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NANOLIME-BASED MIXTURES FOR TREATMENT OF LIMESTONE OFFERING TABLE EXCAVATED FROM SAQQARA, EGYPT: ANALYTICAL, EXPERIMENTAL AND APPLIED STUDY

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ABSTRACT

This paper represents an analytical, experimental and applied study of a limestone offering table, excavated from Saqqara in 2021. The studied limestone offering table was highly affected by damage associated with the burial environment such as subsurface water, salts and soiling. An analytical study was performed using a polarizing light microscope, X-ray diffractometer, scanning electron microscope and energy-dispersive X-ray spectrometer. The experimental study in this work aims to enhance the properties of nanolime in order to be successfully used in the consolidation of the limestone offering table. To achieve the main target of the study, experimental work was carried out including colour measurement, static contact angle, compression strength and morphological investigation. The results showed that the produced nanolime mixtures possess better properties than individual nanolime. The mixture of Calosil E5 + Megaprotec (silane and siloxane-based product) was considered the optimal mixture for the consolidation of the studied object. Finally, treatment was performed using mechanical and chemical cleaning, salt extraction and consolidation.

KEYWORDS

Nanolime; Limestone; polarizing microscope; X-ray diffraction; Consolidation.

الملخص

تعتبر موائد القرابين من أهم المنحوتات الحجرية، حيث تمدنا بالمعلومات الهامة عن الطقوس الجنائزية في العصور المصرية القديمة وحتى العصر اليوناني الروماني. هذا ويتعلق موضوع البحث بإحدى موائد القرابين المنحوتة من الحجر الجيري، والتي تم اكتشافها في منطقة سقارة الأثرية، إذ تعاني هذه المائدة بشكل كبير من تأثير عوامل التلف التي تعرضت لها في بيئة الدفن لفترة زمنية طويلة. ويقدم هذا البحث دراسة تحليلية وتجريبية وتطبيقية لعلاج وصيانة هذه المائدة (موضوع الدراسة). وقد تم تنفيذ الدراسة التحليلية باستخدام الميكروسكوب المستقطب وطريقة حيود الأشعة السينية والميكروسكوب الالكتروني الماسح والتحليل العنصري بوحدة تشتيت الطاقة. وقد أجريت الدراسة التجريبية في هذا البحث بغرض تحسين خصائص مادة هيدروكسيد الكالسيوم النانوية لاستخدامها في تقوية الحجر الجيري المنحوتة منه المائدة. وقد تم تقييم العينات المعالجة باستخدام اختبار التغير اللوني وقياس زاوية اتصال الماء وتعيين مقاومة الضغوط الميكانيكية والفحص باستخدام الميكروسكوب الالكتروني الماسح. وقد أثبتت النتائج أن الخلائط المستخدمة في الدراسة تمتلك خصائص جيدة، كما تبين أن الخليط المكون من (مادة هيدروكسيد الكالسيوم النانوية + مادة ميجا بروتك) هو الخليط الأمثل لعلاج المائدة. وأخيراً، تم تنفيذ إجراءات علاج وصيانة المائدة باستخدام عمليات التنظيف الميكانيكي والكيميائى واستخلاص الأملاح والتقوية.

الكلمات الدالة

النانوليم؛ الحجر الجيري؛ الميكروسكوب المستقطب؛ حيود الاشعة السينية؛ التقوية.

INTRODUCTION

Saqqara is a famous and highly valuable archaeological site in Egypt. It is an important section of the necropolis of Memphis (Regulski, 2011). The cemetery of Saqqara lies on the western side of the Nile, about 30 kilometres southwest of Cairo 29.87° N 31.21° E (Mahmoud et al, 2011). It has been considered the only Egyptian archaeological cemetery with graves, tombs and monumental features from the beginning of the ancient Egyptian history until the Greek and Roman periods (Abdelmegeed, Khalaf, and Refaat, 2021). The plateau of Saqqara is mainly formed of thick unit rocks varying from argillaceous limestone to marl and calcareous claystone of Late Eocene Age (Akarish, and Shoeib, 2011). In December 2020, the joint archaeological excavation mission between the Supreme Council of Antiquities and Misr University for Science and Technology (MUST) started its excavation works on the eastern side of Tebbet El-Gish at Saqqara. During the second season (2021) some stone carvings were discovered. The studied offering table was one of these findings (Figure 1). It is well known that offering tables are among the most significant ancient Egyptian carvings, they provide us with valuable information about funeral rituals throughout the ancient Egyptian and Greco-Roman periods (Abdallah, Kamal, and Abdrabou, 2016). Since ancient Egyptians believed in the Afterlife, they used offering tables as funeral elements on which food and drinks were provided for the deceased by the funerary priests or relatives (Hanafy, 2016). Usually, offering tables were placed in the mortuary chapel of the tomb and at the front of the false door (Abdallah, Kamal, and Abdrabou, 2016).

