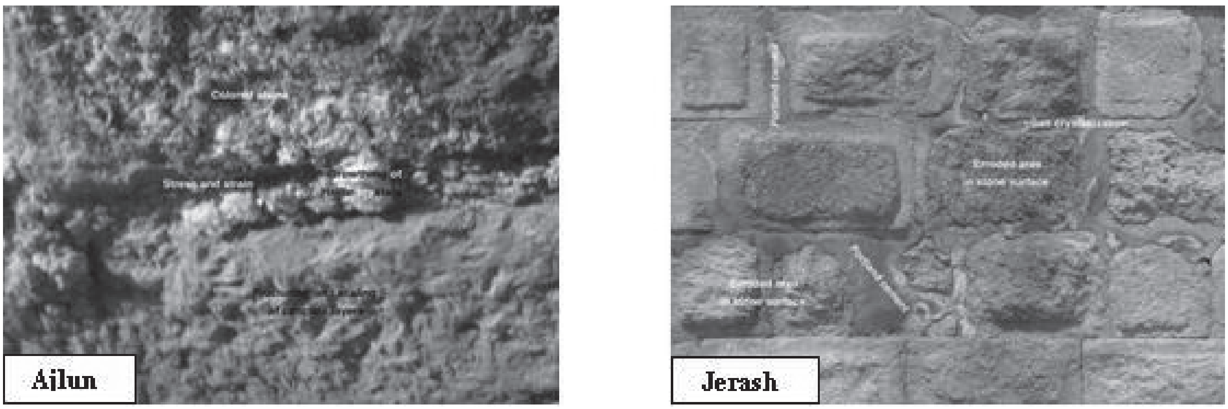

Fig. 1 a, b: Shows deterioration appearances resulting from the effects of using Gray Portland cement

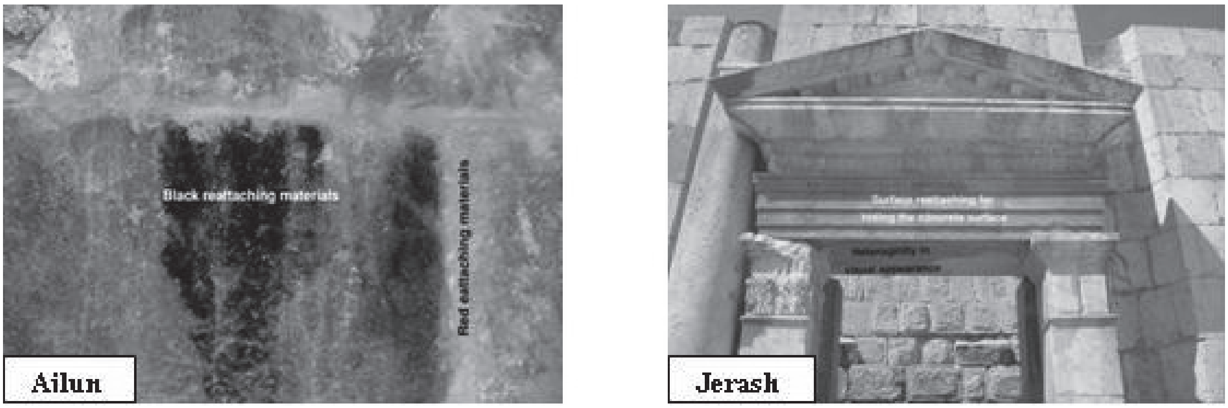

Fig. 2a, b: Shows deterioration appearances resulting from the effects of Surface Retouching

by artists of the same discipline through their efforts to improve the aesthetic appearance of the monument using some limited materials such as beeswax, paraffin wax, flour paste and powder pigmented materials, etc. (Oddy, A., 1992), or to adjust the color of repair materials to match the stone surfaces (Ma, 1995) such as iron oxide "red color" or iron hydroxide "yellow color". All of these procedures were often done through some restorers' touches and changes without considering the original intention of the artist's work or experimentally testing these materials that mostly lead to further deterioration of the artifact on the long run (Kabbani, R., 1997).

In the sites examined in this study, some unsuitable organic pigments are used as retouching during the restoration work for hiding the original features of restoration material "mortar and surface plaster" to give them the same visual appearances and external features; these materials such as botanical smut lead to create some acidic pits and facilitate chemical reaction and later surface erosion as is shown in fig. 2a, b.

1-2-3 Reinforced concrete

Reinforced concrete is composed essentially of black cement, gravels and none-galvanizing steel, and it may be used in some specific and rare circumstances of restoration works for minimizing the depletion of natural resources (ECCO, 1996),

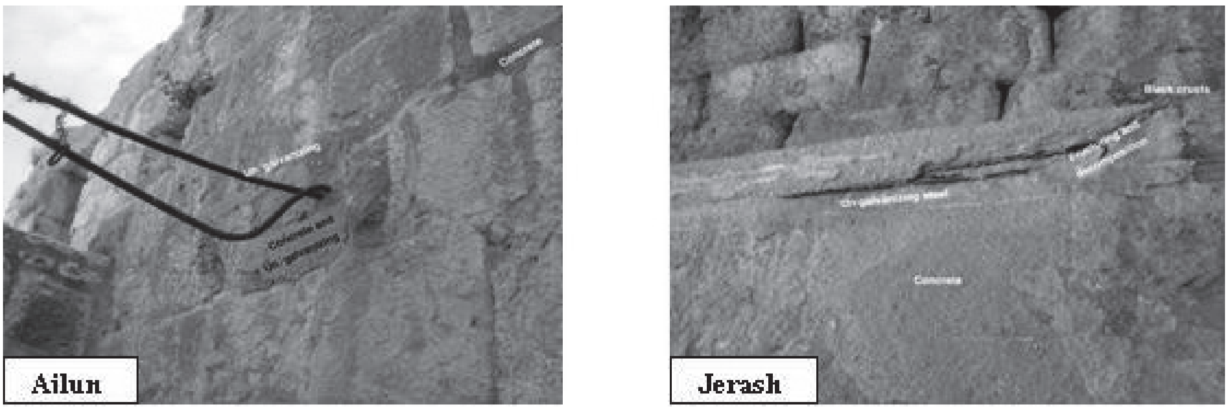

Fig. 3 a, b: Shows deterioration appearances resulting from the effects of using Reinforced Concrete

