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A Comparative Experimental Study to Evaluate the Efficiency of Conventional and Nanosilica-enhanced Acrylic and Silicone Resins as Consolidants for Sandstone Statues of Sphinxes Avenue, Luxor - Egypt

Abdel Rahim Youssef Maky,[1] Mohamed Abdel Hady Mohamed,[2] Mohamed Ahmed Awd,[3] Shaimaa Sayed Mohamed El-Sayed [4,*]

[1] Conservator, Ministry of Tourism and Antiquities, Luxor, Egypt

[2] Conservation Department, Faculty of Archaeology, Cairo University, Giza, Egypt

[3] Conservation Department, Faculty of Archaeology, Sohag University, Sohag, Egypt

[4] Conservation Department, Faculty of Archaeology, Luxor University, Luxor, Egypt

Abstract

The purpose of this study is to evaluate the effectiveness of acrylic, silicone and nano silica additives used to consolidate a sandstone statue in Sphinxes Avenue at Luxor, Egypt. Sandstone samples were taken from separate, hidden parts that do not affect the statue, X-ray diffraction (XRD) analysis, scanning electron microscopy (SEM-EDX) were used to determine its composition and current state, and a standard sample's selection. Six chemical materials were selected for the experimental studies. Two of them belong to acrylic resins (Addicon and Paraloid B72), Kemtekt and Wacker (OH 100) are silicone materials, Nanosilica is an additive material to Paraloid B72 and Wacker (OH 100), these materials were applied in concentrations of 2-5% ,the application was done in two ways : one was by immersing; the second was by brushing. Visual examination of standard and treated samples, physical properties such as density, porosity and water absorption, mechanical properties measurement (compressive strength), scanning electron microscope (SEM) examination, are evaluated to select the most suitable material used for the sandstone consolidation. Treated samples were subjected to artificial aging processes (thermal and salt weathering). The best consolidant was Wacker (OH 100) enhanced by nanosilica, which gave the best results in physical and mechanical properties compared to other materials, Wacker (OH)100 was the second material which could be used in the consolidation processes, followed by Paraloid B72 enhanced by nanosilica. High temperatures have been found to positively affect some hydrophobic materials, such as Siloxanes, making them Superhydrophopic, this is fully compatible with the climate of Luxor governorate, where temperatures are high most days of the year. Nanoparticles also improve the performance of some traditional consolidation materials such as Wacker (OH 100) and Paraloid B72 comparing to Addicon and Kemtekt that did not succeed in achieving the goal of the consolidation process.

Keywords

Luxor; Acrylic; Silicone; Nanosilica; Consolidation; Sandstone; Physical and Mechanical Properties; Scanning Electron Microscope.

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* Correspondence Author: Shaimaa.Sayed@farch.luxor.edu.eg ; shaimaasayed43@gmail.com

دراسة تجريبية مقارنة لتقييم كفاءة راتنجات الأكريليك والسيليكون التقليدية والمحسّنة بنانو السليكا كمواد تقوية لتماثيل الحجر الرملي بطريق أبو الهول (الكباش) الأقصر – مصر

عبد الرحيم يوسف مكي،[١] محمد عبد الهادي محمد،[٢] محمد أحمد عوض،[٣] شيماء سيد محمد السيد [٤]