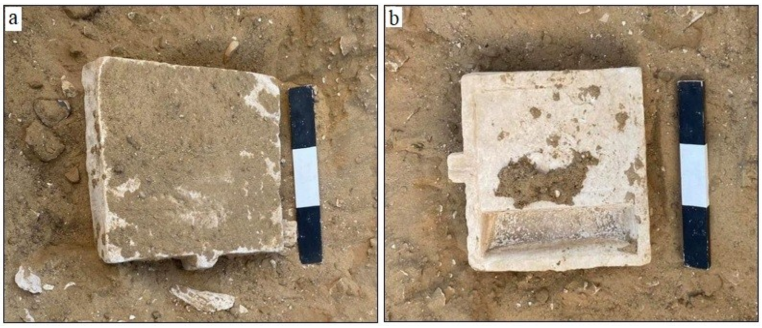

Figure 1 (a, b) The studied offering table during its discovery.

The studied offering table is carved from limestone and hasn't any hieroglyphic inscriptions. Limestone is an abundant sedimentary rock that is spread widely across the surface of the earth and is mainly composed of calcite (Montgomery, 1990). In Egypt, most of the ancient limestone quarries occurred extensively through the hills and escarpments surrounding the Nile valley from Esna to Cairo (Lucas, and Harris, 2012). In addition, some quarries are located along the Mediterranean north coast as well as Suez. The quarries of limestone at Giza, Saqqara, Mokattam, Tura-Ma'sara, Abu Rawash, Tel El Amarna, Qurna and Max are the most common quarries used in ancient Egypt (Aston, Harrell, and Show, 2000; Klemm, and Klemm, 2001). The studied offering table was greatly affected by deterioration including soiling, efflorescence, surficial deformation, granular disintegration, cracking and scaling (Figure 2).

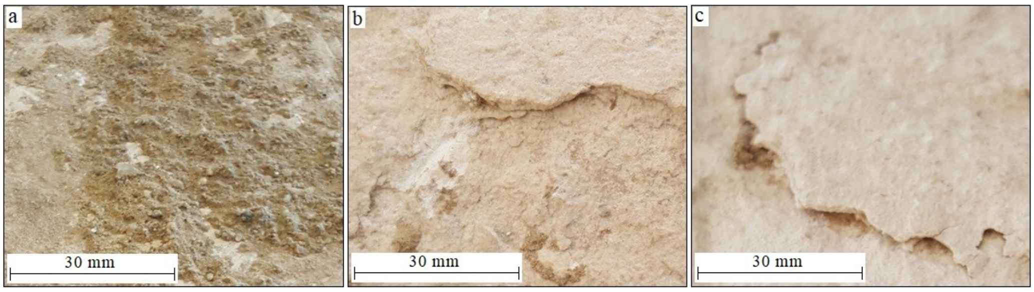

Figure 2 Deterioration aspects of the studied offering table. (a) accumulation of hard soil deposits; (b) efflorescence and surficial deformation; (c) loose parts.

Subsurface water, salts and soiling were the main factors of deterioration for the studied offering table (Cronyn, 1990). Consolidation of the studied limestone offering table is the major and most important treatment procedure for recovering its strength and increasing its durability. In recent years, nanolime is considered to be one of the most famous nanomaterials used in the treatment of calcareous materials. It has been fabricated to overcome the drawbacks of limewater that is traditionally used in the treatment of calcareous substrates (Otero et al., 2017). It is mainly composed of calcium hydroxide nanoparticles dispersed in alcoholic solvents. Nanolime has been successfully used for the consolidation of lime mortars, wall paintings, limestone, renders and plasters. Compared to traditional limewater, nanolime possesses excellent characteristics such as deeper penetration, higher carbonation rate, better consolidation effect and lower whitening of the treated surface. (Otero, Starinieri, and Charola, 2018). However, the treatment of stones with nanolime (as an inorganic material) has some limitations such as poor consolidation effect and hydrophilic characteristics, thus slightly improving the physicomechanical properties of the treated materials (Ershad Langroudi, Fadaei, and Ahmadi, 2019). In many cases, mixtures of two or more materials used in the stone consolidation achieve better results than the individual material by utilizing the specific advantages of each material (Dobrzynska-Musiela et al., 2018). The experimental study in this work aims to enhance the properties of nanolime in order to be successfully used in the treatment of the studied limestone sculpture. For this reason, three novel nanolime-based mixtures were prepared and evaluated to select the best one. Finally, treatment procedures were conducted on the studied limestone offering table based on the results of the experimental study.

MATERIALS AND METHODOLOGY

Samples

Small specimens were carefully taken from damaged parts and separated fractions of the studied limestone object. Experimental samples were collected from the weathered and fractured limestone fragments spread in the archaeological burial environment. They were cut into cubes of various sizes (3 cm^3, 5 cm^3).

