Effectiveness assessment of paraloid B-72 enhanced with Nano materials to improve of mortars properties for conservation of Seti I temple in Al-Qurna, Thebes west bank, Egypt

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Research Article

Keywords: Luxor west bank, Seti I temple, Sandstone, Mortars, Paraloid B72, Nano silica, Nano lime, SEM-EDS, XRD

Posted Date: February 13th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2409498/v2

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Multiscale and Multidisciplinary Modeling, Experiments and Design on March 31st, 2023. See the published version at https://doi.org/10.1007/s41939-023-00152-1.

Abstract

This paper presents an experimental study to assessment of the potential effectiveness of four consolidation treatments performed with: Nano silica 5% dissolved in water, Nano lime 5% dissolved in ethanol, Paraloid B72 3% dissolved in toluene enhanced with Nano silica 5%, and Paraloid B72 3% dissolved in toluene enhanced with Nano lime 5% to improve the physical and mechanical properties of proposed completion mortars that will use to compensation of the missing parts of the sandstone. The experimental samples were exposed to artificial ageing cycles and investigated by several scientific techniques such as; X-Ray Diffraction (XRD), Polarized light microscope (PLM), Scanning Electron Microscopy (SEM) coupled with X-ray energy dispersive system (EDS), and the physical and mechanical properties tests to determine the appropriate mortar for the completion process. Results of this study indicated that the mortar which consolidated by 3% of paraloid B72 enhanced with 5% of Nano silica and 3% of paraloid B72 enhanced with 5% of Nano lime achieved the best results.

1- Introduction

The ancient site of Gebel el Silsila is located in Upper Egypt, between Kom Ombo and Edfu, at the Nile's narrowest point. Once a cataract-like location, the site is now divided into east (Gebel el Silsila) and west (Ramadi Gibli) portions, each with historic quarries stretching 2.5 and 5 km down the Nile (including the northern site of Nag el Hammam). The concession covers roughly 30 km. Gebel el Silsila is well-renowned for its numerous New Kingdom stelae, burial shrines, and the rock-cut temple known as the Speos of Iswap. It was also ancient Egypt's greatest sandstone quarry, which supplied the most coveted blocks for the ancient architects. It was also ancient Egypt's greatest sandstone quarry, which supplied the most sought-after blocks for the construction of some of the world's most famous temples, including Karnak, Luxor, The mortuary temple of Seti I, Ramesseum, Dendera, Edfu, Kom Ombo, and many more. Furthermore, Gebel el Silsila has been preserved with not just evidence of ancient extraction processes and transportation techniques [1, 2].

Sandstone is the basic building material that was used in the construction of most pharaonic monumental buildings in Upper Egypt, Most of these buildings suffer from continuous and different factors of damage; all of these factors combine to form a complex damage mechanism that negatively affects the basic building material used in the temples [3]. The ability of sandstone to absorb moisture from the air or soil allows salt solutions to penetrate its pores, causing physiochemical damage, especially when the dissolved salts crystallise in the stone's pores, causing cracks in the stone's structure due to internal pressures [4]. The dissolved salts react with the sandstone's components, leading to the disintegration and separation of the binding material [5, 6]. When the water evaporates, the interaction products are deposited on the stone surface. Due to the continuous loss of the binding materials of the mineral crystals, an external crust forms on the stone's surface. When the hard crust falls off, the stone is exposed to continuous bleeding of its components [7]. If the physicochemical reactions continue, the rate of stone material loss will become extremely dangerous [8].

The mortuary temple of Seti I at Al-Qurna has been suffering from several deterioration factors, such as the high groundwater level, contaminated sewage water, variation between temperature and relative humidity, and urban trespasses. All of these factors contributed to the occurrence of various types of sandstone weathering. Many studies confirm that stone repair materials fail due to incompatibility between their properties and those of the monument [9]. In addition to the high groundwater level in the studied area, which is regarded as the primary cause of mortar alteration and deterioration and results in chemical dissolution, mechanical erosion, and physical damage, The paraloid B72 is the most widely used resin in the consolidation of building materials. Many recent studies have confirmed the benefits of paraloid in various conservation procedures.

When testing or evaluating new products, paraloid is frequently used as a reference because of its relative stability, transparency, mechanical resistance, and reversibility [10]. Baraloid B72 is a 70/30 copolymer of ethyl methacrylate (EMA) and methyl acrylate (MA). However, research of the commercial product using GC–MS (gas chromatography–mass spectrometry) indicated that an additional component, butyl methacrylate (BMA), made up approximately 2% of the composition [11, 12]. A less volatile solvent, such as toluene, improves the degree of resin penetration into the material, allowing it to be effectively consolidated.

Nanomaterials and synthetic nanocomposites have recently gained popularity in the consolidation and improvement of the properties of archaeological building materials, particularly mortars, which are heavily influenced by the damage factors outlined above. Many recent studies [13, 14] have confirmed that Nano silica and Nano titanium improved the effectiveness of building material consolidation and strengthening, as well as the preparation of restoration mortars. Nano silica and Nano titanium have been shown in studies to improve the consolidation efficiency and strength of ancient building materials. These nanomaterials were also very effective in the preparation of the restoration mortars [15, 16]. The addition of calcium carbonate nanoparticles ($CaCO3$) to an acrylic-based polymer (EMA/MA) improved its physiochemical and mechanical properties, allowing it to be used in the consolidation and protection of limestone monuments, when compared to those treated with polymer without the nanoparticles; the polymer containing $CaCO3$ nanoparticles could significantly reduce water absorption rates inside stone bulk while also improving stone durability [17, 18]. When particle size is reduced to the nanoscale, materials with the same chemical composition have better characteristics than those with larger grain sizes. The nanoparticles dispersed in polymers used in consolidation and protection procedures enhance the effectiveness of materials used to extend the life of stone monuments [19, 20]. The growing awareness of monumental building deterioration, as well as the threat of irreversible cultural heritage loss, has prompted significant conservation efforts on cultural heritage all over the world. By reviewing the points of agreement and differences between the previous studies, we point out that the current study agrees with the previous studies in its main subject and general objective, but it differs from them in several aspects that represent the scientific gap that the study addresses, which is to improve the properties of the mortars used in sandstone restoration. The current study aims to evaluate a number of nanomaterials added to Paraloid B72, which has been used to improve the physical and mechanical properties of restoration mortars to conform with the properties of sandstone used as a basic building material in Seti I's mortuary temple in Al-Qurna on Luxor's west bank in Upper Egypt. This temple has been affected by several deterioration factors, the most important of which is the high level of ground water, which led to the occurrence of several damage aspects such as granular disintegration, loss of stone material, flaking of stone layers, etc.

In this research, the most important tests were carried out in order to evaluate the potential use of adding nanomaterials and nanocomposites to the mortars for the restoration and consolidation of the sandstone used in Seti I Temple. The properties of the treated mortar samples were evaluated comparatively by using different methods; the selected products were tested under artificial aging. A scanning electron microscopy (SEM) examination is performed to evaluate the morphology of the surface and the homogeneous distribution of consolidation materials used on the mortar's surface. Improvements in the mortars' mechanical properties were evaluated by compressive strength tests. Improvements in the mortars' physical properties were also evaluated by physical properties tests, such as bulk density, porosity, and capillarity water absorption. In this paper the study was oriented by the following hypotheses:

- Before any intervention procedures, the building must be examined using several scientific methodologies, according to international conventions.
- To ensure the preservation and survival of the archaeological building, it is necessary to improve the properties of building materials that have been deteriorated as a result of the influence of various weathering factors.
- This study relied on experimental scientific methodology.

2- THE MORTUARY TEMPLE OF SETI I

The mortuary temple of Seti I (19th Dynasty, 1314–1304 B.C.) at West Thebes was inscribed as a World Heritage Site (UNESCO) in 1979 as a part of ancient Thebes and its Necropolis. It is located nearly 670 km south of Cairo in the Theban Necropolis in Upper Egypt, the construction of this temple was begun in the 13th century BC by Pharaoh Seti I and completed by his son Ramesses II.

the most northerly of the Theban mortuary temples, and situated just past the road to the Valley of the Kings, towards the village of el-Tarif, its location Latitude: 25°43'57", Longitude: 32°37'42.96", it was reached by a canal that extended from the Nile along the main overland road on the West Bank that led to Deir el-Bahari, The temple and his other temple at Abydos, as well as the reliefs in his tomb in the Valley of the Kings, embody and rank among the finest ever executed), architectural, constructional, religious, and astronomical values.