[١] أخصائي ترميم آثار، وزارة السياحة والآثار، الأقصر، جمهورية مصر العربية

[٢] قسم ترميم الآثار، كلية الآثار، جامعة القاهرة، الجيزة، جمهورية مصر العربية

[٣] قسم ترميم الآثار، كلية الآثار، جامعة سوهاج، سوهاج، جمهورية مصر العربية

[٤] قسم ترميم الآثار، كلية الآثار، جامعة الأقصر، الأقصر، جمهورية مصر العربية

الملخص

يهدف هذا البحث إلى تقييم أداء راتنجات الأكريليك والسيليكون، بصورتها التقليدية، وعند تحسين خواصها بإضافة جزيئات النانو سليكا، كمواد تقوية لتماثيل الحجر الرملي بطريق أبو الهول (الكباش)، الأقصر – مصر، حيث تم أخذ عينات من الأجزاء المنفصلة والغير ظاهرة من أحد التماثيل، وتم تحليلها بواسطة حيود الأشعة السينية، الفحص بواسطة الميكروسكوب الإلكتروني الماسح والتحليل العنصري بواسطة وحدة تشتيت طاقة الأشعة السينية الملحقة بالميكروسكوب الإلكتروني الماسح، وذلك لتحديد مكونات العينة والحالة الراهنة لهذه التماثيل واختيار العينة القياسية في الدراسة التجريبية. تم اختيار ست مواد للدراسة التجريبية، مادتان منهما تتبعان مركبات الأكريليك وهما (الإديكون والبارالويد ب ٧٢)، ومادتان تتبعان المركبات السيليكونية وهما: الكيم تكت والفاكر (OH100)، بالإضافة إلى استخدام مادة النانو سليكا التي تم إضافتها إلى كل من: البارالويد ب ٧٢ والفاكر (OH100)، تم تطبيق هذه المواد بتركيزات من ٢–٥% ، وتم التطبيق بطريقتين : الأولى عن طريق الغمر، والثانية عن طريق استخدام الفرشاة. تم الفحص البصري للعينة القياسية والعينات المعالجة، قياس الخواص الفيزيائية والميكانيكية، بالإضافة إلى الفحص بالميكروسكوب الإلكتروني الماسح ولذلك لاختيار أفضل مادة للتقوية. تم تعريض العينات المعالجة بعد التقوية لعمليات التقادم الاصطناعي (التجوية الحرارية والملحية) ، ومن خلال عمليات التقييم تبين أن أفضل مواد التقوية هي مادة الفاكر (OH100) المحسنة بجزيئات النانو سليكا والتي أعطت أفضل النتائج مقارنة بباقي المواد، كما جاءت مادة الفاكر (OH100) بصورتها المنفردة في المرتبة الثانية ، ثم مادة البارالويد ب ٧٢ المحسنة بجزيئات النانو سليكا، وقد وجد أن درجات الحرارة العالية تؤثر إيجابيا على المواد الطاردة للماء مثل: مركبات السيلوكسان ،حيث تجعلها فائقة القدرة على طرد الماء وهو ما يتناسب تماما مع مناخ محافظة الأقصر حيث درجات الحرارة المرتفعة معظم أيام العام ،وقد حسنت الجزيئات النانوية من أداء بعض مواد التقوية التقليدية مثل : الفاكر (OH100) والبارالويد ب ٧٢ مقارنة بمادة الإديكون ومادة الكيم تكت، والتي لم تنجح في تحقيق الهدف من عملية التقوية.

الكلمات الدالة

الأقصر؛ أكريليك؛ سيليكون؛ نانو السليكا؛ تقوية؛ الحجر الرملي؛ الخواص الفيزيائية والميكانيكية؛ الميكروسكوب الإلكتروني الماسح.

Introduction

Luxor is located in the southern region of Upper Egypt, between latitudes 25 and 36 degrees north and 32 and 33 degrees east, 670 km south of Cairo. It also houses a third of the Egyptian antiquities. The city of Luxor consists of two parts:

- Eastern Bank: In the time of the Pharaohs, this was called the city of neighborhoods, with religious temples and palaces for kings and commoners.
- Western Bank: Called the City of the Dead with tombs and funeral temples[1].

By the late period, the eastern bank of Luxor had all but disappeared, leaving only a few simple archaeological features. The most important of them are Karnak Temple and Luxor Temple. The Luxor Temple is about 3 kilometers north of the Karnak temple. It was connecting the two temples with a sacred street known as Avenue of the Sphinxes. It was founded by Nectanebo I, founder of the 30th Dynasty. This road later became known as Rams Road. The Way of the Sphinxes (Rams) is one of the largest ancient sacred roads built by ancient civilizations to connect the two largest sacred areas on the eastern bank of Luxor (Fig.1-2).

The sphinxes of the 18th dynasty are notable for their construction in that they are taller than the sphinxes of the 30th dynasty and their heads are in the shape of rams (lamb heads)during the 18th dynasty symbolized the god Amun. In the 30th dynasty, it was in the shape of a head, but it is in the shape of a sphinx (the god of Sekhmet), and the size of the statue and pedestal are smaller than those of the 18th dynasty. The pedestal also contained a cartouche inscribed with the king's name[2] (Fig.3).