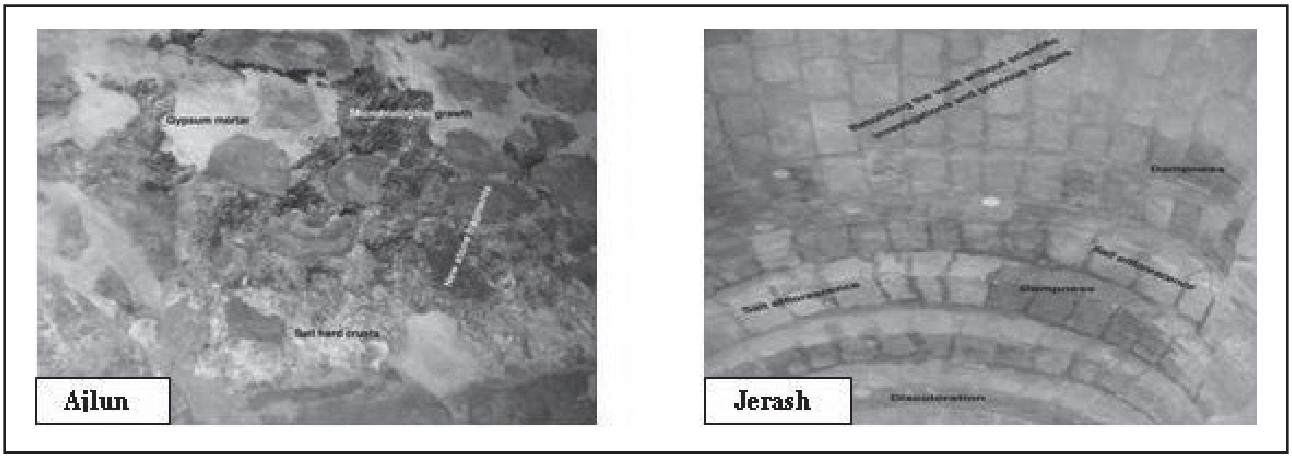

Fig. 4 a, b: Shows deterioration appearances resulting from the effects of using Wrong Techniques

but this may be suitable in dry areas. On the other hand, most concrete deterioration forms can be attributed to water penetration where concrete absorbs moisture until it becomes saturated and prevents water from gathering on surfaces (Mailvaganam and Litvan, 1997). From this point of view, it could be seen that moisture not only fosters the deterioration mechanisms and promotes chemical reactions, but also carries dissolved chemicals that can have further reaction with the steel, lime and other components in the concrete. It also plays a major role in concrete deterioration through freeze/thaw cycling. In addition, corrosion of steel reinforcement eventually leads to spalling of concrete and propagation of original surface damages as shown in fig. 3 a, b.

1-3 Wrong Techniques Used

It is well known that our cultural heritage is suffering from some forms of destruction due essentially to several wrong applications and techniques. In our field, we can quantify two destruction types: "destruction through negative governmental role and destruction through using unsuitable application methods".

1-3-1 Destruction through negative governmental role

This type of destruction is mostly owing to some wrong political or administrative roles and inadequate decisions that face all conservation policies. Although the conservation techniques used for archaeological artifacts are complex and specialized operations, administrative roles can lead to some problems such as lack of funding, closing of laboratories, downsizing of employees and shortage in specialized training (Evans, 2003). Moreover, the conservation process has been marginalized in many cases or, at least, done without following any international legislations or policies.

1-3-2 Destruction through improper application techniques

This second type of destruction is due to the use of some protective and strengthening materials through unsuitable application techniques without any experimental tests. Before being used, these materials and techniques should be tested and proven in a laboratory for a period of at least one year, and if positive results were obtained, we can use them (Agnew and Demas, 2002) as shown in fig. 4 a, b.

Finally, after the analysis of all previous data, the evaluation of all conservation works and the scientific evaluation of the surrounding environmental situation in the study areas, we can make some conclusions as shown

Site Name	Ajlun castle		Jerash city	
Site Code "Jadis no"	2219035		2318002	
Location	About 76 km North West of Amman		About 50 km North of Amman	
Date of Construction	Islamic period		Late Bronz to Islamic periods	
Surrounding Environment	Cultivated and Populated		Populated	
	1950 "A"	*	1925 "A, D"	**
	1992 "E"	**	1962 "B, C"	**
Conservation and Scientific Remarks and Evaluation according to Codes of Practice	1993 "A, B, D"	*	1973, 4, 5 "A, B"	*
	1998 "A, B"	*	1976 - 1977 "E"	**
	2001 - 2002 "A"	**	1982 - 1984 "E"	**
	2003 "A"	**	1990 - 1992 "E"	**
	2004 "A"	**	1993 – 2005 "E"	**
	2005 "E"	**	2006 "E"	**

Table 1: Shows the resulted materials after some conservation works in Ajlun Castle and Jerash City
A= Cleaning and salt removal "Simple" B= Consolidation "pre and pro" C=Fixation and Stabilization "Moderate"
D= Reconstruction and replacement "Heavy" E= All categories "Completely restoration works"
***= Commendable works **= Not Commendable works**

in table 1. Those conclusions were verified against the International Codes of Practice and Conservation Guidelines

2- Experimental Studies Used for Evaluating Conservation Work

In this part of the study, investigated samples were divided into two essential parts and can be described as follows:

1st part, concerning field observations that were done on some surface crust layers and underlying stone materials which were scraped off separately from different zones to assess and evaluate the process of decay and deterioration states resulting from different improper materials and wrong application methods during the previous conservation work. All of these samples were submitted to some field observations that were done by a critical eye and magnifying glasses to organize and evaluate the validity of previous conservation work in both sites through defining visual appearances.

2nd part, concerning some laboratory measurements that were done on some samples of new mortars composed according to the same components and percentages made by the Department of Antiquities of Jordan to evaluate their external appearances and some physio-mechanical properties - "density, porosity, water content, water uptake and micro-abrasion resistance".