Polarizing microscope

Thin sections of limestone samples were prepared in the laboratory of thin section preparation, geology department, Cairo University. Limestone samples were firstly strengthened by an epoxy resin, then fixed to glass slides. After that, the thin sections were mechanically polished

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until obtaining the desired thickness (30 microns). Prepared thin sections were petrographically studied with a Nikon eclipse LV100POL polarizing light microscope equipped with a digital camera. This examination aims to preliminarily identify the mineralogical composition, textural features and weathering aspects.

X-ray diffraction analysis

Samples of limestone affected by crystallized salts were mineralogically studied through PANanalytical X-ray diffractometer model X′Pert PRO, working with a secondary monochromator, Cu-radiation (l=1.542Å) at 45 K.V., and scanning speed 0.04^{o}/sec. Diffraction peaks were obtained in the range $2\theta = 2^{o}$ and 60^{o}. The obtained XRD pattern and relative intensities were comparatively studied with the reference database of ICDD (Stuart, 2007).

SEM investigation

Micromorphology and microstructure of the archaeological limestone specimens were investigated by Quanta FEG 250 scanning electron microscope. In addition, the efficiency of the used mixtures in consolidating the treated limestone samples was evaluated by SEM. The samples were examined without coating, and the micrographs were taken in backscattered electron (BSE) mode.

EDS microanalysis

EDS unit attached with the above-mentioned scanning electron microscope was employed for the elemental analysis of the archaeological limestone and its weathering aspects.

Nanolime-based mixtures

In the present work, nanolime was selected as the main component in the prepared mixtures due to its advantages in the treatment of calcareous materials such as physicochemical compatibility and high durability (Slizkaova, and Frankeova, 2012). The nanolime product used in the preparation of the studied mixtures is Calosil E5 which has been manufactured by IBZ-Salzchemie, Germany. It is composed of calcium hydroxide nanoparticles dispersed in ethanol with a concentration of 5 g/L and a particle size of 50-150 nm. In order to improve the properties of nanolime, it was mixed with three commercial polymers. The polymers used to prepare the mixtures are: (1) Econo-Seal (Aqua mix Inc, America) potassium methyl siliconate; (2) Eucoprotect (SwissChem Construction Materials, Egypt) acrylic-based polymer; (3) Megaprotec (Intrade chemicals, Egypt) silane and siloxane-based polymer. These three polymers are ready to use and are water-based products. Preparation of the studied mixtures was performed by mixing nanolime (Calosil E5) with each product in the proportion 3:1 by volume. Homogenous mixtures were obtained using magnetic stirring for 5 minutes. On the other hand, Calosil E5 was individually used for comparative study. Products and mixtures used in the current study are elucidated in Table 1.

Table 1 The used products and mixtures.

Symbol	Products/Mixtures	Proportion (by volume)
C5	Calosil E5	-----
CE	Calosil E5 + Econo-Seal	3: 1
CP	Calosil E5 + Eucoprotect	3: 1
CM	Calosil E5 + Megaprotec	3: 1

Application of consolidants

Firstly, experimental limestone samples were repeatedly rinsed with distilled water to remove any impurities. After that, the samples were dried in an oven for 24 hours at 105 °C, then left to cool at room temperature and weighed again. Secondly, the samples were treated with C5, CE, CP and CM by brushing. Each treatment was applied to the limestone samples three times. The treated samples were left at room temperature for 30 days until completely dried. Afterwards, the samples were weighed, and the consolidant absorption was estimated through the next equation: -

$$\text{Consolidant absorption (\%)} = \frac{Wt - W_o}{W_o} \times 100$$

Where (W_o) is the sample mass before treatment and (W_t) is the sample mass sample after treatment. The average percentages of consolidant absorption are clarified in Table 2.

Table 2 Average percentages of consolidant absorption achieved by the treatments.

Consolidant	Consolidant absorption (%)
C5	0.31
CE	0.40
CP	0.60
CM	0.49

Colorimetric analysis

A Colorimetric test was performed to identify the colour alterations that resulted from the studied treatments. Chromatic alterations between treated and control samples were assessed by an Optimatch 3100 spectrometer. The total colour change (ΔE^*) was obtained based on the following equation: -

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^*, Δa^* and Δb^* are the variations in the L*, a* and b* coordinates for the treated and control limestone samples according to CIELAB colour space (Schanda, 2007).

Static contact angle

Static water contact angle represents a useful method to evaluate the water repellency of the consolidants and protection materials (Hefni, 2020). The hydrophobic properties of treated and control limestone samples were comparatively estimated using the contact angle meter model

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Kruss Advance Drop Shape. Five measurements were performed for each treatment in addition to the control sample.