This road was built entirely of Nubian sandstone. This sandstone came from the same types of Jabal al-Silsila and Masa'id quarries that were used to build the Luxor and Karnak temples. Nubian sandstone contains a variety of hard iron nodules, shells and fossils, and the mineral composition of the stone includes "micaceous minerals", in which case the stone is called "micaceous sandstone". In addition to micaceous minerals, there are gypsum crystals and pyrite crystals (FeS_2).

The Jabal al-Silsila quarry is a series of mountains composed mainly of Nubian sandstone that stretches along both banks of the Nile for an estimated length of about 800 kilometers, and is located 30 km north of Aswan between Edfu and Kom Ombo; the mountain is 140 meters thickness. The mountain stones are pink, brown and gray and are characterized by high porosity. There are writings listing the names of kings such as Queen Hatshepsut, Seti I, Ramesses II and Merneptah indicating that the quarry was in use from the 18th Dynasty[3].

[1] Weeks, K.R. (2005). The Illustrated Guide to Luxor – Tombs, Temples and museums, Stars s.p.a , Vercelli, Italy,169

[2] Boraik, M. (2013).The sphinxes avenue excavations , second report chapters de Karnak 14, Supreme Council of Antiquities, 13-32.

[3] Abdel Kader, R.R., *etal*. (2019). Study The Severe Effects of Iron Compounds Presenting in Sandstone on the Deterioration of Wall Paintings of Archaeological Tombs in Bahariya Oasis-Egypt , Budapest International Research in Exact Sciences (BirEx) Journal, Vol.1, Issue.3,5-13.

Materials and Methods

Samples were taken from separated parts of a statue on Sphinxes Avenue and the composition of the sandstone was determined by X-ray diffraction analysis and scanning electron microscopy, in addition to elemental analysis by EDX (Fig.4).

A. Preparation of sandstone samples for the experimental study

Through the study that took place on sphinxes avenue in Luxor, it was found that most of the stones used in its construction were sandstones brought from Jabal Al-Silsila quarry, so a group of sandstone blocks were brought from the same quarry, further refining them and cut into regular cubes with dimensions 3 cm x 3 cm x 3 cm, for use in the experimental study (Fig.5).

B. Acrylic, silicone consolidation materials and nano silica additives used in the experimental study

Six consolidation materials were identified for use in the experimental study, the selection of which took into account that they consisted of different consolidation materials, the consolidation materials being two materials from the group of silicone materials, namely (Wacker OH100, Kemtekt)., which also contained two acrylic group materials, namely (Paraloid B72, Addicon). It also included two synthetic nanomaterials, to which nanosilica was added to Wacker (OH100) and Paraloid B72. These materials are introduced below:

1. Wacker (OH 100)

Wacker is one of the Tetra Ethoxy Silane (TEOS) compounds[4] and one of the chemical compounds used to strengthen archaeological stones with a high penetration power[5,6]. This was effectively used to consolidate and isolate low-porosity archaeological stones in the form of consolidation cycles, waiting for each consolidation cycle to dry [7]. That is why it was chosen for the consolidation and isolation processes.

2. Kemtekt

Kemtekt is a transparent silicone-based consolidant with a low viscosity that absorbs quickly into the pores without forming a clear - coloured film or a film. It prevents water droplets from accumulating and expelling them from the surfaces, it prevents the absorption of rainwater and groundwater. It is economical, recyclable and easy to apply. [8]

3. Paraloid B72

Paraloid B72 is a type of acrylic resin. They are solid transparent crystals and can be dissolved in many solvents such as toluene, xylene, acetone and trichloroethylene. It is

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[4] Doehne,E., and Price , A.C.(2010). Stone Conservation (An Overview of Current Research), second edition, the Getty Conservation Institute, California, USA, 40.

[5] Malaga, K., *etal*. Consolidation of Gotland sand stone ,Swedish national testing and research institute, Sweden,4.

[6] Khallaf, M.K., and Mohamed, R.A. (2014). Treatment and Conservation of Six Egyptian Archaeological Stone Sarcophagi , Shedet,1.

[7]Tsakalof, A. , *etal* .(2007). Assessment of synthetic polymeric coatings for the protection and preservation of stone monuments , Journal of Culture Heritage, 8.

[8] El-Sayed, SSM . (2016).Evaluation of Wild and Domestic Trees and Plants Hazards , their Role in the Deterioration of Archaeological Buildings Ruins, Methods of Treatment and Assessment of these Hazards Applied on a Chosen Historical Building and Site , Unpublished PhD thesis , Conservation department , Faculty of Archaeology , Cairo University , Egypt ,115.

characterized by resistance to high and low temperatures and combines all the advantages of acrylates. One of its disadvantages is that high humidity can lead to fungal growth[9].