2-1 Visual Appearance Changes

It could be said that most of the stone treatments used as protection materials or water repellents cause serious changes in the color and external features of the treated stone. These changes are intensified as if the stone surface were wetted by any sources of water (Riecken and Schwamborn, 1995) Also, they may hide all artistic surface features and lead to the creation of some stresses by salts crystallization action and hydration pressures (Huovinen, et al., 1998) which play an important role in complete disintegration of the stone monuments and may cause cracking and spalling forms. In the present study, following ASTM D1729 (1999), some of these changes that represent some differences in the external appearances of all treated surfaces and vary between Green, Gray,

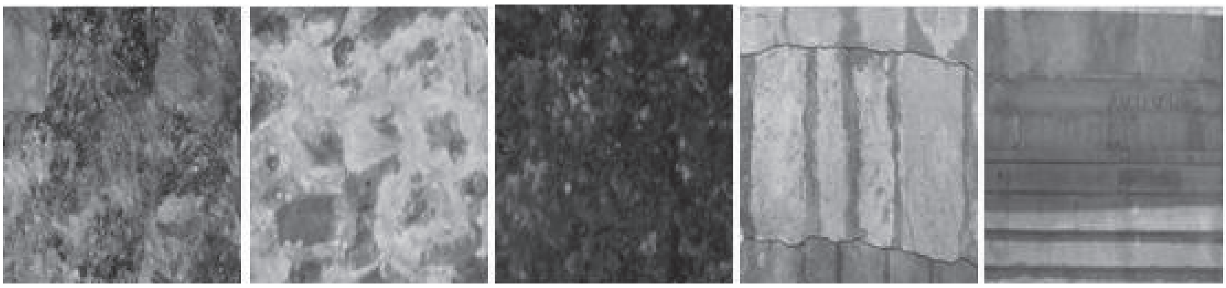

Fig. 5: Shows different colored surfaces resulting from improper materials used in conservation works

Black, White and Brown colors according to the kind and nature of conservation materials used, are observed - Fig. 5.

2-2 Morphological Features by SEM

SEM examinations of some samples collected from treated surfaces that were done according to NORMAL 8/81 proved that there are several deterioration forms resulting from the uses of improper materials in conservation work, which can be categorized as follows:

- Accumulating some dust particles and small aggregates derived from GPC and GRC such as Quartz, Kaolinite and Montmorillonite, Fig. 6a.
- Presence of some internal strains, cracks and spalling features resulting from internal stress through using None-Galvanizing Steel, Fig. 6b.
- Hiding some treated surfaces by some non-porous treatment materials that lead to the creation of some micro cracks and the falling

Physical properties	Jordanian Lime stone	Portland cement		Reinforced Conc.	
		Gray	White	Gray	White
Density gm/cm3	2.407	1.7960	1.9780	1.8130	2.0670
Porosity %	5.434	21.605	18.953	21.779	19.426
Water up take %	2.258	12.026	9.5800	12.007	9.3960
Water content %	0.381	1.6970	0.7710	1.5500	0.5760

Table 2: Shows Physical properties of the materials used in conservation works in Ajlun Castle and Jerash City

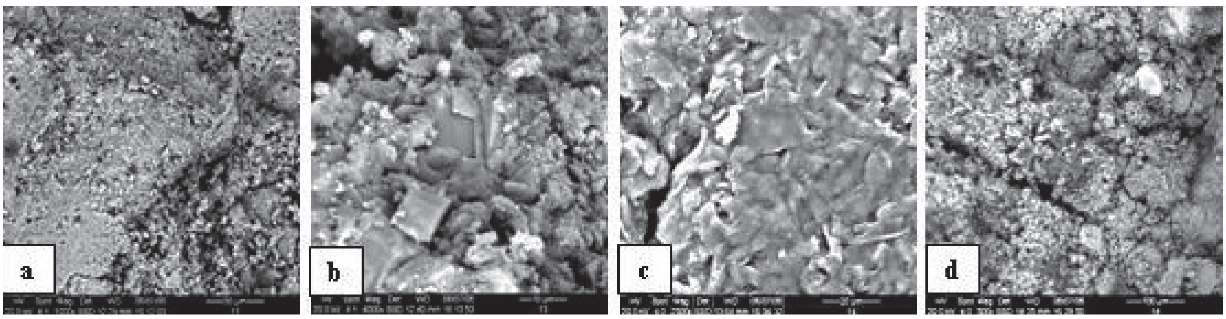

Fig. 6: SEM micrographs showing the different symptoms of deterioration resulted from aggressive effects of Gray Portland Cement and None-Galvanizing Steel

Investigated Samples		Weight Lost gm			Depth Lost	
		Before	After	%	mm	%
Limestone		141.71	141.22	0.35	.028	0.652
Gray	Portland Cement	93.130	89.820	3.55	5.81	14.61
	Reinforced Concrete	90.280	88.620	1.84	4.04	10.38
White	Portland Cement	112.83	112.70	0.12	0.60	1.403
	Reinforced Concrete	117.92	117.80	0.12	0.43	1.010

Table 3: Shows micro-abrasion resistance of the materials "GPC and GRC" used in conservation works in Ajlun Castle and Jerash City

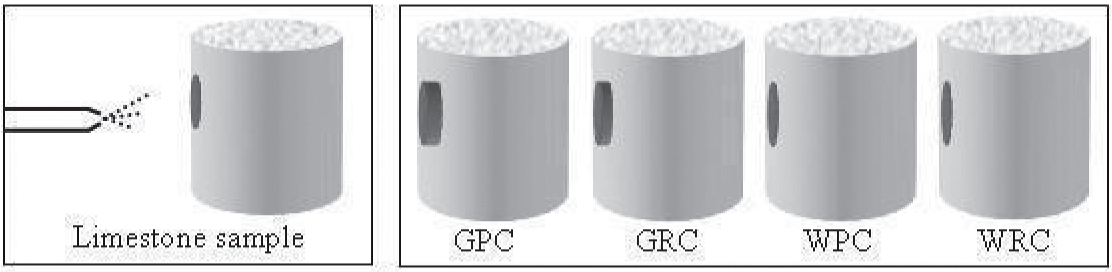

Fig. 7: Shows micro-abrasion resistance of the materials used in conservation works in Ajlun Castle and Jerash City

down of some fragments of these surfaces - Fig. 6c.

- Growing of some salt crusts on the stone surfaces as Gypsum, Halite, Niter and Soda niter, creating some deterioration features like cracks and surface fracture - Fig. 6d.

2-3 Defining Physical Properties

Some important techniques were used for defining physical properties of materials to evaluate the different kinds of conservation materials, the alterability and different patterns of stone degradation such as Density and Porosity (Pérez, et al., 1995), in addition to Water Uptake (Ling, et al., 1993b) and Water Content (Binda, et al., 1996). In the present study, these properties were defined for studying some relations between them especially emigration of some particles or salt components of conservation materials used. All final results are presented in table 2.