The mortuary temple of Seti I was the first destination in the procession known as "The Beautiful Feast of the Valley" because of its location on the West Bank, a privilege it retained until the Roman Empire. It was accessible via a canal that ran from the Nile to Deir el-Bahari on the West Bank's main overland thoroughfare. Many Theban temples were reused after the New Kingdom period, and the temple was utilised as a work location for artists during the Roman period, and then later during the Coptic era, elements of the temple were turned into a church and houses (in the northern courtyard). During the Roman era, portions of the temple's materials were also employed in other construction projects [21, 22]. Recent excavations have uncovered much of the outer complex of the temple, with its rows of storage magazines to the north of the site and reconstructed walls and plinths in the courtyards. On the south side of the temple is a little sacred pool that is now dry. Most of the frontal courts and pylons are in ruins, and just beyond the eight remaining columns of the colonnade are three doors leading to the inner part of the temple. This temple was swept away by flash floods in ancient times, and only about 47 metres remain of its original length of 158 meters, including the area of the sanctuary, halls, and antechambers. The temple was originally encircled by a mud brick enclosure wall with tower buttresses at regular intervals. The tripartite structure of this temple, which faces east towards Karnak, is unique. Two open courtyards make up the outer and middle parts. The enormous pylons that once stood at the front of the outer perimeter have all but vanished. A pair of huge sphinxes stand just within and against the inner half of the pylons; however, only their pedestals and a few fragmentary elements survive (Fig. 1). The temple has been damaged by earthquakes and ancient flash flooding since ancient times, and it continues to be damaged by factors and causes of deterioration such as groundwater raising, urban trespasses and man-made destruction, pollution and infection of groundwater beneath the temple and its surroundings, and increased plant growth. This temple has not gotten enough attention from conservation experts. Any negative changes that may affect the structural behaviour of the structure due to increased mechanical effects or a reduction in the structural efficiency of the building elements due to the impact of various damage factors are referred to as "structural damage." In most cases, the damage is exacerbated by the monumental buildings' structural design, which is inadequate for seismic stresses. Many historic structures were severely damaged, with some even collapsing (totally or partially). The seismic action, the differential settlement of the soil due to the variability of the water table, and the disintegration of the materials are three sources of structural damage to the monuments, which influence the buildings [23, 24]. Many symptoms of deterioration were monitored during field visits to the case study, such as loss of stone material, granular disintegration, exfoliation of the surface, and salt crystallization, which induces granular disintegration and scaling of the stone, where the degradation pattern is called flaking, the most important of which is the presence of loss in building material (sandstone), which necessitates work to complete the missing parts in accordance with international conventions in order to conserve the monument and guarantee its continuity (Fig. 2).

3- MATERIALS AND METHODS

3.1-MATERIALS

3.1.1- Sandstone

Sandstone samples were collected from the detached and fallen parts of the walls of the Seti I temple located at Qurna. The sample (A) was taken from the base of the columns in front of Hypostyle Hall; the samples (B, C) were taken from the western wall of Hypostyle Hall; and the sample (D) was taken from the eastern wall of Hypostyle Hall.

3.1.2- Preparation of experimental samples

3.1.2.1- Mortars samples

Two restoration mortars were selected for sandstone repair material. The first mortar (RM1) consists of coarse grains of sandstone with a binder/aggregate ratio of 1:3 (v:v), a water/lime ratio of 1:6 (w:w), and a 2mm maximum aggregate dimension of sand.

The second mortar (RM2) consists of a fine mortar with fine grains of sandstone and a binder/aggregate ratio of 1:1 (v:v), a water/lime ratio of 1:1 (w:w), and a 1 mm maximum aggregate dimension of sand.

The mortar consists of the following materials:

Essential binder materials:

Lime is formed as a result of the calcination of limestone by heating it at a temperature between 950 and 1050°C and then turning it into a powder by extinguishing it with water.

Secondary binder materials:

Red brick powder

It contains various formations of mineral oxides, but the most important of its formations are silica and alumina, those materials that give it the properties of hardening to obtain a hydraulic mortar (susceptible) when mixed with water, in its presence as a mixture with lime.

Limestone powder

It is a sedimentary rock consisting primarily of calcium carbonate ($CaCO_3$), which is in the form of calcite or aragonite. Limestone may also contain large amounts of dolomite, which is a mixture of calcium carbonate and magnesium carbonate.

Filler materials:

Sand

It is one of the most important fillers in the mortar. It is a loose, incoherent rock that consists of non-clay siliceous materials and has grains of various dimensions ranging from 0.62 to 3 mm. It is composed of silicon dioxide, SiO2, in the form of quartz, and some clay minerals and iron oxides may be present with it, such as hematite and limonite, which are found in sand compounds in different proportions. Sand not only serves as a filler, but it also contributes to the hardness of the mortar. The proportion of the filler in the mortar ranges from 70 to 75% by volume.

3.1.2.2- Paraloid B72 and its Nanocomposites with Nano silica and Nano lime

All consolidation materials purchased from C.T.S Company (www.ctseurope.com), Rome, Italy, they are ready to use as a direct apply.

Paraloid-B72

It was prepared as a Co-polymer of methyl Methacrylate/ethyl acrylate (MMA/EA) monomers (Aldrich, Darmstadt, Germany) with a composition Ratio of 70/30.

CaLoSiL® E25 (Nano lime)

It is a ready to use stone consolidator, which contains calcium hydroxide Nano-particles suspended in ethanol. The particle sizes range from 50 to 250 nm, which guarantees good penetration, even in materials with low porosity. Solid calcium hydroxide layers are formed after evaporation of the solvent. These convert into calcium carbonate by reaction with atmospheric carbon dioxide. CaLoSil (Nano lime) is a commercial ready to use product of nanoparticles of lime hydrate ($Ca(OH)_2$) suspended in ethanol with a concentration of 25 gL^{-1}, according to the manufacturer's specifications.

Nano silica

It is an aqueous colloidal solution of Nano-size particles (10–30 nm). These particles, according to the product's technical sheet, are smaller than those found in acrylic micro emulsions (40–50 nm) and Nano lime (200 nm). The Nano-size silica particles bind among themselves forming a silica gel, similarly to that obtained for ethyl silicate consolidates.

According the supplier's guidelines, the commercial product has to be diluted with 1–2 parts of deionized water because it is a concentrate. Therefore, NS was directly applied in light of the substrates' destruction after 500 C^0 heating. They made sure that its polymerization at $20C^0$ takes 3 to 4 days to complete [25].

Nano composite consisted of synthesis the acrylic polymer (Paraloid-B72) with fixed concentration 3% w/v (solid content 3gm/100ml), then the Ca $(OH)_2$ nanoparticles were added during the synthesis of the polymer with concentration 5%, and SO_2 nanoparticles (concentration 5%) were added during the synthesis of Paraloid-B72 with fixed concentration 3% w/v [26, 27].

Table 1
Concentrations of consolidation materials

Consolidation materials (Code)	Ca (OH)2 nanoparticles concentration	SO2 nanoparticles concentration	Polymer solid content	The obtained nanocomposite
Nano lime (N.L)	5%	--	--	Zero nanocomposite
Nano silica (N.S)	--	5%	--	Zero nanocomposite
Nano lime (N.L) + Paraliod B-72 (P)	5%	--	3gm/ 100 ml	Ca (OH)2 nanoparticles / polymer nanocomposites (5%)
Nano silica (N.S) + Paraliod B-72 (P)	--	5%	3gm/ 100 ml	SO2 nanoparticles / polymer nanocomposites (5%)

3.2 | Methods

3.2.1| Examination and mineralogical composition

Thin sections of deteriorated sandstone samples were examined using Polarized Light Microscopy (PLM) LEITZ WETZLAR (GERMANY)), with an LEICA Cam Max. 100 W (307-148.002 -514687).

Microstructure and chemical compositions of the deteriorated sandstone samples were determined by Scanning Electron Microscope (SEM) Model Quanta 250 (FEG) Field Emission Gun (Accelerating voltage 200V-30kV Operating Voltage 5-30kV, Magnification: 30X- 300kX) coupled with X-ray energy dispersive system (EDS) with accelerating voltage 30 K. V., Magnification 14× up to 1,000,000 and resolution for Gun. In, K550X Sputter Coater, England.

3.2.2| Physical and mechanical properties of the studied samples

The physical properties tests were carried out according to (ASTM C97-18) [26] to determine the physical (bulk density, water absorption, porosity). The deteriorated sandstone samples were cut into cubes 4 × 4 × 4 cm. Then, its physical properties were measured according to the following equations;

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

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

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

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

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

The water uptake coefficient was measured in the laboratory on dry specimens following the standard test (DIN EN 1925) [28].

W-value = $\frac{\Delta m}{A\sqrt{t}}$

Where: w-value: water absorption coefficient [kg/ (m^2.h0.5)];

Δm: mass of absorbed water in time interval;

A: the area of the stone surface in contact with water [m^2]; t: time interval [h].

Compressive strength of samples were carried out according to (ASTM C170), calculate the compressive strength of each specimen carried out as follows:

C = M/A

Where; C = compressive strength of the specimen in kg/cm^2. M = Total load at which failure occurs in Kg. A = Calculated area of the bearing surface in cm^2

4- The Experimental study

4.1-Consolidation treatments of mortars samples

The mortars samples were prepared into cubes

approximately in (4 × 4 × 4 cm^3) for both types of restoration mortars. The laboratory experiments were conducted on 24 samples were selected for each type of restoration mortars to apply consolidation materials. After that, artificial ageing experiments were performed on twelve consolidated samples were selected for each type of restoration mortars which carried out the consolidation on them.