Compression strength

Compression strength was undertaken on the treated and control limestone samples to assess the consolidation effect of the prepared mixtures. Three cubic samples (5 cm^3) of each treatment were comparatively tested with the control samples.

RESULTS AND DISSCUSION

Petrographic study

The petrographic investigation (Figure 3) declared that the studied limestone is principally formed of a very fine-grained matrix of calcite (micrite) as a major component. Minor and very small amount of quartz was also observed. In addition, rare amounts of dolomite, iron oxides and opaque minerals were detected. Moreover, this examination clarified that the sample contains a significant number of microfossils which are scattered in the very fine-grained matrix of calcite. Some of these microfossils are filled with recrystallized fine-grained carbonates.

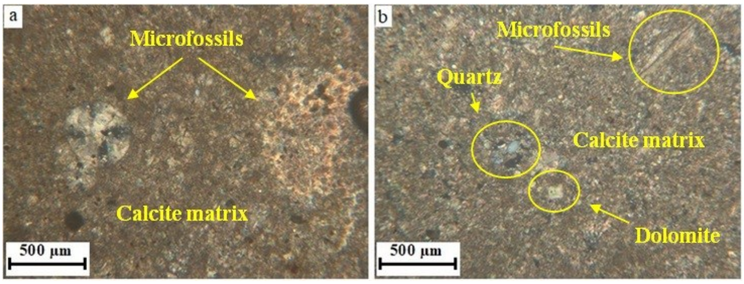

Figure 3 Micrographs of the limestone sample under cross-polarized light. (a) microfossils are scattered in a very fine-grained matrix of calcite; (b) the calcite matrix contains microfossils, rare dolomite and quartz.

Mineralogical characterization

The results of the XRD analysis (Figure 4) declared the presence of calcite (90%) as the main component of limestone. Quartz (3%) was also identified as a minor constituent in the sample composition. Moreover, small amounts of gypsum (5%) and halite (2%) were detected as weathering products. Although a small amount of dolomite was observed by a polarizing microscope, it wasn’t revealed by XRD as a result of its very low proportion in the sample. Quartz usually exists as a minor constituent in carbonate stones (Barnoos, Oudbashi, and Shekofteh, 2020). Gypsum and halite are considered to be the most common salts spread in the soil and geological formation of Saqqara (Akarish, and Shoeib, 2011). Indeed, salt weathering plays a destructive role in the damage of porous stones. It can infect the stone with many forms of deterioration such as discoloration, cracking, disintegration, erosion, flaking and finally loss of material (Ruffolo et al., 2013). Water is the major factor controlling the effect of salts on stones, as it significantly contributes to providing, solubilizing, mobilizing and precipitating salts at the surface of the stones or inside their pores (Oguchi, and Yu, 2021).

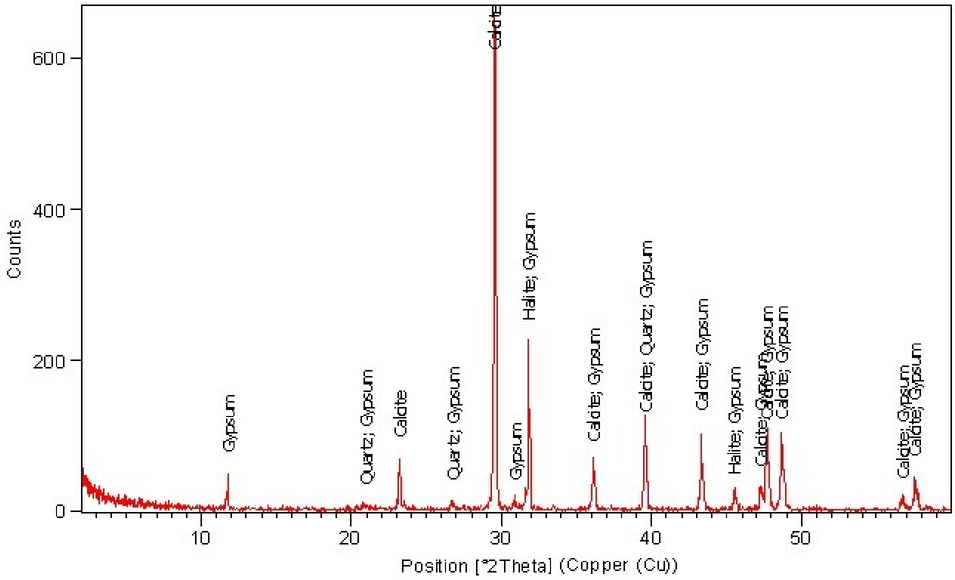

Figure 4 XRD pattern of the studied limestone shows that the sample mainly comprises of calcite in addition to minor amounts of quartz, gypsum and halite.