2-4 Micro-abrasion Resistance

This parameter is one of the important indicators that point to the strength of the bond between the particles of stone (Kumar and ginell 1995). It can be interpreted in terms of hardness and is considered one of the famous methods used to evaluate all relative effectiveness of the treatment (Phillips, 1982) (Nishiura, 1995). It is also used to define the materials' resistance by sand plasting technique with different abrasive materials "either in kind or diameter". In this part, different samples of Stone, Portland cement mortar and Concrete "gray and white" were exposed to mechanical abrasion by sand plasting instrument model Micro Tip I according to the next specific schedule that depended essentially on some scientific varieties as follows:

- Time of exposure is 105 seconds, Abrasive powder is sand particles no 500 micron
- Nozzle diameter is 1.07 mm

Surface Crusts Composition %			Conservation materials and techniques used							
			Portland Cement		Retouching Materials		Reinforced Concrete		Improper Techniques	
			Ajlun	Jerash	Ajlun	Jerash	Ajlun	Jerash	Ajlun	Jerash
Essential Components		Calcite	3.12	23.66	-	67.62	86.52	61.90	30.65	69.52
		Dolomite	11.84	2.44	-	10	-	-	-	-
Weathering components	Gypsum		49.22	30.98	68.50	-	-	4.76	33.47	13.33
	Quartz		-	12.92	-	22.38	-	21.70	14.92	17.14
	Kaolinite		12.50	4.63	-	-	-	-	12.10	-
	Montmorillonite		6.23	3.41	-	-	-	-	-	-
	Orthclease		7.78	-	-	-	-	-	-	-
	Halite		-	-	5.51	-	-	-	-	-
	Nepheline hydrate II syn.		2.80	1.22	-	-	-	-	-	-
	Andalusite		2.50	.98	-	-	-	-	-	-
	Cholorite syn		-	-	-	-	-	-	8.87	-
	Goethite		-	-	-	-	13.48	11.64	-	-
	Glaucophane syn		4.36	1.95	-	-	-	-	-	-
	Niter		-	-	11.81	-	-	-	-	-
	Soda Niter		-	-	14.17	-	-	-	-	-
	Carbonate hydroxyl abatite		-	15.12	-	-	-	-	-	-
	Huntite		-	2.68	-	-	-	-	-	-

Table 4: Shows: qualitative and semi-quantitative materials resulted after some conservation works both in Ajlun Castle and Jerash City

- Distance between sample and nozzle is 100mm
- Pressure is 2 bar, all results listed in table 3 and Fig. 7

2-5 Mineralogical Investigations

Mineralogical analysis methods can be used in the study of archaeological artifacts (Parkes, 1986), especially for materials that are deceptively similar to each other in appearance. Chemical tests are of course a necessity for the purpose of differentiation (Caley, 1948). Also, they are usually employed to determine the materials from which an object is made, and often to identify trace elements that may give a clue to the origins and date of the object (Ciantar and Mallia, 2003). Additionally, these methods of analysis allow us to determine different chemical and mineralogical profiles both of fresh and affected samples.

The XRD technique was used to identify the crystalline materials as a qualitative and semi-quantitative technique for studying some samples collected from some restored and treated zones in the present study areas. All results are listed in table 4

3- Discussion

The detailed investigations have led to various considerations and can be summarized in the following points:

3-1 Deterioration Processes

Several deterioration processes and related problems were observed in our case study; these were resulting essentially from aggressive mechanisms due to Portland cement and concrete negative effects. Those processes and their different mechanisms created some deterioration forms that can be attributed to both chemical and physical actions such as:

- Increasing the dampness of stone units and other building materials particularly ancient mortars because of the low porosity index of Portland cement, which prevents water evaporation in the internal pores of stone, then accelerates their damage cycles.
- Surface crack patterns and pitting features resulting from the aggressive Alkali Silicate reactions (Thaulow and Jakobsen, 1997) that take place in aggregate particles between alkaline pore solution of the cement paste and silica (Ferraris, et al., 1997).
- Sulfation or salt crustation and crystallization that may be formed by Sulphate attack which occur when concrete is in contact with sulphate containing water or pollutants ambient in the air that lead to form gypsum crusts (El-Gohary, 2007).
- Breaking rocks surfaces down into smaller pieces and fragments that essentially result from degradation processes that had been created through physical actions which lead to the break of the stone surfaces down (Roy, and Jiang, 1997). Also, these actions may lead to the leaching of calcium ion and may increase the porosity index of the surface layers, then affecting the durability of building components "mortar, concrete and most of stone surfaces" (Delagrave, et al., 1997). Again, the chloride induced corrosion of reinforcing steel is a very common deterioration cause of reinforced concrete structures, where it enters concrete mainly via diffusion through the concrete pore solution (Streicher and Alexander, 1997), and finally leads to the creation of some aggressive stress and internal strains

3-2 Visual Appearance Changes

It is well known that direct visual examination is frequently sufficient for identifying the general type of materials used for stone artifacts (Tite, 1972). From the examination and data presented above, it could be argued that the different color appearances in the external treated surface are due essentially to different kinds of conservation materials that were used and their reactions with environmental components in the surrounding area. The presence of these colors is due to different deterioration mechanisms as follows:

Green color mostly appears on the stone surfaces treated by some consolidant materials without any experimental studies that lead to the growth of some species of microorganisms as Algae and Bacteria. Gray color appears as a direct result of using gray Portland cement as a joining mortar or re-pointing filler material between stone blocks. Black color is essentially due to the use of some families of surface organic consolidants and water repellents such as calcium oxalate mixed with dust particles which compose heterogeneous materials affected rapidly by sulphation processes which then lead to the darkening and blackening symptoms of treated surfaces as discussed earlier (see: Alessandrini, et al., 2000; Fassina, V., 2000). White color appears on the surfaces treated with some cement materials as gypsum, lime mortars and white Portland cement using Sweileh sand characterized by different colors. Finally, Brown color appears as a result of using some organic consolidants such as Casein, Shellac and PVA that have a good ability for absorbing air moisture and reacting with other materials in surrounding environment; the process leads to new surface crusts through photochemical reactions.

3-3 SEM Observations

Having analyzed SEM figures of the present samples that represent the surfaces treated by several improper treatment materials particularly Portland cement, surface retouching, organic consolidants and reinforced concrete, we can see that there are highly disintegration effects and several decaying forms that resulted essentially from aggressive deterioration mechanisms either chemically or physically; in particular, wetting and drying cycles. Furthermore, crystallization pressures created by aggressive deterioration mechanisms resulted from salt crystallization action and rusting of steel bars in reinforcement concrete.