The test samples were dried in the oven at 65°C for 24 h to reach constant weight then left to cool at room temperature with RH 50%. The pure acrylic polymers and nanocomposites were applied on the mortars samples by direct contact capillary absorption on both restoration mortars (RM1 + RM2); application through direct contact when compared to alternative treatments, capillary absorption was chosen because it allows for more treatment control, consistency of results, and the ability to generate greater impregnation depths [28]. Treated samples were left for 21 days at room temperature and controlled RH 50% to allow polymerization to occur. After the polymerization was completed, the treated samples were subjected to examination by a scanning electron microscope (SEM), the physical and mechanical properties tests.

4.2- Artificial weathering

To study the effect of artificial ageing on mortars properties, the two different

Types of restoration mortars were subjected to accelerated ageing, by simulating the atmospheric conditions which occur in environment of Seti I temple. The treated samples were subjected to two experiments; the first was salt weathering and the second was simulation of the annual temperature and relative humidity, Fig. 4; [31, 32].

4.2.1- Salt weathering

The test was determined in accordance with (BS EN 12370 – 1999), which includes the following:

The samples were dried at 65°C for 24 hours to reach a constant weight, then the dry weight of samples were recorded (W_0). The experiment involves thirty cycle, each cycle is consist of the following: the samples were left to absorb NaCl / Na SO_4 solution with a concentration of 14% by a capillary absorption for 4 hours, then the samples were dried in the oven at 65°C for 18 hour, after that the samples were left to cool down in room temperature for 2 hours, after the end of the last cycle of the experiment, the weight of the samples were recorded (W_n).

Table 2 The weight of treated samples (before and after salt weathering cycles)

Samples	Before		After		Rate of weight change (decrease)	
	W0		Wn		WR %	
	RM1	RM2	RM1	RM2	RM1	RM2
Untreated	123	124	108	107	12.19	13.70
Nano lime (N.L)	130	128	123	119	5.4	7.03
Nano silica (N.S)	129	127	123	120	4.7	5.5
Nano lime (N.L) + Paraliod B-72 (P)	133	131	128	125	3.8	4.6
Nano silica (N.S) + Paraliod B-72 (P)	132	129	127	124	3.8	3.9

W (Rate of weight change) = $W_0 - W_n / W_0 \times 100$

W_0 = the weight of samples before the experiment of ageing

W_n = the weight of samples after the experiment of ageing (thirty cycle)

Table 2 The weight of treated samples (before and after salt weathering cycles)

4.2.2- (Wet- Dry) weathering

The test was determined in accordance with (BS EN 14066 – 2003), which includes the following:

The samples were dried at 65°C for 24 hours to reach a constant weight, then the dry weights of samples were recorded. The experiment involves thirty cycle, each cycle is consist of the following: the submerged samples in water were exposed to a temperature of 110°C on oven for 8 hours, then the samples were dried in the oven at 110°C for 8 hours, after that the samples were left to cool down in room temperature for 16 hour, after the end of the last cycle of the experiment, the weight of the samples were recorded by the same method such as salt weathering test.

After performing artificial ageing tests of the treated samples, the effectiveness of consolidation materials was evaluated by a scanning electron microscope, the physical and mechanical properties tests.

Table 3
The weight of treated samples (before and after (Wet- Dry) weathering cycles)

Samples	Before		After		Rate of weight change (decrease)	
	W0		Wn		WR %	
	RM1	RM2	RM1	RM2	RM1	RM2
Untreated	123	124	114	113	7.31	8.87
Nano lime (N.L)	130	128	125	122	3.8	4.7
Nano silica (N.S)	129	127	124	121	3.9	4.7
Nano lime (N.L) + Paraliod B-72 (P)	133	131	130	127	2.3	3.05
Nano silica (N.S) + Paraliod B-72 (P)	132	129	129	125	2.3	3.1

5- Results and discussion

5.1- The deteriorated sandstone samples

The examination of the sandstone samples under polarized microscope shows sandstone is composed mainly of quartz (main component), rock fragments, carbonate minerals (calcite), clay minerals (kaolinite), opaque matter, feldspar (microcline, albite), iron oxides.

Mineralogical study using X-Ray diffraction patterns, using a Philips X-ray PW 1840 diffractometer with Cu-Kα radiation generated at 40 kV and 40 mA. It covers 2θ from 5˚ to 50˚. The sandstone samples were investigated by XRD showed all samples are mainly composed of quartz (SiO_2 / 70%), Albite ($NaAlSi_3O_8$ / 4%), Calcite ($CaCO_3$ / 12%), kaolinite ($Al_2Si_2O_5(OH)_4$ / 8%), and halite (NaCl / 6%) Fig. 5.

The investigation of the deteriorated sandstone samples revealed that dissolution of binding materials occurred of the sandstone, resulting in an increase in porosity, disintegration, and loss of cohesiveness of the stone, causing the sandstone and decrease in durability of the stone.

EDX microanalysis of the sandstone samples showed that (Si / 85%), (Mg / 2.4%), (Fe / 2.5%), (Ca / 3.25%), (Al / 2.9%), (Ti / 0.04), (K / 2.05%), (Cl / 1.5%), (S / 0.65%) and (Na / 1.69%). Results of micro analysis confirmed the presence of Mg, Fe, and Ca in the deteriorated sandstone samples as a result of the presence of iron oxides, addition to the presence of Na, Ca, and Al as a result of the presence of clay minerals.

Archaeological samples have been consolidated by four consolidation treatments performed with: 5% Nano silica dissolved in water, 5% Nano lime dissolved in ethanol, Paraloid B72 3% enhanced with Nano silica 5%, and Paraloid B72 3% enhanced with Nano lime 5% to improve the physical and mechanical properties of sandstone. The investigation results showed the consolidated samples by Paraloid B72 3% enhanced with Nano silica 5% achieved the best result in coating of mineral granules, filling voids and good diffusion of polymer, in addition to the growth of deteriorated quartz crystals Fig. 5. The values of density and apparent porosity of consolidated samples refers to positive change and improvement in physical properties of sandstone samples which is represented by an increase in density and a significant decrease in the porosity, as well as a decrease in the percentage of capillarity water absorption, The physical properties of the damaged sandstone samples are shown in Fig. 7. In addition to improvement in mechanical properties of monumental sandstone, the mechanical properties of the damaged sandstone samples are shown in Fig. 8.

5.2- The restoration mortars samples

5.2.1- The treated restoration mortars

Investigation of the mortars samples by SEM revealed that treated samples with 5% Nano silica (N.S) enhanced with 3% Paraliod B-72 (P) and 5% Nano lime (N.L) enhanced with 3% Paraliod B-72 (P) have achieved the best results. SEM micrographs showed that the nanoparticles dispersed in polymers used in consolidation and protection procedures enhanced the effectiveness of materials used to improve of restoration mortars. The microscopic investigation showed that the composite nanomaterials coated the mineral grains of restoration mortars more than the individual nanomaterials Fig. 8.

The physical and mechanical properties of the treated samples are given in Table 4.

The specimens were placed in a water tank, so that the water level is maintained around 2 mm above the bottom of the specimen. The specimens were weighted on specific time intervals, which were selected depending on the type of the stone and its water absorption capacity. Highly absorbing stones (weathered stones) are weighted after 0.5, 1, 2, 4, 8, 16, 30, 60, 120, 240 and 1440 minutes. The water absorption coefficient is then calculated as the slope of the linear part of the curve depicting the amount of water absorbed per area against the square root of time. The samples treated with 5% Nano silica enhanced with 3% B72 achieved the best results, achieving an increase in density by 4% and a decrease in porosity by 30.76% compared to untreated samples, there was an increase in compressive strength by 13.5 compared to untreated samples.

Table 4
The physical and mechanical properties of the treated samples

Samples	Bulk		Porosity		W- value (Gr/cm2hr0.5)		Compressive strength (kg/cm2)	
	RM1	RM2	RM1	RM2	RM1	RM2	RM1	RM2
Untreated	1.91	1.92	23	21	3.38	3.09	150.093	140.65
Nano lime (N.L)	2	2	19.5	17.96	2.87	2.55	160.59	160.17
Nano silica (N.S)	2	1.98	18.75	17.36	2.76	2.55	170.02	160.53
Nano lime (N.L) + Paraliod B-72 (P)	2.07	2.04	17.36	16.85	2.55	2.48	170.34	160.75
Nano silica (N.S) + Paraliod B-72 (P)	2.06	2	15.92	15.62	2.34	2.99	170.45	160.82

5.2.2- The treated restoration mortars after artificial ageing cycles

After exposing the treated mortars to artificial aging cycles, they were examined with SEM, Investigation of the mortars samples after (wet-dry) cycles revealed that treated samples with 5% Nano silica (N.S) enhanced with 3% Paraliod B-72 (P) and 5% Nano lime (N.L) enhanced with 3% Paraliod B-72 (P) have achieved the best results Fig. 9. Investigation of the mortars samples after salt weathering cycles revealed that treated samples with 5% Nano silica (N.S) enhanced with 3% Paraliod B-72 is still homogeneous and coating the mineral grains Fig. 10.