SEM of the archaeological limestone

A scanning electron microscope assisted in observing the microfeatures of the studied archaeological limestone. SEM examination (Figure 5a) revealed that the studied sample is significantly affected by mechanical and physicochemical weathering agents. The specimen is very friable, corroded, and disintegrated and contains a lot of voids. The high level of porosity in the stone is considered a crucial factor in its damage, as it allows the mobility of saline solutions inside its pore structure. Salt crystallization results in high internal pressure which can cause significant mechanical deformation (Ruffolo et al., 2013). The degradation caused by salt crystallization beneath and at the surficial layer of the studied limestone was obviously observed by SEM (Figure 5b).

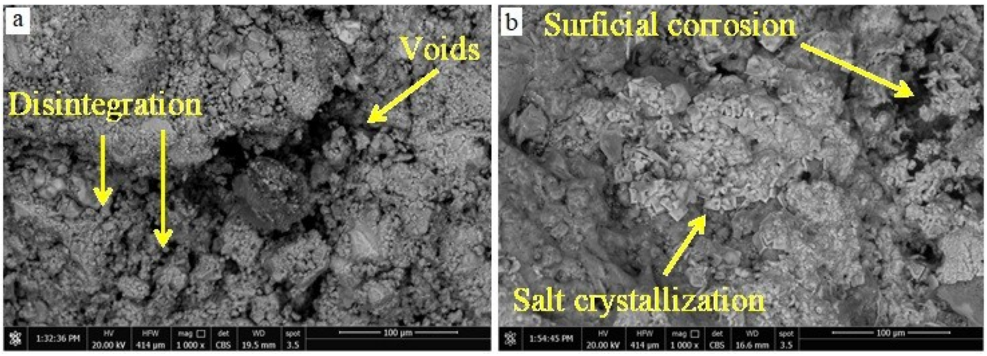

Figure 5 SEM micrographs of the studied limestone. (a) very fragile and corroded surface that is highly affected by disintegration, voids and etch-pits (b) salt crystallization beneath and at the surficial layer.

Elemental composition of the archaeological limestone

EDS spectrum showed the presence of calcium (29.26%), oxygen (43.25%), carbon (8.08%), silicon (5.49%), sodium (3.01%), magnesium (2.68%), aluminium (2.55%), sulfur (1.25%), chlorine (3.17%) and iron (1.25%). The element of sulfur confirmed the existence of gypsum

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in the sample while the elements of chlorine and sodium emphasized the presence of halite. Also, it was suggested that the presence of aluminium, magnesium and iron arose from the clay mineral impurities in the stone or the soiling materials at the excavation site. The results of the EDS elemental analysis are illustrated in Figure 6.

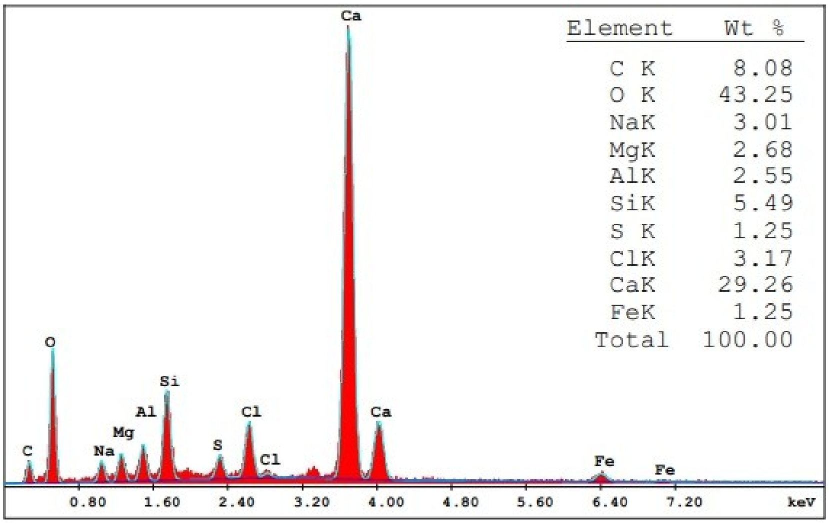

Figure 6 The results of EDS analysis of the studied limestone.

Assessment of colour alteration

The preservation of optical properties and the general appearance of the treated archaeological materials represents a significant challenge for the conservators. The optimal treatments should not cause obvious colour changes in the treated objects (Tsakalof et al., 2007). Colorimetric analysis was utilized to estimate the colour variations induced by the studied treatments. Indeed, the ideal treatment should not cause a total colour variation of more than the value of 5 (Otero, Starinieri, and Charola, 2018). The results (Table 3) elucidated that all treatments used in this study except CE are aesthetically acceptable, as they achieve a total colour change of less than 5.

Table 3 Results of colorimetric measurements.