3-4 Defining Physical Properties

After evaluating the resulting data in table 2, it could be said that there are some differences between physical properties of conservation materials and those characterized the limestone as an essential building material. It could be seen that there are recognized differences between Density index of mortar and concrete samples (gray or white) on the one hand, and limestone samples, on the other. This means that the desired compatibility between mortars and stone walls will be lost and its workability will be insufficient. This leads to additional deterioration mechanisms and forms in the future according to dominated internal forces due to volume expansion between them as argued in a similar case by Kovacs (2000). Also, the noticeable differences between the porosity index in all mortar samples and Limestone will lead to irregular distribution of water sources and water content dominant in the study areas, which then creates other problems of salt crystallization (Binda, et al., 1997) and hydration cycles particularly in the presence of some salt sources as hydro soluble sulfates which can be carried from water in wet masonry through capillary rising resulting from foundations or through wind transportation in marine environments (Corinaldesi, et al., 2003), in addition to continuous surface dampness. Thus, this phenomenon leads to the creation of some deterioration forms of mortar layers and decomposition of the concrete which essentially depends on some varieties such as porosity of the cement paste, acid concentration, solubility of calcium and fluid transport through the concrete (Constantiner and Diamond, 1997). This leads also to the corrosion of steel bars in reinforced concrete structures (Bucea, et al., 2005) especially in the presence of the same differences in both Water Uptake and Water Content.

Thus, we can see that the dampness is a common problem that causes destruction of ancient walls and the collapsing of the cement chemical structure and decreasing the concrete durability (Mao and Kagi, 1995). All these problems result in different decay products both inside and outside the building stones which are considered important topics of stone weathering mechanisms as discussed earlier by Holzwarth (1996).

3-5 Micro-abrasion Resistance

After measuring the micro-abrasion resistance of different samples to define the compatibility

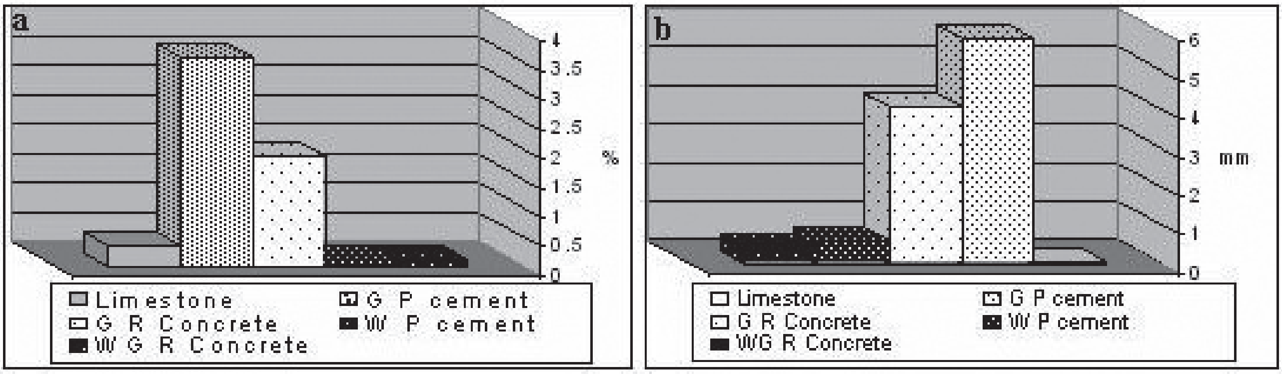

Fig. 8: Shows the differences of micro-abrasion resistance between limestone mortar and concrete samples (a) in Weight lost and (b) in Depth lost

between them, we conclude that:

- All samples were affected gradually according to the kind of the cement materials, where white samples, mortar and concrete, are characterized by a higher resistance than gray ones.
- All samples, mortar and concrete, had a minor micro-abrasion resistance in comparison with Limestone samples as shown in Fig. 8a.
- All resulting holes created by this test vary: they increased in mortar samples and decreased in concrete ones due to the role of steel reinforcement beams as shown in Fig. (8 -b).
- The resistance degree decreased after scratching the external surface of the samples, owing essentially to the smoothing degree of external surface and low superficial porosity index in comparison to the internal core of the samples.

Although the tested samples of mortar and concrete were characterized by low hardness index compared to Limestone samples, they had some unsuitable and un-commendable physical properties, particularly those concerning water and moisture behavior such as porosity, water absorption and water content.

3-6 XRD Investigations

Scientific analysis of XRD data confirmed that the investigated samples were divided into 4 categories according to their degree of alterability as follows:

1st category represents, Limestone, as the essential components of building material which includes Calcite and Dolomite with very occasional crystals of Quartz.

2nd category includes all salty hard crusts such as Gypsum, Halite, Niter and Soda niter. From a scientific point of view, we can decide that the presence of these amounts of salts is essentially due to the use of Portland cement as a repairing mortar which causes sever deterioration mechanisms and forms affecting historic structure materials because of their inherent physical and mechanical properties and soluble salt content as demonstrated before (Arnold & Zehnder, 1989) in similar cases. It can also be argued that the gypsum and halite crusts result essentially from dissolution mechanisms through chemical weathering in the presence of some complex alternative cycles of drying and wetting (El-Gohary, 2006; Franz and Storey, 2000). On the other hand, the presence of other species of salts was essentially due to some agricultural activities in surrounding areas which used some organic fertilizers like Niter and Soda niter (El-Gohary, 2000).

3rd category contains all dusting materials and accumulation particles such as Kaolinite, Montmorillonite and Chlorite; all of these materials resulted from different mechanisms of deterioration whether physical or chemical. Again, pigmented materials such as Goethite, which mostly resulted from the main components of mortar and additive materials used as retouching for improving the final appearance of the surfaces, all of them led to the creation of some colored surfaces according to their components that range between red, brown, yellow, black and gray (Goffer, 1980).

4th category contains some strange minerals such as Nepheline hydrate IIsyn, Andalusite and Glaucophanesyn that may be essentially due to natural occurrence within Sweileh sand particle used in Jordanian mortar composition, or through hydrothermal decomposition of Amphiboles. Moreover Carbonate hydroxyl apatite and Huntite present essential components in Jordanian mortar Portland cement.

From an analytical point of view, it could be said that the main reasons behind the presence of these several kinds of weathering products on the stone surfaces were the wide gap between expansion and contraction index of all components resulting from stone and different conservation materials especially Portland Gray cement and Reinforced Concrete according to the degree of dominant air temperature and other deterioration factors. Furthermore, we can see that the use of pure Portland cement as a mortar displays harsh workability, inadequate water retentivity, an undesirable low water and vapor transmission rate, excessive compressive strength and deformability. Thus, its use should be avoided for historic masonry (Suter, et al., 2001) because of dangerous internal and external stress, strains and crystallization pressure created through attacking by sulfate diffusivity (Tixier and M.ASCE, 2003).