The physical and mechanical properties of samples after (wet-dry) cycles are given in Table 5, the obtained results from the tests demonstrate that the treated specimens by Nano silica enhanced with 3% Paraliod B-72 achieved 3.88% decrease in density, 5.56% in porosity, increase 20.37% in W- value (Gr/cm2hr0.5), and there was a decrease in the pressure resistance value by 3.44%.

Table 5
The physical and mechanical properties of the treated samples after (wet-dry) cycles

Samples	Bulk		Decrease%	Porosity		Increase%	W- value (Gr/cm2hr0.5)		Compressive strength (kg/cm2)	
	RM1	RM2		RM1	RM2		RM1	RM2	RM1	RM2
Nano lime (N.L)	2	2	5	19.5	17.96	9.6	2.87	2.55	160.59	160.17
Nano lime (N.L)/ (Wet-Dry) cycles	1.90	1.91		21.5	19.95		3.56	3.75	150.4	150.0
Nano silica (N.S)	2	1.98	5.5	18.75	17.36	13.94	2.76	2.55	170.02	160.53
Nano silica (N.S)/ (Wet-Dry) cycles	1.89	1.87		21.6	20.35		3.98	3.95	160.5	150.5
Nano lime (N.L) + Paraliod B-72 (P)	2.07	2.04	5.31	17.36	16.85	5.22	2.55	2.48	170.34	160.75
Nano lime (N.L) + Paraliod B-72 (P)/ (Wet-Dry) cycles	1.96	1.94		18.25	17.95		3.12	3.21	160.5	150.8
Nano silica (N.S) + Paraliod B-72 (P)	2.06	2	3.88	15.92	15.62	5.56	2.34	2.99	170.45	160.82
Nano silica (N.S) + Paraliod B-72 (P)/ (Wet-Dry) cycles	1.98	1.97		16.90	16.5		3.02	3.26	160.9	160.2

The physical and mechanical properties of samples after salt weathering cycles are given in Table 6, the obtained results from the tests demonstrate that the treated specimens by Nano silica enhanced with 3% Paraliod B-72 achieved 7.36% decrease in density, 10.38% in porosity, increase 26.02% in W- value (Gr/cm 2hr0.5), and there was a decrease in the pressure resistance value by 6.04 %.

Table 6
The physical and mechanical properties of the treated samples after salt weathering cycles

Samples	Bulk		Decrease%	Porosity		Increase%	W- value (Gr/cm2hr0.5)		Compressive strength (kg/cm2)	
	RM1	RM2		RM1	RM2		RM1	RM2	RM1	RM2
Nano lime (N.L)	2	2	9.75	19.5	17.96	20.48	2.87	2.55	160.59	160.17
Nano lime (N.L)/ salt weathering cycles	1.81	1.80		24.4	22.91		5.75	5.83	140.7	140.2
Nano silica (N.S)	2	1.98	8.79	18.75	17.36	19.17	2.76	2.55	170.02	165.3
Nano silica (N.S)/ salt weathering cycles	1.82	1.81		23.23	21.45		5.98	5.96	150.6	140.6
Nano lime (N.L) + Paraliod B-72 (P)	2.07	2.04	8.27	17.36	16.85	13.85	2.55	2.48	170.34	160.75
Nano lime (N.L) + Paraliod B-72 (P)/ salt weathering cycles	1.90	1.87		20.27	19.45		4.25	4.27	160.1	150.6
Nano silica (N.S) + Paraliod B-72 (P)	2.06	2	7.36	15.92	15.62	10.38	2.34	2.99	170.45	160.82
Nano silica (N.S) + Paraliod B-72 (P)/ salt weathering cycles	1.88	1.88		17.92	17.3		3.32	3.86	160.5	150.7

6- Conclusion

This study dealt with Paraliod B-72 enhanced with nanomaterials and its effect on improving the properties of restoration mortars to bring them to a level close to the properties of sandstone. The restoration mortars were consolidated after their preparation in order to evaluate the effectiveness of the consolidation materials on the physical properties (Bulk density, Porosity, W- value) of the samples. Through the findings of the experimental study, the study recommends the use of 5% Nano silica enhanced with 3% Paraliod B-72 and 5% Nano lime enhanced with 3% Paraliod B-72 as additives to improve of physical properties of restoration mortars. The study concluded that the polymer containing $Ca(OH)_2$ nanoparticles and Nano silica could significantly reduce water absorption rates inside mortars bulk while also improving material durability, SEM micrographs showed that the nanoparticles dispersed in polymers used in consolidation and protection procedures enhanced the effectiveness of materials used to improve of restoration mortars. After finish artificial ageing cycles the microscopic investigation showed that the restoration mortars samples treated with 5% Nano silica enhanced with 3% Paraliod B-72 were slightly affected compared to the individual nanomaterials. The physical and mechanical properties of samples showed 5% Nano silica enhanced with 3% Paraliod B-72 achieved the best results compared to the individual nanomaterials.

Declarations

Conflict of Interest:

The author declares that they have no conflict of interest.

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Figures

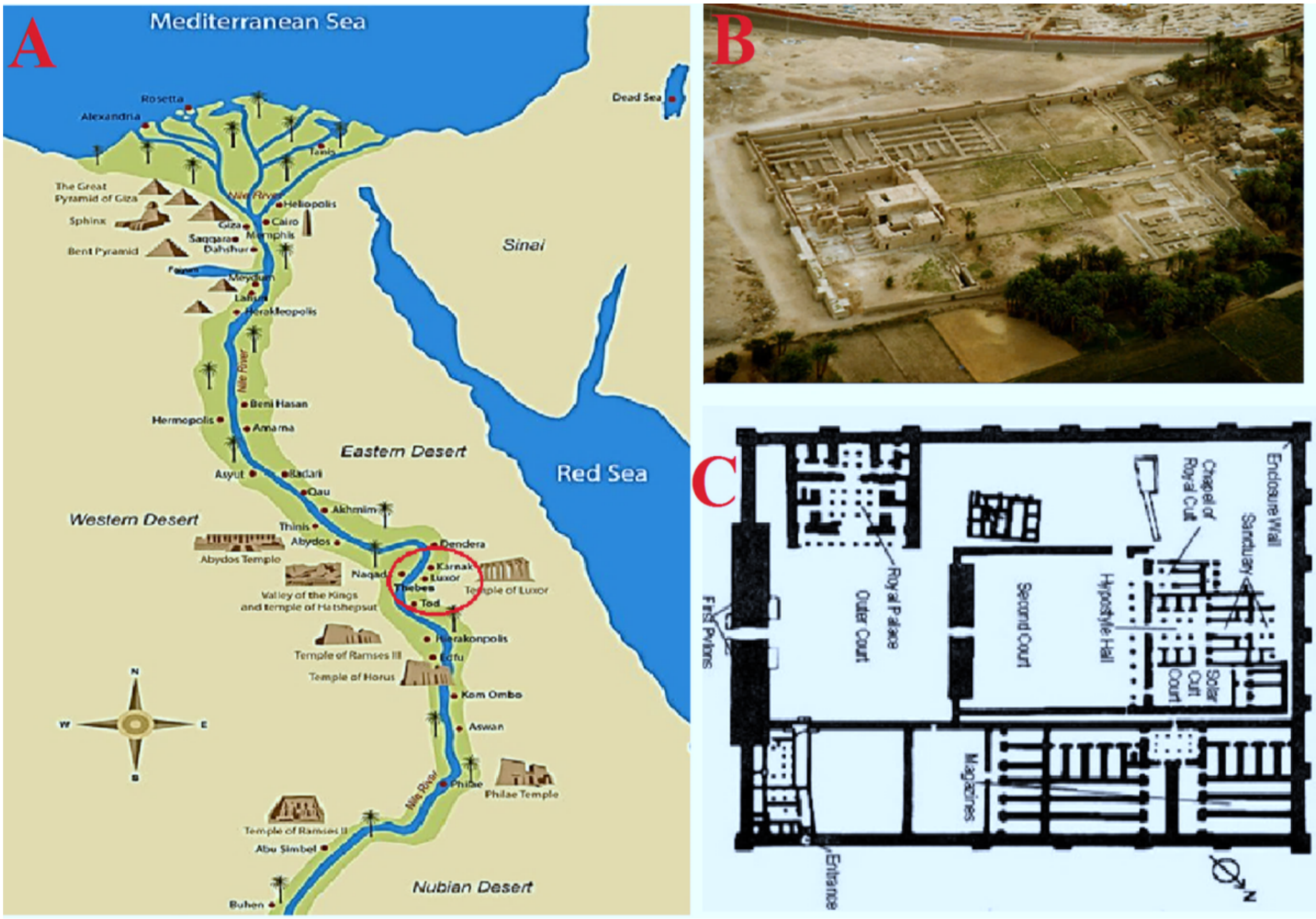

Figure 1

(A) Egypt map, the circle indicates the site of Thebes; (B) General view of Seti I temple and its urban surrounding (After; Google maps); (C) horizontal projection of Seti I