4. Addicon

Addicon is an Egyptian product and an acrylic resin. It is composed of dimethyl methacrylate. It is transparent and has excellent moisture and weather resistance. It has a drying time of 2-4 hours and a density of 1.01 kg/liter. Apply with a brush or spray to clean surfaces.

5. Wacker (OH 100) enhanced by silica nanoparticles

Composites are prepared by adding nanoparticles (reinforcing materials) to a polymer medium (base material) and mixing these materials well to obtain a uniform nanocomposite, characterized by good properties, which are not available in these materials when used alone.

Wacker (OH 100) nanoparticles supported material is a mixture of silica nanoparticles suspended or dispersed in a Wacker (OH 100) compound. This material was prepared by adding silica nanoparticles to Wacker (OH 100) at a concentration of 2% w/v and mixing these components well until the silica nanoparticles were uniformly dispersed in the polymer.

6. Paraloid B72 enhanced by silica nanoparticles

This is a mixture of nanosilica particles suspended or dispersed in Paraloid B72 dissolved in trichloroethylene at a concentration of 5%. This material was prepared by adding silica nanoparticles to Paraloid B72 at a concentration of 2% w/v and mixing these components well until the silica nanoparticles were uniformly dispersed [10,11].

This study highlights the evaluation of acrylic and silicone consolidation materials used to strengthen the sandstone statues of Sphinxes Avenue in Luxor, Egypt, comparing them before and after adding nanoparticles to the materials to highlight the role of them in improving performance of the selected consolidation materials.

C. Determination of physical and mechanical properties for the experimental samples

The physical properties of the experimental sandstone samples were evaluated during the consolidation processes to determine the effect of the consolidation materials on the properties of the treated sandstone and to compare different consolidants to select the most suitable one. Inspected and measured before and after. A material's density, porosity, water absorption, etc. are among the most important physical properties that need to be studied and tested. Compressive strength is one of the mechanical properties that should be tested on sandstone samples before and after the consolidation processes.

D. Consolidation processes of the experimental samples

The previous six consolidants were applied to sandstone cubes used in the laboratory as following:

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[9] Horie, C. V.(1998) Materials for Conservation, Organic Consolidants, Adhesives and Coatings, Routledge , Taylor and Francis group, Oxford, London,103-112.

[10] Manoudis, P., *etal*.(2009). Super hydrophobic films for the protection of outdoor cultural heritage assets, Applied Physics materials science and processing, 97 (2), 351-360.

[11] Ntelia, E., and Karapanagiotis, I.(2020). Superhydrophobic Paraloid B72, Progress in Organic Coatings, 139, 224.

1- The sandstone cubes are equipped with size (3cm x 3cm x 3cm) (ASTM C1528).

2- Prepare the materials to be used for consolidation at a concentration of 2-5%.

3- Drying the cubes in an oven at a temperature of 105 °C for 24 hours to ensure dryness and weight stability.

4- Measurement of physical and mechanical properties before consolidation (ASTM C97).

5- The consolidation process was performed using two methods: one was by immersing the samples in consolidants; the second was by brushing, then leaving the sample for 24 hours, and repeating this process for 3 consecutive days. This takes into account that we started with the lowest concentration diluent and then with the higher concentration diluent. The samples are then covered with polyethylene and left at normal room temperature for 3 weeks. This is enough time to complete the polymerization process (Table.1).

6- Measurement of physical and mechanical properties after consolidation (ASTM C170)[12].

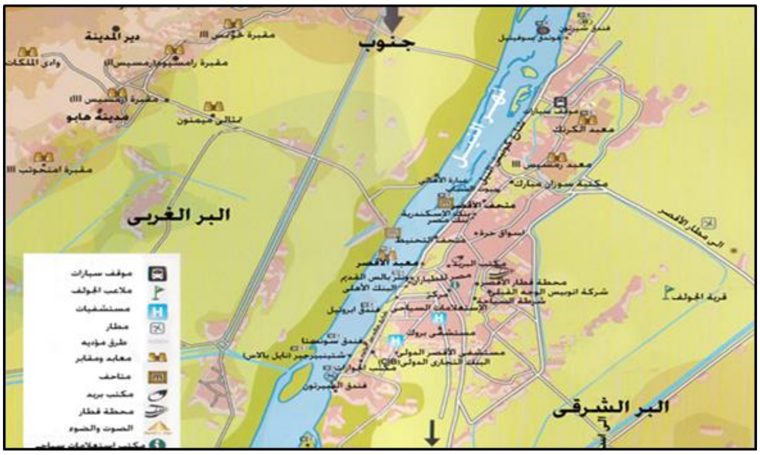

Figure 1. Luxor Governorate tourist map, taken from the State Information Service - Luxor Governorate*