Recommendations

After assessing and evaluating all problems affecting our two sites resulting from aggressive effects of wrong techniques and improper materials, some scientific recommendations should be followed to remove different deterioration forms. These recommendations can be used as part of an initial conservation plan that should be adopted. The recommendations are:

1. Applying different steps of mechanical cleaning by brushes, caters air blowers and other electric instruments, then using different chemical cleaning methods by suitable materials such as some clay poultices "Attapulgite or Sepiolite" or paper pulp poultices for cleaning the sensitive surfaces of Limestone under conservation.

2. Using a mixture of white Portland cement and Lime mortars because the interaction between the two binders means getting good properties of final mortar product, where Lime contributes to the mortar's workability and retentivity while the Portland cement controls the mortar's strength gain and final compressive strength.

3. New methods should be developed to evaluate the efficiency of the treatment materials that are used in stone conservation particularly porous building materials such as stone, mortar and plaster.
4. Greater care should be given to mortar choice; its components should be well chosen and characterized by finest quality, free of salt, clay, loam, soil particles or any other impurities to avoid weakness or discoloring that may lead to some problems on the long run.
5. Finally, all conservation steps and materials must be tested and proven in different scientific laboratories and should be done in accordance with recognized international charters and codes of practice.

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ملخص: يتناول هذا البحث عملية التشخيصَ العلميَ والتقنى المسببة لتدهور الخواص الطبيعية والكيميائية لبَعْض مكونات المبانى الأثرية الأردنيةِ الناتجة عن استعمال تقنياتِ ترميم غير ملائمة وموادِ معالجةِ غير مناسبة. فطبقا للدراسات العلمية والمواثيق الدوليةِ فى هذا المجال فقد تمت مراجعة أعمال المعالجةَ والترميم المنفذة في اثنين مِنّ أهم المواقعِ الأثرية بالأردن «قلعة عجلون و مدينة جرش» وذلك لتَقييم صلاحية و إستقرارهذه الأعمال بمضى الزمن. ولإنجاز هذا الهَدف، فقد تم استخدام بعض التقنيات والطرق العلميةِ مثل تَقييم المظاهر البصرية باستخدام بعض العدساتَ والكاميرات العلمية الخاصّةَ، بالإضافة إلى دراسة بعض الخواص الفيزيائية المميزة لعينات من المونات الأثرية والحديثة باستخدام العديد من الطرق العلمية الحديثة ومنها جهاز السفع بالرمال والذى استخدم للتعرف على مدى صلادة السطح ودراسَة مقاومته للخدش. كما تمت دراسة كل من التركيب المعدنى للعينات بإستخدام تكنيك حيود الأشعة السينية وكذا دراسة المميزات والخصائص المورفولوجية للعينات باستخدام الميكروسكوب الإلكترونى الماسح. وقد ثبت من خلال هذه الدراسات أن المبانى الحجرية موضوع الدراسة قد عانت ومازالت تعانى من العديد من أشكال التلف التى تعزى للعديد من العوامل والميكانيكيات المتلفة ومنها زيادة مظاهر الرطوبة المؤثرة على الوحدات الحجرية بكلا الموقعين، وجود العديد من أنماط الشروخ والتصدعات بالإضافة إلى ظاهرة التلف الحفرى المميز للأحجار الجيرية فى المناطق الرطبة، وجود العديد من مظاهر التلف الملحى والمتمثلة فى تبلور بعض فصائل الأملاح على أسطح الجدران بكلا الموقعين بالإضافة إلى وجود العديد من مظاهر التحطم والانهيار الأخرى ومنها تحطم الكتل الحجرية وظهور العديد من الضغوط والانفعالات الداخلية الناتجة عن صدأ المواد المعدنية المستخدمة فى عمليات الترميم الخاطئة.

References

Abd Allah, T. and Yahya, F. 1988. Urban ecology of Jerash1983, **Arabic Jornal of humanities science**, Vol. 8, Kuwait, pp: 426 – 448

Abdel–Jalil, A. 1989. Four Byzantine symbolic elements from Jerash, **Annual of the department of antiquities of Jordan**, Vol. 33, Amman, pp: 353-356

Agnew, N. and Demas, M. 2002. **Principles for the Conservation of Heritage Sites in China**, Getty Institute, pp:1-91

Alessandrini, G., Casadio, F., Colombo, C and Toniolo, L. 2000. Analytical investigation of films and patinas on the Istria stone, 5th **International symposium on the conservation of monuments in the mrditerranian basin**, Seville, spain, pp: 60-61

Al Kodah, Z. 1993. Final report of conservation and maintanance works in Ajlun cetadle 10-5- to 30-9 1992, **Annual of the department of antiquities of Jordan**, Vol. 37, Amman, pp: 61-70

Arnold, A. & Zehnder, K. 1989, Salt Weathering on Monument, **Proceedings of the 1st International Symposium on the Conservation of Monuments in the Mediterranean Basin**, Bari, pp: 31-58

ASTM 1999. **Visual evaluation of colour difference of opaque materials**, D1729, pp:1-6

Binda, L., Squarcina, T. and Van Hees, R. 1996. Determination of moisture content in Masonry materials. calibration of some direct method, 8th **Intternational congress on deterioration and conservation of stone**, Berlin, pp: 423-435

Binda, L., Henriksen, J., Mirwald, P., Nappi, A., Price, C., Van Balen, K., Vergès-Belmin, V., Wendler, E. and wittmann, F. 1997. Group report. How can we diagnose the condition of stone monuments and arrive at suitable treatment programs?, **Saving our archetictural heritage. the conservation of historic stone structure**, New York, pp: 199-221.

Brus, J and Kotlit, P. 1996. Consolidation of stone by mixtures of Alkoxysilane and acrylic polymer, **Studies in conservation**, Vol. 41, London, pp: 104-110

Bucea, L. and Sirivivatnanon, V. 2003. Salinity Hazard and Deterioration Mechanisms in the Built Environment, Manufacturing & Infrastructure Technology, **CSIRO** Australia, pp: 1-28

Bucea, L. Khatri, R. and Sirivivatnanon, V. 2005. Chemical and Physical Attack of Salts on Concrete, UrbanSalt Conference, **CSIRO**, Australia, pp: 1-16

Burra Charter, Articles 13-16, Australia, 1979 Revised 1999

Caley, E. 1948. On the application of chemistry to archaeology, **OHIO J. of Science**, Vol. XLVIII, No.1, pp: 1-14

Camuffo, D. 1995. Physical weathering of stone, **The science of the total environment**, pp: 1-14

Ciantar, V. and Mallia, J. 2003. Conservation of archaeological objects. the archaeologist's point of view, Malta Centre for Restoration, 12 pages

Constantiner, D. and Diamond, S. 1997. Pore solution analysis. Are threepressure effects? Mechanisms of chemical degradation of cement-based system, 1st ed., London, pp: 22-29