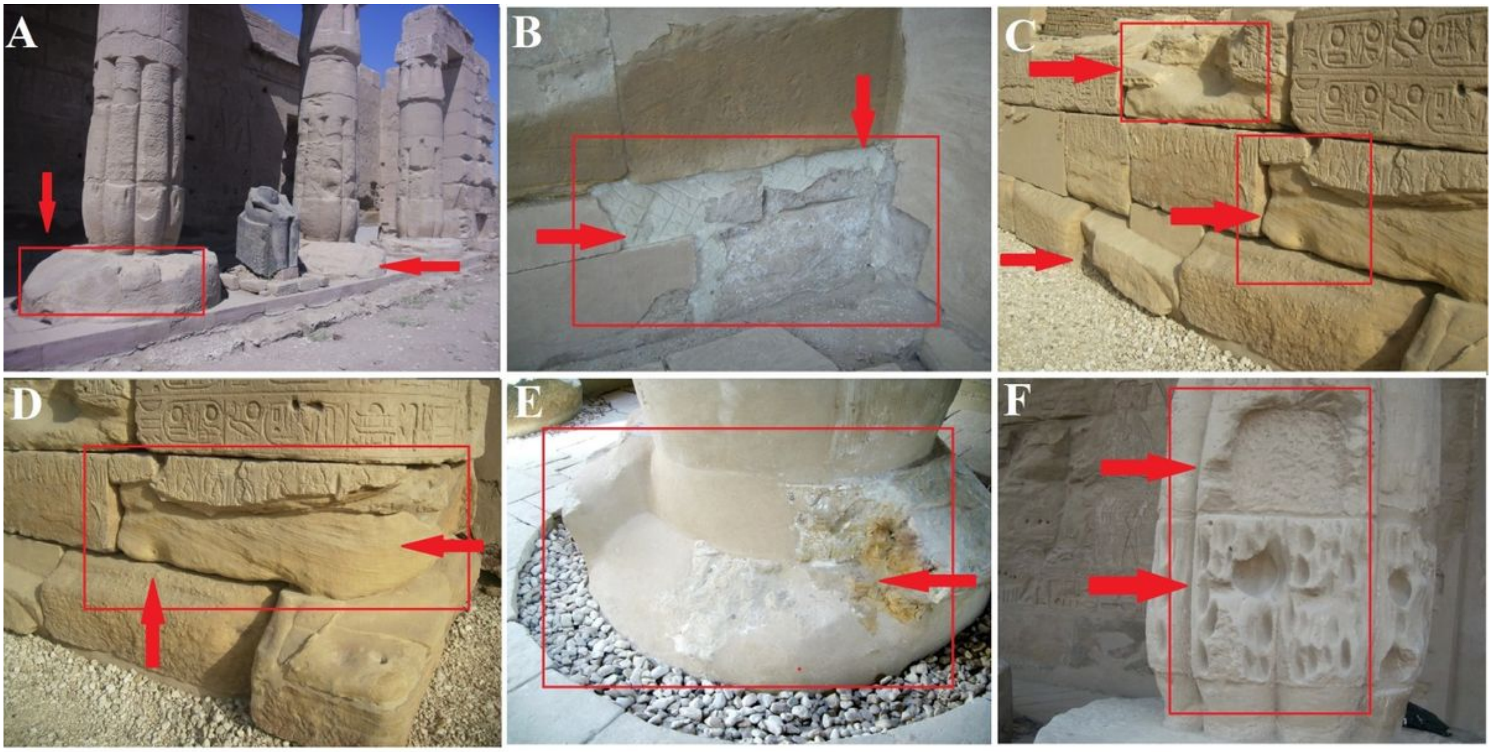

Figure 2

Different deterioration symptoms of Seti I temple (A) weathering out of columns bases. (B, E) Weathering and deterioration of repair mortar of sandstone. (C, D) Loss of stone material as a result of the effect of stone components and their interaction with external factors. (F) Weathering due to anthropogenic impact.

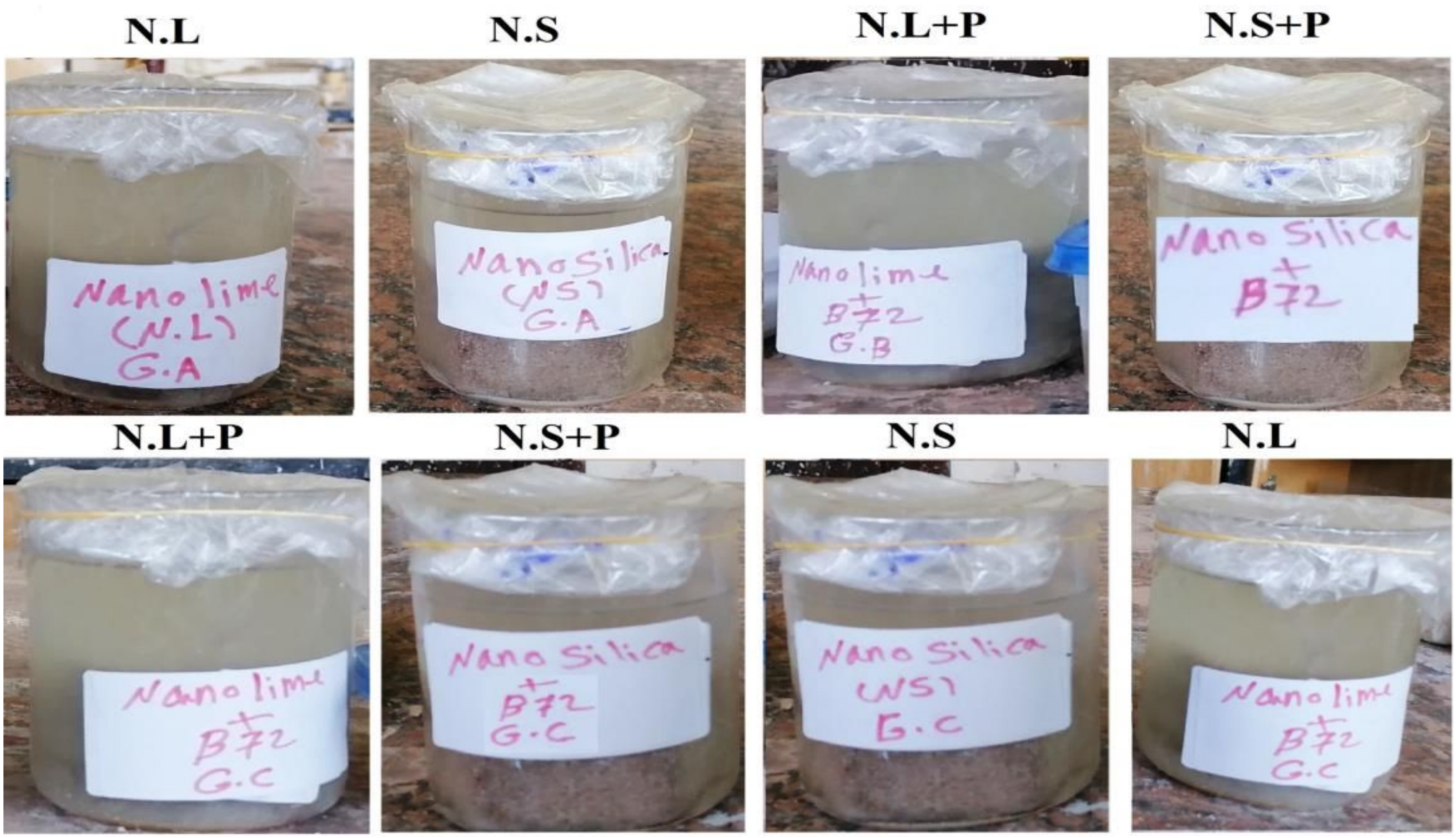

Figure 3

Consolidation treatments of mortars samples (RM1 + RM2)