Figure 2. Sphinxes Avenue, Luxor, Egypt.

Figure 3. The Sphinxes statues in Luxor

[12] Technical Bulletin of Marble Institute of America .(2014).Dimension Stone Test Methods, Guides, and Standards, Volume VII, Issue I.

*https://sis.gov.eg/Story/237104/%D9%85%D8%AD%D8%A7%D9%81%D8%B8%D8%A9-%D8%A7%D9%84%D8%A3%D9%82%D8%B5%D8%B1?lang=ar

Figure 4. The statue where the samples were taken (as arrow refers)

Figure 5. Preparation of the experimental samples

Table 1. The consolidants and samples ' codes

Code of samples	Consolidation Material
A	Wacker (OH 100)
B	Kemtekt
C	Paraloid B72
D	Addicon
E	Wacker (OH 100) enhanced by silica nanoparticles
F	Paraloid B72 enhanced by silica nanoparticles

E. Evaluating the suitability and efficiency of the materials used to consolidate sandstone samples (before artificial aging)

Effectiveness and Efficiency of materials used to strengthen sandstone specimens was evaluated by measuring the effect of various consolidants on the physical and mechanical properties of the samples, as well as visual examination and scanning electron microscopy (SEM), to determine the extent of the ability of these materials to bond between sandstone grains and their efficiency in penetration and diffusion between sandstone grains.

1. Visual examination

As shown, there were some consolidation materials that had no effect and others that had a minor effect on the overall appearance; results differed with respect to appearance.

2. Measurement of physical and mechanical properties after consolidation processes

Physical properties like density, water absorption and porosity are measured for the untreated and treated samples to evaluate the used consolidation materials.

1. Measurement of mechanical properties

The Mechanical properties of the treated samples were measured and compared with the untreated samples to determine the ability of the consolidation materials to improve the mechanical properties of the treated samples.

2. Scanning Electron Microscopy (SEM-EDX)

Scanning electron microscope (SEM) examination of the treated samples to identify the extent of the spread and penetration of the consolidation materials between grains and components of the stones and to evaluate its efficiency in the consolidation processes.

F. Artificial aging of the consolidated samples

The importance of artificial weathering tests lies in the fact that they represent the process of keeping pace with the ambient environmental conditions, especially that open environment that is characterized by variable weather factors, very complex and sharp, as is the case in the sphinxes avenue, in addition to the importance of these tests in determining the success of the consolidation materials used in the experimental study, the performance of its role under those different environmental conditions, and therefore the possibility of comparison among them in order to select the best and most stable solution for consolidating and protecting the treated samples. These tests were performed as follows:

1. Wet – dry weathering cycles

This test was carried out by following steps:

- Drying the samples in a drying oven for 24 hours at a temperature of 105°C, then recording their weights (According to UNI EN 14066:2013 standard).

-Submerging the samples in water and then placing them in a drying oven at a temperature of 60°C for 5 hours.

-Putting the samples while they are dry in the drying oven at a temperature of 60° C for 10 hours.

-Cooling the samples at room temperature for 15 hours. This process was repeated for ten consecutive cycles.

2. Salt weathering

The samples were immersed in a sodium chloride solution at a concentration of 10% (ASTM D5312 and UNI EN 12370:2001[13]) for 4 hours, then the samples were dried in an oven at a temperature of 45 ° C for 8 hours, then the samples were left at room temperature for 12 hours. This process was repeated for ten successive cycles, the effect of salt weathering on treated stones was also evaluated.

G. Evaluating of the suitability and efficiency of materials used to consolidate sandstone samples (after artificial aging)

The evaluation process was performed in the same previous methods after artificial aging by visual examination and physical and mechanical properties measurement in addition to examination by SEM microscope.