Corinaldesi, V., Moriconi, G. and Tittarelli, F. 2003. Thaumasite. evidence for incorrect intervention in masonry restoration, **Cement & Concrete Composites**, Vol. 25, Elsevier, 1157–1160

D'Avino, S. 1995. Theory and practice in the restoration of stone materials, **preservation and restoration of cultural heritage**, Montreux, pp: 745-753

De Witte, E. 1982. Resins in conservation. Introduction to their properties and applications, Resins in conservation, **Proceding of the symposium**, **edinburg**, 6 pages

Delagrave, A., Gérard, B. and Marchand, J. 1997. Modelling the calcium leaching mechanisms in hydrated cement pastes, **Mechanisms of chemical degradation of cement-based system**, 1st ed., London, pp: 38-49

Drakaki, E., Karydas, A. G., Klinkenberg, B., Kokkoris, M., Serafetinides, A.A., Stavrou, E., Vlastou, R. and Zarkadas, C. 2004. Laser cleaning on Roman coins, **Appl. Phys**., Vol 79, No. 4-6, pp: 1111-1115.

El-Gohary, M.A. 2000. Effect of groundwater on Sandstone used in some Egyptian temples in upper Egypt with scientific and application methods for its conservation and maintenance, PhD, Conservation dept., Faculty of archeology, Cairo Univ., pp: 106-135

El-Gohary, M.A. 2006. Observation and explanation of Limestone weathering in Middle delta, El-Tuba minaret, as a case study-El Mehalla, Egypt, 2nd **International conference on conservation and restoration. The future view of conservation and rehabilitation of**

archaeological areas, El-Minia Univ., Egypt, pp:167-190

El-Gohary M. A. 2007. Air Pollution and Aspects of Stone Degradation Umayyed Liwān - Amman Citadel as a Case Study, 2nd **Architectural conservation international conference and exhibition on opportunities and challenges on the 21st century**, Dubi.

Environment and Heritage Service 2006. **Stonework repairs. Technical note no. 39**, Belfast, pp: 1-4

Environmental Council of Concrete Organizations 1996. **Cement, concrete, and the environment**, 2 pages.

Evans, D. M. 2003. The current state of archaeology in the United Kingdom, All- Party Parliamentary Archaeology Group, London, pp: 1-38

Fassina, V. 2000. Different forms of decay in relation to natural weathering and past man-made intervention on the S, Maria del Giglio façade (Venice), 5th **International symposium on the conservation of monuments in the mrditerranian basin, Seville**, spain, pp: 91-93

Ferraris, C. F., Clifton, J. R., Grabociz, E. J. and Davis, F. L. 1997. Stress due toAlkali-Silica reaction in mortars, **Mechanisms of chemical degradation of cement-based system**, 1st ed., London, pp:75-82

Franz, A. and Storey, P. 2000. The 17th centuray mural paintings in the Regalia room, Archbishobis palace, Trondheim, Norway. history, Paint technology and weathering of the west wall, **The restoration workshope of Nidaras catghedral**, Zurich, pp: 4-66

Goffer, Z. 1980. **Archaeological chemistry**, John Wiley, Publication, NY, pp: 113-115

Hammecker, C. 1995. The importance of the petrophysical properties and external factors in the stone decay on monuments, **PAGEOPH**, Vol. 145, No. 2, Basel, pp: 337-361

Hammer, I. 1995. Preservation of wall paintings and other surfaces of architecture affected by salt. Interdisciplinary remarks to interpretation of the physical system and the damage processes, **preservation and restoration of cultural heritage**, Montreux, pp: 575-599

Hanna, S. B. 1984. The use of organo-silanes for the treatment of Limestone in an advanced state of deterioration, **adhesives in consolidants**, Paris congress, IIC, pp: 171-176

Holzwarth, D. 1996. Building stone from Southern dalatinata (western side of the oberrheingraben) and their petrographical and geotechnical properties, 8th **Intternational congress on deterioration and conservation of stone**, Berlin, pp: 21-27

Huovinen S., Bergman, J and Hakkarainen, H. 1998. Deterioration defects and repair metrhods of facades, **Helsinki university of tecnology**, Finland, pp: 4- 60

ICOM 1984. The Conservator-Restorer. a Definition of the Profession, **ICOM Committee for Conservation Copenhagen**.

John Milner Associates 2002. Sandstone Conservation Assessment. East & West Towers, **John Milner Associates, Inc**, Alexandria, Virginia, pp: 1-22

Kabbain, R. 1997. Conservation a collaboration between art and science, **Springer Verlag**, Vol. 2, No.1, NY, pp: 1-18

Koh, Y. S. 2006. Laser cleaning as a conservation technique for corroded metal artifacts, Ph. D. Thesis, Luleå University of Technology, Sweden, p. 6

Kovacs, T. 2000. Deterioration of reinforced concrete repair mortar layers, **Periodica polytechnica Ser. Civ. Eng**, Vol. 44, No. 2, pp: 197-206

Kumar, R and ginell, W. S. 1995. Evaluation of consolidants for stabilization of weak Maya Limestone, **Methods of evaluating products for the conservation of building materials in monuments**, ICCROM, Rome, 163-178

Ling, A. Tao, M., Senthlage, R and Wendler, E. 1993a. Investigation on stone conservation, **Entwedcklung und erprobung von konservierungtechnologien füt kunst- und kuiturgüter der provinz shaanxi/VR china-deutchen zusammenarbeut in der denkmalpflege**, München, 10 pages

Ling, A. Tao, M., and Senthlage, R. 1993b. The Sandstone varieties and their properties in Dafosi Gratto, **Entwedcklung und erprobung von konservierungt echnologien füt kunst-und kuiturgüter der provinz shaanxi/ VR china-deutchen zusammenarbeut in der denkmalpflege**, München, 12 pages

Ma, J. 1995. Leshan grand Buddha. investigation of traditional and alternative materials for repair, **Methods of evaluating products for the conservation of building materials in monuments**, ICCROM, Rome, 29-40

Mailvaganam, N. P. and Litvan, G.G. 1997. Durable concrete structures can be achieved only through careful attention to many details. This Update discusses the key determinants of durability for both new construction and repair, **National Research Council of Canada, Ottawa**, pp: 1-4

Manaresi, R. R., Charola, A. E., Koestler, T. A and wheeler, G. E. 1984. study of accelerated weathering Limestone treated with an Acrylic-Silicon mixture, **7th triennial meeting, ICOM committee for conservation**, Copenhagen, pp: 102-104

Mao, L. and Kagi, D. 1995. Methods for assing liquids for the remedial treatment of rising damp, **Methods of evaluating products for the conservationof building materials in monuments**, ICCROM, Rome, 359-371

Maria Cristina, B. 1986. An example of local sculpture at Jerash, **Annual of the department of antiquities of Jordan**, Vol. 30, Amman, pp: 207-210

McDougall and Vines 2004. **Conservation Guidelines**, Department for Environment and Heritage, South Australia, pp: 1-47

Nara Document on Authenticity 1994. **Convention concerning the protection of the worled cultural and natural heritage**, Japan.