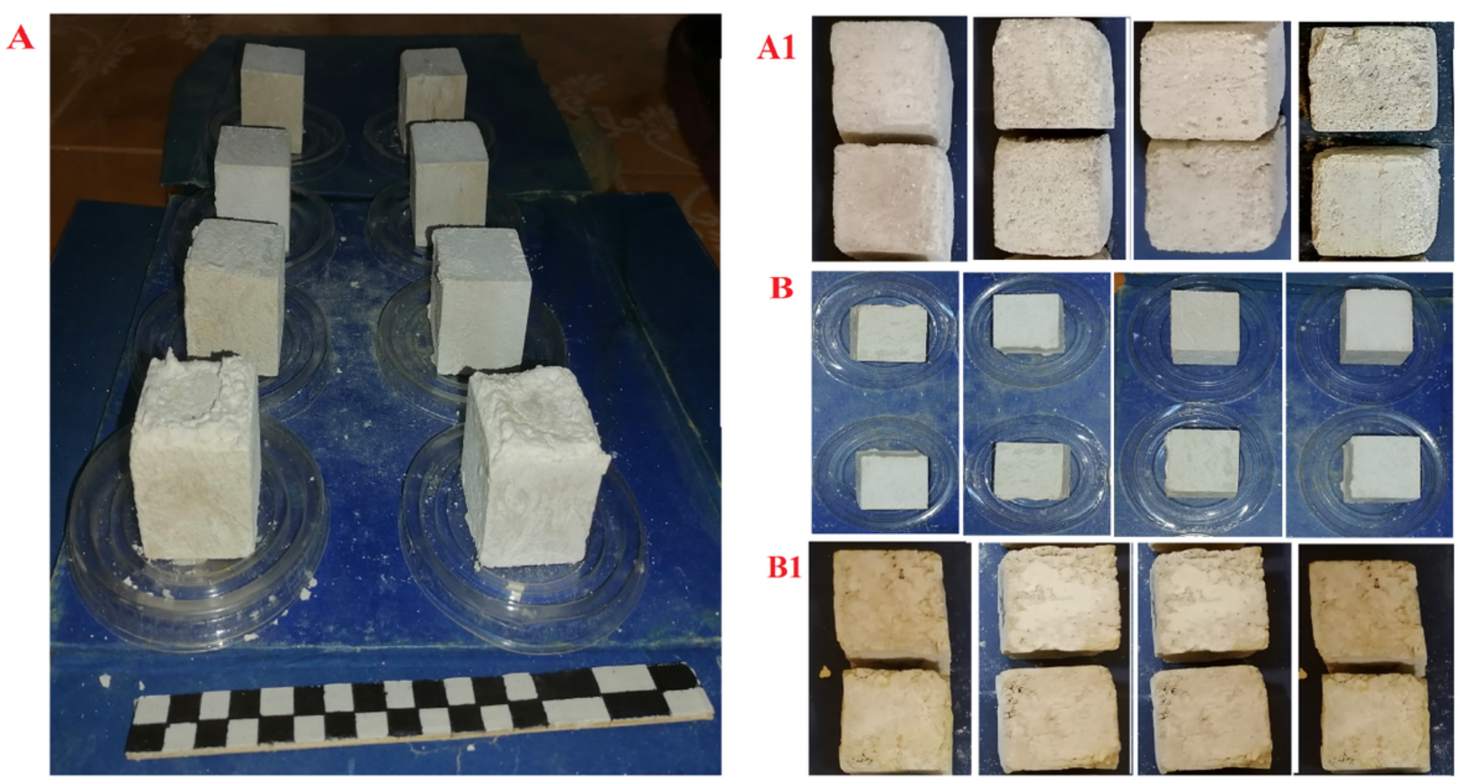

Figure 4

Consolidation treatments of mortars samples (RM1 + RM2) after artificial ageing cycles. (A, A1) the mortars samples after salt weathering cycles, (B, B1) the mortars samples after (wet-dry) cycles.

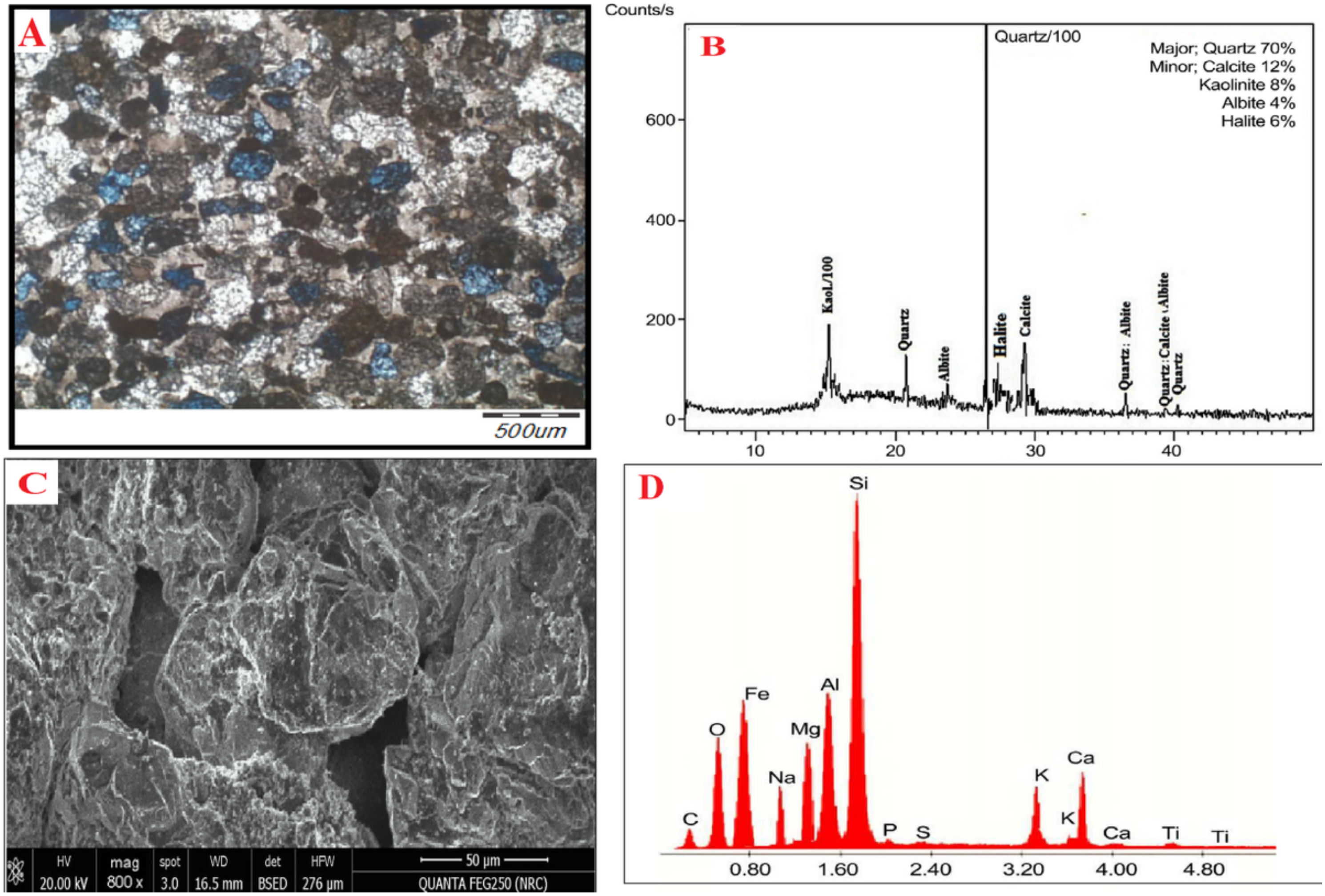

Figure 5

Thin section photomicrographs of deteriorated sandstone, (A) showing quartz grains that are medium to coarse-grained, rounded to surrounded, and presence iron oxides cement, addition to heavy minerals. (B) XRD pattern of deteriorated sandstone. (C) SEM micrographs of the studied sandstone, showing erosion in quartz crystals and abundance of salts.