Consolidant	ΔL*	Δa*	Δb*	ΔE*
C5	1.41	-0.78	-3.13	3.52
CE	3.43	-1.69	-6.12	7.22
CP	1.76	-1.00	-3.62	4.15
CM	0.80	-0.50	-2.45	2.63

Morphological aspects of the treated samples

SEM micrographs (Figure 7) of the treated limestone samples illustrated that all treatments applied in this study can bond the grains together and fill the voids in addition to partially closing the highly porous network. C5 led to the formation of a homogenous layer filled with tiny pores and appeared to be relatively more brittle than the other treatments. CE produced a condensed network filled with nanoparticles and had a relatively low level of porosity. CP is characterized by a good distribution inside the pores and voids as well as the formation of obvious bridges between the grains. CM formed a rough microstructural network composed of nano-protrusions.

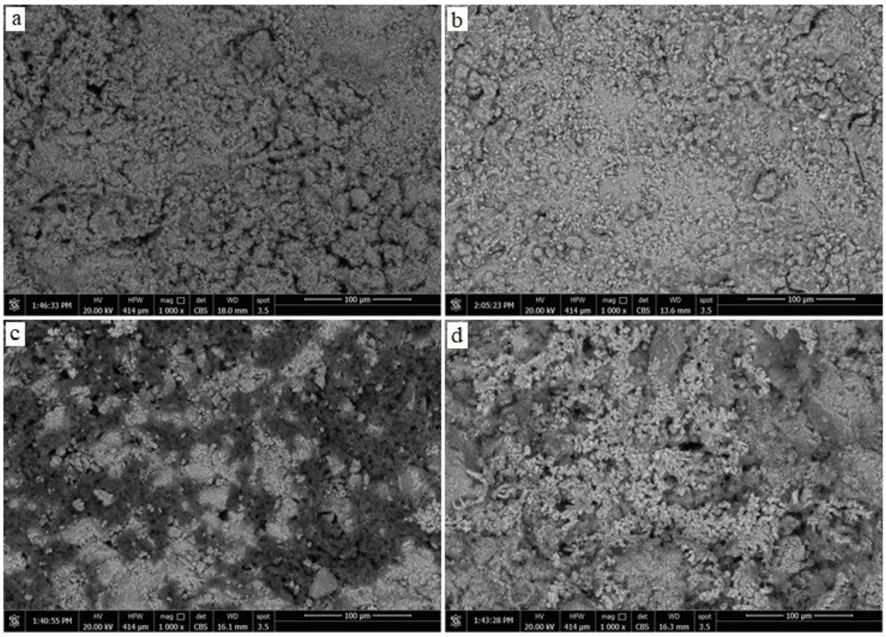

Figure 7 SEM micrographs of the treated limestone samples; (a) homogenous and porous layer produced by C5; (b) condensed network of CE mixture; (c) good distribution and bridges resulted from the CP mixture; (d) nano-protrusions and roughness achieved with the CM mixture.

Water repellency

Many studies have demonstrated that most of the damage mechanisms of stones are originated from condensed water (Tsakalof et al., 2007; Manoudis et al., 2009; Oguchi and Yu, 2021). The decreasing of moisture penetration inside the stones contributes to their preservation (Manoudis et al., 2009). The water repellency of the treated and untreated limestone samples was comparatively measured through the test of static water contact angles. The untreated sample fully absorbed the water droplets. As expected, the consolidant of C5 (Calosil E5) didn't show good results in this test, as it produced a hydrophilic layer on the stone surface. Also, it was observed that the used nanolime-based mixtures achieved better static contact angles than the individual nanolime, this is due to the hydrophobic properties of the polymers mixed with it (Torraca, 2009). CM presented an ultra-hydrophobic surface with a high static contact angle (131º) which is ascribed to: (1) the low surface tension of Megaprotec, the silicon product used in the preparation of this mixture; (2) the rough microstructural network formed on the stone surface as a result of dispersing $Ca(OH)_2$ nanoparticles in the polymer matrix. As observed from SEM micrographs, the micromorphology of CM appears to contain a lot of nano-protrusions. The trapping of air between these protrusions and the water droplets decreases their contact areas, and consequently, the ultra-hydrophobicity or super-hydrophobicity of the surfaces is produced (Manoudis, et al., 2009). This phenomenon was previously demonstrated in the Cassie-Baxter work (Cassie, And Baxter, 1944). CE resulted in the formation of a hydrophobic surface with a static contact angle (110º). However,

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CP appeared with a hydrophilic character, it had a relatively acceptable contact angle (74º). Figure 8 shows the results of static water contact angles of treated limestone samples.