Natural Environmental Research Council 2005. Cement raw materials, **British geological survey**, pp: 1-20

Nishiura, T. 1995. Exprimintal evaluation of stone consolidants used in Japan, **Methods of evaluating products for the conservation of building materials in monuments**, ICCROM, Rome, 189-202

NORMAL -8/81 1981. Esame delle caratteristiche morflogiche al microscopio elettronico a scansione (SEM), **CNR-ICR**, Italia, pp:1-12

O'Brien, P., Bell, E., Orr, T. and Cooper, T. 1995. Stone loss rates at sites around Europe, **The science of the total environment**, pp: 111-121

Oddy, A. 1992. **In The Art of the Conservator**, Smithonian Institution Press, Washington DC, pp 7–27

Ostrasz, A. A. 1991. The Excavation and Restoration of the Hippodrome at Jerash . A Synopsis, Annual of the department of antiquities of Jordan, Vol. 35, Amman, pp: 237-250

Ostrasz, A. A. 1997. The Citadel of Amman . The Conservation and Restoration of the Ayyubid Tower, **Annual of the department of antiquities of Jordan**, Vol. 41, Amman, Pp: 395-402

Palumbo, G. 1994. **Jordan Antiquities Database and information System**, The department of antiquities of Jordan, Amman, Jordan, pp: 3.1-3.27

Parkes, P. A. 1986. **Current scientific techniques in archaeology**, Palgrave Macmillan, London, pp: 143-183

Pérez, J., Villegas, s., Vale, J. F., Bello, M. A. and Alcalde, M. 1995. effective of consolidants and water repellent treatments of the porosity and pore size distribution of Limestone **Methods of evaluating products for the conservationof building materials in monuments**, ICCROM, Rome, 203-211

Phillips, M. W. 1982. Acrylic precipitation consolidants, **congress on science and technology in the service of conservation** washington D C., pp: 56-60

Pini, R., Siano, S., Salimbeni, R., Pasquinucci, M., and Miccio, M. 2000. Tests of laser cleaning on archaeological metal artefacts, **Jornal of Cult. Heritage**, Vol. 1, pp: 129-137.

Plenderleith, H. J. 1986. Problems in the preservation of monuments, The **conservation of cultural properties**, UNESCO, Switzerland, pp: 124-134

Raccomandazione NORMAL 8/81 1981. Esame delle caratteristiche morfologiche al microscpio elettronico a scansione **(SEM)**, CNR, ICR, Rome, pp:1-12

Riecken, B and Schwamborn, B. 1995. Laboratory simulation of aggeressive climatic conditions theoriticle background and experimental results, **Methods of evaluating products for the conservation of building materials in monuments**, ICCROM, Rome, 451-459

Righini, G. C. 2002. Electro-optical technologies and systems in art conservation. developments and perspectives, **Microelectronics and cultural heritage**, pp: 19-31

Rizzi, G. and Volta, S. 1995. Conservation and anastylosis structural re-integration at the Sanctury of Arthenis, Jerash, **Preservation and restoration of Cultural heritage** Montreux, pp: 83-88

Rodrigues, J. D. and Charola, A. E. 1996. General report on water repellents, **Science and technology for cultural heritage**, Vol. 5, No. 1, pp 93-103

Rodrigues, J. D. 2001. Consolidation of decayed stones. A delicate problem with few practical solutions, **Historical Constructions**, Guimarães, pp: 3-14

Rogan, E.L. 1988. Al-Salt, jabal 'Ajlun and the advent of direct ottoman rule. the 1868 travel journal of F. A. Klein **Jordainan university studies**, Jordan, Vol. 15, pp: 23 – 46

Roy, D. M. and Jiang, W. 1997. Concrete chemical degradation. ancient analogues and mordern evaluation, **Mechanisms of chemical degradation of cement-based system**, 1st ed., London, pp:14-21

Saffarini, G. A. 1989. Geochemical characterization of a carbonate-hosted hydrothermal iron ore. the Warda iron deposit/ Ajlun – Jordan, **Jordainan university studies**, Jordan, Vol. 16, pp: 23 – 46

Streicher, P. E. and Alxander, M. G. 1997. Diffusibility changes due to the presence of choloride ions, **Mechanisms of chemical degradation of cement-based system**, 1st ed., London, pp: 50-57

Stremyr, P. and Küng, A. 2002. **Conservation of mural paintings and paint on stonework in the choir's North aisle vault**, Expert center für denkmalpflege, Zurich, pp: 1-52

Suter, G. T., Borgal C. P. and Blades, K. 2001. Overview of mortars for Canadian historic structures, **Proceedings of the 9th Canadian Masonry Symposium**, Canada, 8 pages

Tender document, 2004. **Repairing of catter pillar rooms in dumper repair HEMM. workshop at Kakri Project**., Part 1, India, pp:43-54

Tennis, P. D.. Portland cement characteristics-1998, **Portland Cement Association**, Vol. 20, No. 2, pp: 1-8

Thaulow, N. and Jakobsen, U.H. 1997. The diagnosis of deterioration of concrete by optical microscopy, **Mechanisms of chemical degradation of cement-based system**, 1st ed., London, pp: 3-13

Tite, M. S. 1972. **Methods of physical examination in archaeology**, Seminar press, London, p. 208

Tixier, R. and M.ASCE, M. B. 2003. Modeling of Damage in Cement-Based Materials Subjected to External Sulfate Attack. II. Comparison with Experiments, **Journal of materials in civil engineering**, pp: 314-322

Venice Charter. Articles 9-13, **ICOMOS**, Italy, 1964

Washington Charter 1987. On the conservation of historic towns and Areas, **ICOMOS**, USA,

Wessman, L. 1997. Studies on the frost resistance of natural stone, **Lund Institute of Technology, Division of Building Materials**, Lund, Sweden, pp: 24-32

Zayadine, F. 1985. Recent Excavation and Restoration at Qasr El Bint of Petra, **Annual of the department of antiquities of Jordan**, Vol. 29, Amman,, pp: 239 – 249