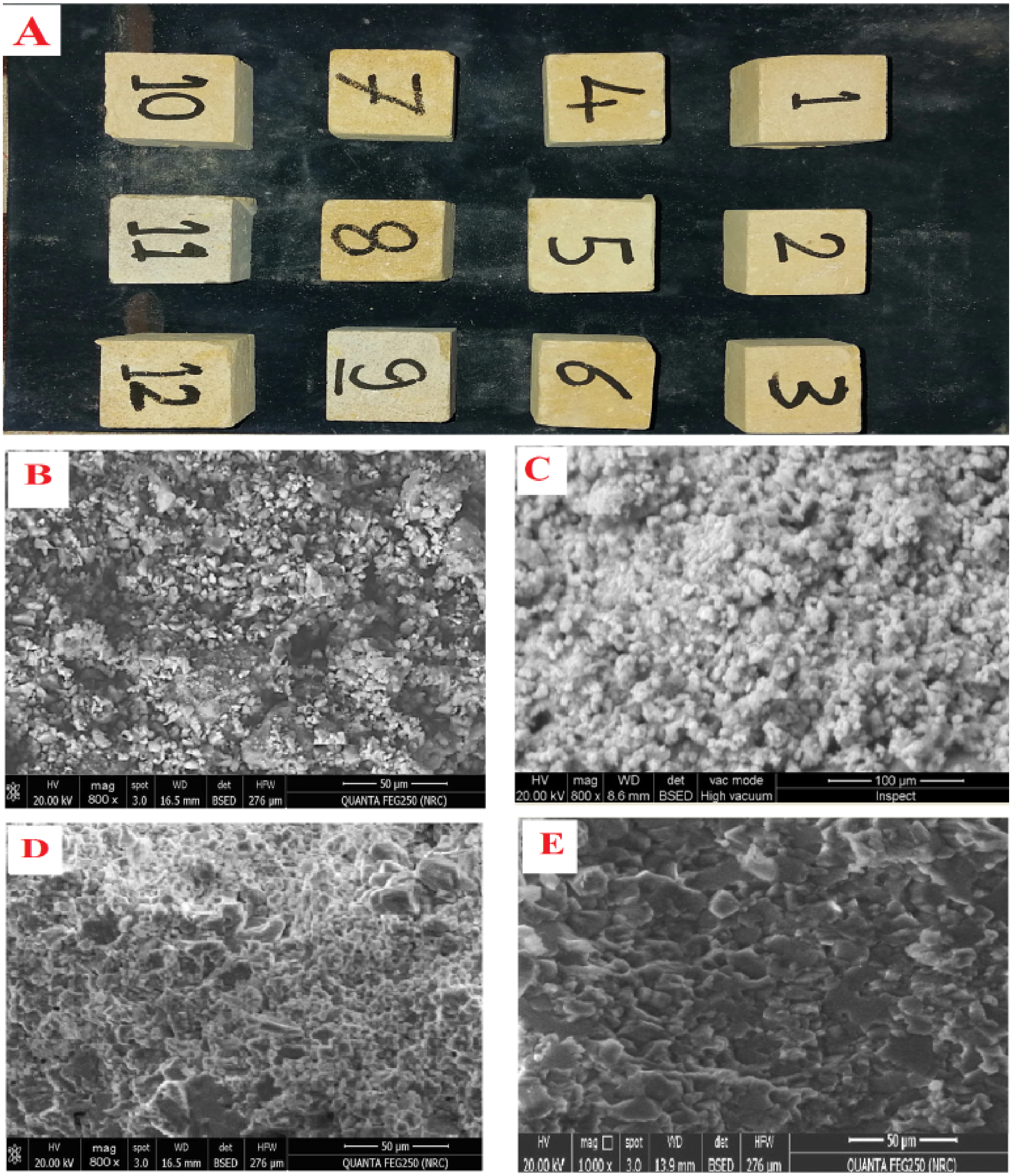

Figure 6

SEM micrographs of the monumental sandstone. (A) Archaeological samples. (B) A good dispersion of Nano lime inside internal structure of material. (C) A good coating of mineral grains by Nano silica. (D) A good dispersion of Nano lime enhanced with 3% Paraliod B-72 (E) A good coating and dispersion of Nano silica enhanced with 3% Paraliod B-72 inside internal structure of stone.

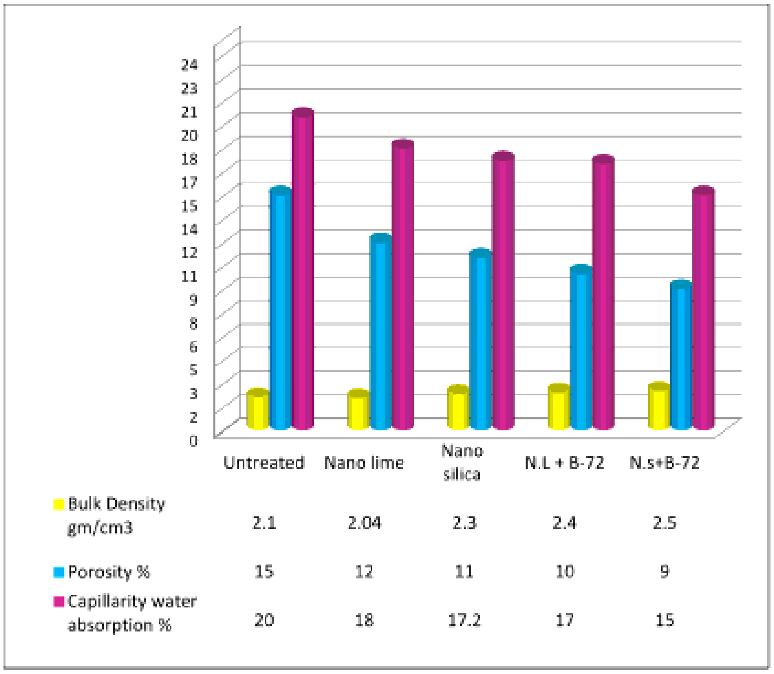

Figure 7

The physical properties of the damaged sandstone samples

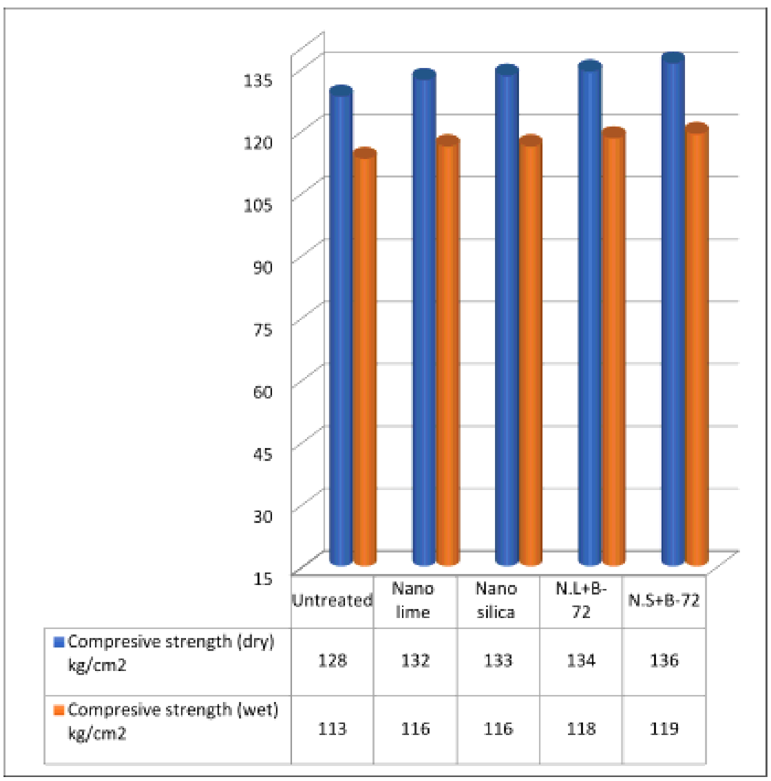

Figure 8

The mechanical properties of the damaged sandstone samples

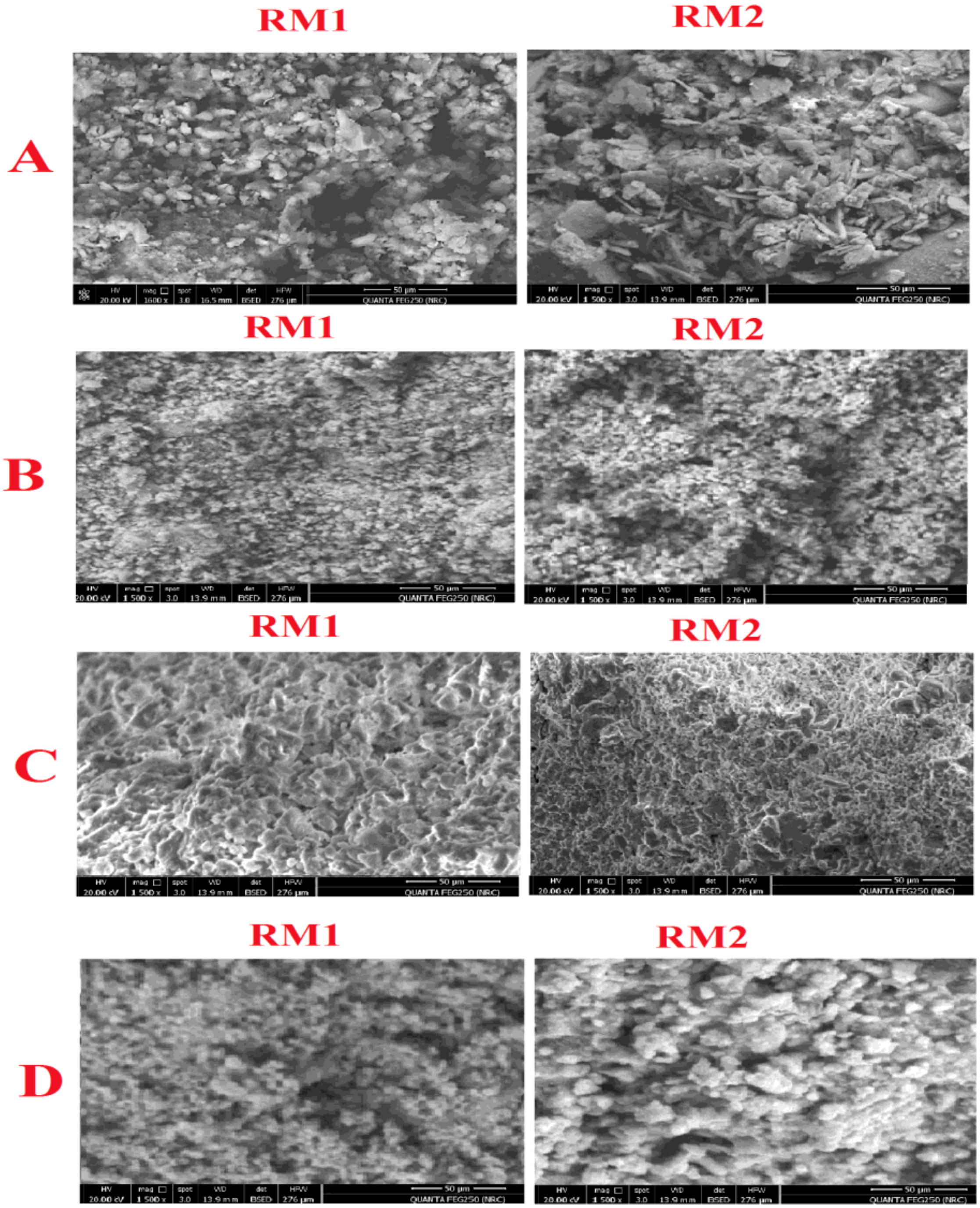

Figure 9

SEM micrographs of the treated restoration mortars. (A) Mineral grains coated of Nano lime and a good dispersion of nanoparticles. (B) A good dispersion of Nano silica inside internal structure of material. (C) A good coating of mineral grains by Nano lime enhanced with 3% Paraliod B-72. (D) A good dispersion of Nano silica enhanced with 3% Paraliod B-72.