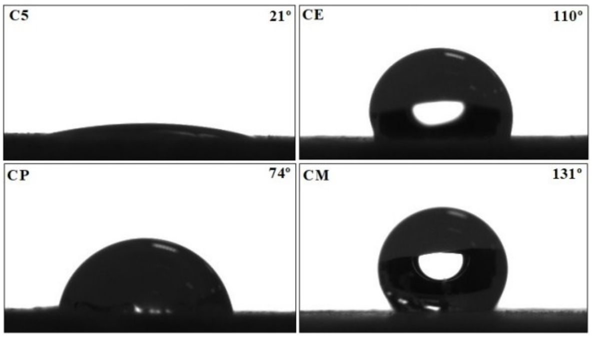

Figure 8 Static water contact angles of treated limestone samples declare the degrees of water repellency achieved by individual nanolime (C5) and the prepared nanolime mixtures (CE, CP and CM).

Mechanical performance

The consolidation treatment aims to recuperate and recover the cohesion between the grains of damaged stones, in addition to improving their mechanical properties and consequently increasing their durability (Pesce, et al., 2019). According to the data of compression strength, all the studied treatments increased the compression strength of the treated limestone samples. The treatment by C5 (Calosil E5) succeeded in improving the compression strength of limestone with an average increase of about 19.7%. The consolidation effect of nanolime (Calosil E5) depends on the reaction between $Ca(OH)_2$ nanoparticles and carbon dioxide which leads to the precipitation of calcium carbonate inside the stone voids and pores (Otero, Starinieri, and Charola, 2018). In comparison with Calosil E5, the prepared nanolime-based mixtures achieved higher values of compression strength. This is suggested to be a result of the additional consolidation effects granted by the polymers used in these mixtures. Moreover, the dispersion of $Ca(OH)_2$ nanoparticles in the used polymers matrices increases their mechanical properties and improves their interactions with the stone grains (Al-Dosari et al., 2017). Moreover, water (the solvent in polymers mixed with Calosil E5) plays a fundamental role in slowing the evaporation rate of the solvent which can decrease the back migration of $Ca(OH)_2$ nanoparticles, leading to their precipitation in-depth and thus achieve good consolidation effect. If $Ca(OH)_2$ nanoparticles back migrate, they concentrate below the treated surface and thereby the in-depth consolidation is not obtained. (Borsoi et al., 2016; Moussa, 2018; Otero et al., 2020). CP produced the highest value of compression strength with an average increase of about 72.4%. This can be ascribed to the adhesion properties of the acrylic polymer used to prepare this mixture (Carretti et al., 2013). Moreover, it was found that the results of compression strength are matched with the values of consolidant absorption. Therefore, it can be suggested that the increase in consolidant absorption of the treatment contributes to its consolidating effect (Al-Omary, Al-Naddaf, and Al Sekhaneh, 2018). Table 4 shows the results of compression strength for the treated and untreated limestone specimens.

Table 4 Compression strength values of treated and untreated limestone specimens.

Consolidant	Average compression strength MPa	Average increase (%)
Untreated	34.5	---
C5	41.3	19.7
CE	45.7	32.4
CP	59.5	72.4
CM	47.6	37.9

TREATMENT PROCEDURES

The studied limestone offering table was treated depending on the results of experimental studies while complying with the conservation criteria.

Cleaning

Cleaning processes are essential and fundamental steps in the treatment of archaeological stones. They not only contribute to revealing and highlighting the artistic and aesthetic values of archaeological objects but also play a vital role in their preservation by removing the harmful materials from their surfaces (Ashurst, 2009).

Mechanical cleaning

Undoubtedly, mechanical cleaning techniques represent the safest and most controlled methods for the cleaning of archaeological materials. The treated object was mechanically cleaned using a selective set of hand tools such as a manual blower, brushes, scalpel, and wooden and metal carving tools (Orabi, and Ahmed, 2020). These hand tools helped in removing dust, sand and various soil deposits from the surface of the offering table, as well as reducing all the solid and calcified sediments (Figure 9a, b, c, d). A combination of ethyl alcohol and distilled water softened the very hard deposits and facilitated their mechanical removal. It is worth mentioning that fragile and separated parts were primarily consolidated before conducting mechanical cleaning.

Chemical cleaning

Chemical cleaning processes were applied to the studied object to clean the hard deposits which were too difficult to be cleaned by mechanical cleaning without damaging the object's surface. Cotton poultices saturated with a solution of acetone and distilled water achieved good results in removing the hard deposits (Figure 9e). These poultices were used five times. Then the solution was locally applied until the complete cleaning occurred (Figure 9f).