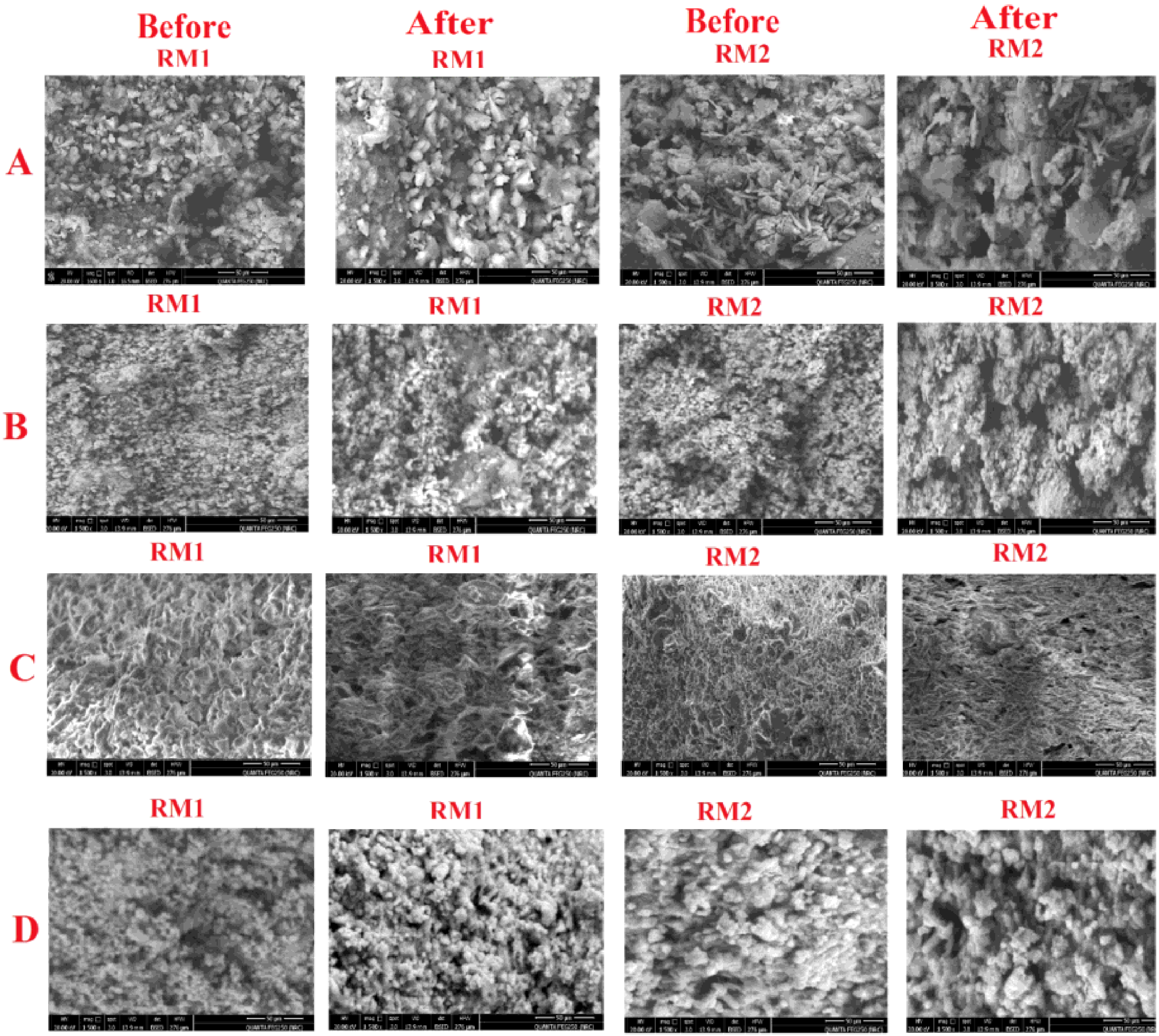

Figure 10

SEM micrographs of the treated restoration mortars before and after (Wet-Dry) cycles. (A) Nano lime exposed a slight shrinkage due to the effect of ageing cycles. (B) A good dispersion of Nano silica inside internal structure of material with a little shrinking in places. (C) Nano lime enhanced with 3% Paraloid B-72 is slightly affected of ageing cycles. (D) A good dispersion of Nano silica enhanced with 3% Paraliod B-72.

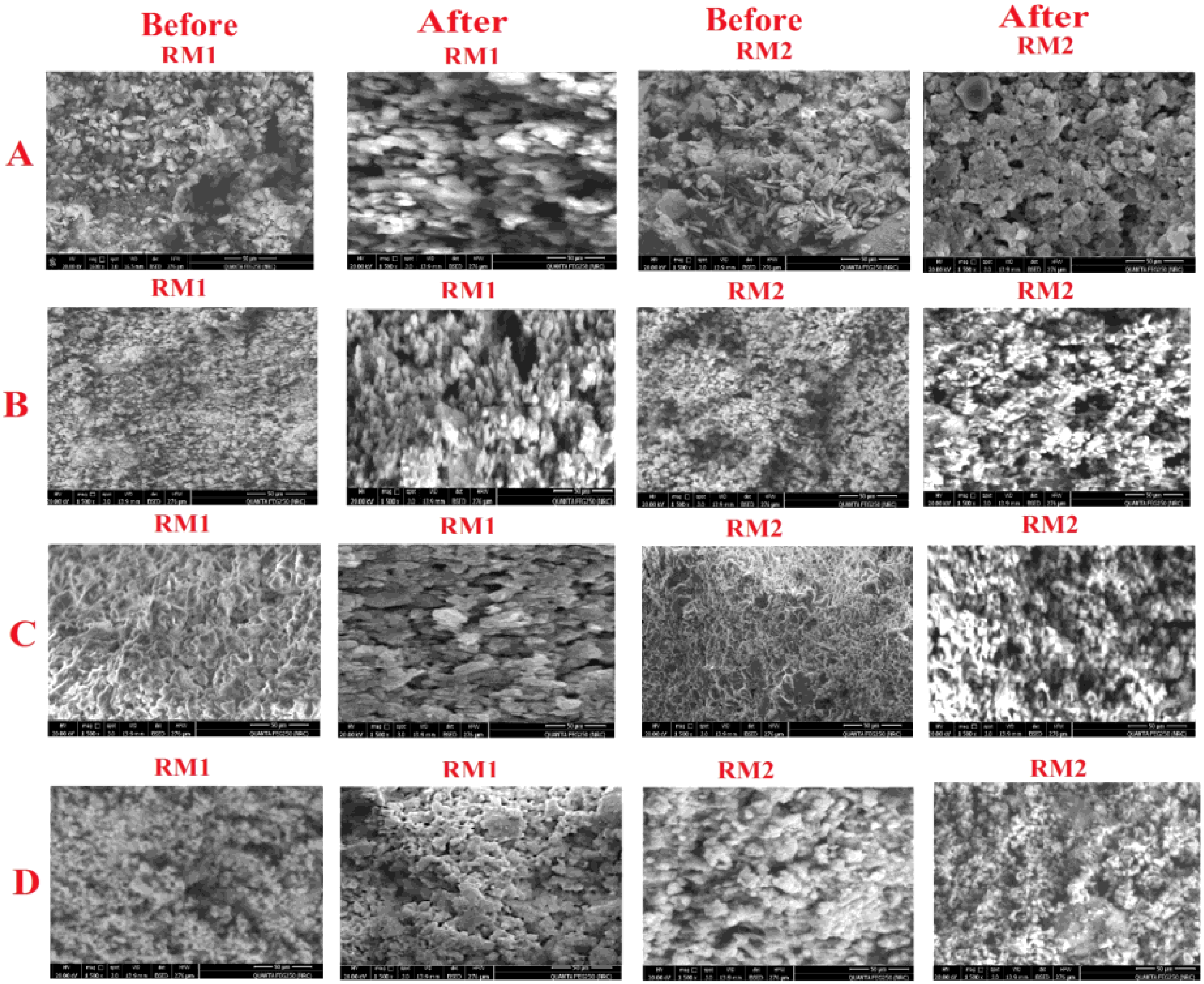

Figure 11

SEM micrographs of the treated restoration mortars before and after (Salt weathering) cycles. (A) Nano lime exposed to contraction with voids due to the effect of ageing cycles. (B) Nano silica exposed to loss inside internal structure of material with a little shrinking in places. (C) Nano lime enhanced with 3% Paraloid B-72 is slightly affected of ageing cycles. (D) Nano silica enhanced with 3% Paraliod B-72 is still homogeneous and encapsulates the mineral grains.