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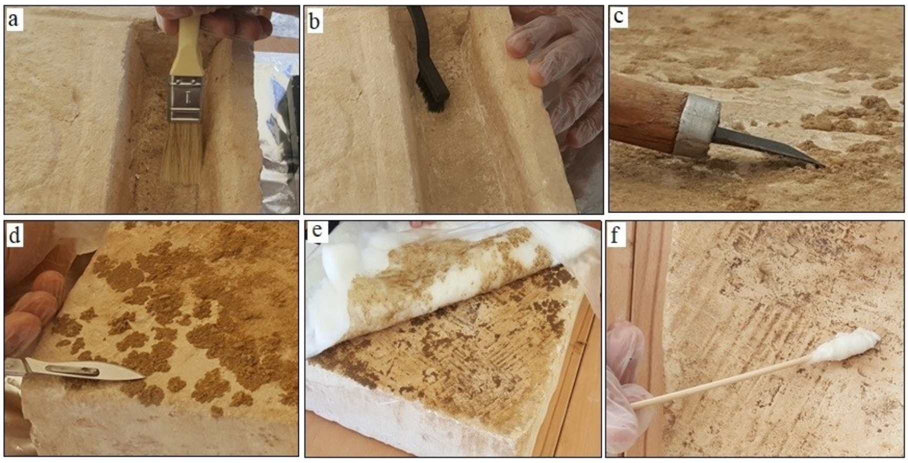

Figure 9 Different stages of mechanical and chemical cleaning. (a, b) mechanical cleaning using brushes; (c, d) mechanical cleaning by carving tool and scalpel; (e) chemical cleaning using cotton poultice saturated with a solution of acetone and distilled water; (f) local application of chemical cleaning.

Extraction of salts

The salt was alternately removed by mechanical and chemical cleaning. A thick layer of the salts deposited on the stone surface was mechanically removed using a scalpel (Figure 10a). Then, chemical cleaning of the gypsum salts was conducted using a cotton poultice saturated with a solution composed of 60 g ammonium bicarbonate, 60 g sodium bicarbonate, 25 g EDTA in 1000 ml of distilled water (Figure 10b). This poultice is prepared based on the formula of Mora AB57 poultice. After that, the surface was locally cleaned with distilled water to remove any residues of the used chemical solutions (Ashurst, 2006).

Figure 10 Extraction of salts. (a) using a scalpel for the mechanical removal of salts; (b) using a cotton poultice saturated with a chemical solution.

Consolidation

According to the data of the experimental study, it was observed that the mixture of CM is very suitable for consolidating the studied limestone object. The consolidation process was performed by applying three applications of CM mixture to the studied object using a brush. Small cracks, flakes and cavities were injected by a suitable syringe. Big cavities under the loose flakes were fixed with a composite containing a suitable amount of lime powder added to the CM mixture. Figure 11 illustrates some consolidation procedures, while Figure 12 shows the studied offering table before and after treatment.

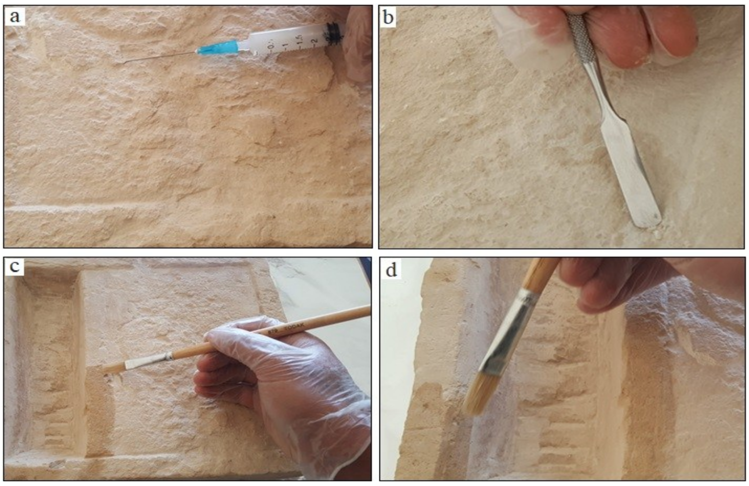

Figure 11 Different steps of consolidation. (a) injection of flakes with CM mixture; (b) filling the big cavities with a paste composed of CM mixture and lime powder; (c, d) brushing the object with the CM mixture.

Figure 12 The studied offering table before and after treatment.

CONCLUSION

Based on the visual observation and analytical study, the studied limestone offering table suffered from physicochemical and mechanical deterioration factors. The dominant damage aspects were soiling, salt efflorescence, disintegration, flaking, fragility, and loss of integrity. Mechanical and chemical cleaning methods were successfully employed to clean the object from the layers of soil and salt crystals. Due to the high fragility and disintegration of the treated object, the consolidation process represented the primary and most crucial challenge in the treatment. In order to utilize the excellent properties of nanolime (Calosil E5) and overcome its limitations, nanolime-based mixtures were prepared and experimentally studied. Individual nanolime was also used for comparative study. The results showed that mixing nanolime with the selected water-based polymers greatly improves its properties by producing compatible nanolime/polymer mixtures characterized by higher consolidation effect and better water repellency and not causing aesthetical changes to the treated stones. The mixture of CM (Calosil E5 + Megaprotec) was selected for the consolidation of the treated object, as it had the lowest value in colour change and the highest degree of water repellency. Moreover, it increased the mechanical performance of the treated samples.

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