- Scanning Electron Microscope (SEM) examination after artificial aging

The examination is conducted using the scanning electron microscope for the treated samples after exposing artificial weathering cycles to determine the extent to which they are affected in different deterioration factors, and therefore we can identify the materials that are

[13] Sitzia,F., *etal*.(2021). Accelerate ageing on building stone materials by simulating daily, seasonal thermo-hygrometric conditions and solar radiation of Csa Mediterranean climate, Construction and Building Materials, 266, 121009.

given the best results in the process of consolidating and preserving of stones.

Results and Discussion

Examination and analysis of sandstone's sample taken from one of the statues on Sphinxes avenue revealed that the sandstone was composed of 85% quartz, 8% calcite, as well as 7% halite.

Scanning electron microscopy examination reveals the presence of voids and vulnerabilities in the internal texture of the sandstone sample surface, the elemental analysis (EDX) results showed that the sample consisted of 46.15% silicon (Si), 37.66% oxygen (O), 9.53% calcium (Ca) , sulfur (S) 3.31%, iron (Fe) 1.46% , Aluminum (Al) 1.35% , and potassium (K) 0.55%. As shown in (Table.2) and (Fig.6,8). This means the presence of quartz mineral due to the presence of Si and O , gypsum due to the presence of calcium, sulfur and oxygen, in addition to the presence of a small percentage of pyrite FeS_2, which is one of the iron compounds due to the presence of the elements Fe and S. The presence of potassium K and Aluminum Al indicate the presence of a small percentage of clay minerals, which means that the sandstone from which the samples were taken is Nubian sandstone.

The average values of the physical and mechanical properties of the untreated experimental samples (standard sample) were calculated, and the average density was 1.50 g/cm^3, the porosity was 25.80%, and the water absorption was 18.15 % and the compressive strength was 107 kg/cm^2.

After the sandstone sample consolidation processes (before artificial aging), the materials: Wacker (OH 100) and Wacker (OH 100) enhanced by nanosilica had no color change and no gloss on the sample surface as confirmed by visual examination. On the other hand, other treated samples showed changes in color and gloss and were excluded from the following comparisons (Fig.9)- (Table.3).

The physical properties measurements as density, porosity and water absorption show that Wacker (OH 100) and Wacker (OH 100) enhanced by nanosilica are the best materials where the density was recorded in the sample of Wacker (OH 100) 1.74 g/cm^3 and sample of Wacker (OH 100) enhanced by nanosilica 1.64 g/cm3 , the porosity in Wacker (OH 100) sample 2.85% and Wacker (OH 100) enhanced by nanosilica 2.80% , while the proportion of water absorption of Wacker (OH 100) 1.25% and Wacker (OH 100) enhanced by nanosilica 1.20% which explains the benefit of these materials in isolation of the sphinxes statues beside their consolidation comparing to the other consolidation materials like : Addicon , Paraloid B72, Kemtekt and Paraloid B72 enhanced by nanosilica (Table.4)- (Fig.10, 12).

The compressive strength values of Wacker (OH 100) sample was 204 kg/cm^2 while the sample of Wacker (OH 100) enhanced by nanosilica was recorded 230 kg/cm^2 (Table.5).

The examination using scanning electron microscope for Wacker (OH 100) shows its success in making a good and homogeneous proliferation between stone granules which are fully packed, some accurate crackdowns were found in parts of the polymer filled with relatively large paramedics, and the polymer was highly observed density in some places while the examination for Wacker (OH 100) enhanced by nanosilica showed the success of this material in reducing the proportion of water absorption and porosity for the treated stone samples and thus achieving isolation function , it is illustrated by its good packaging for granules and linking them to all spaces and gaps in stone's texture (Fig.13,14).

The procedure of artificial aging (thermal and salt weathering) of the treated stone samples , it was found that there weren't any changes in color and appearance of the treated samples of Wacker (OH) 100 and Wacker (OH 100) enhanced by nanosilica, the physical properties values of the samples differed after from before aging , as well as the mechanical properties (compressive strength), Where the values of density 1.55 g/cm^3 , porosity 10.70%, and water absorption 7.10% of Wacker (OH 100) sample after artificial aging , while Wacker (OH 100) enhanced by nanosilica recorded density 1.58 g/cm^3, porosity 4.70%, and water absorption 7.0%(Table.6) , (Fig 15,17).

The compressive strength value was 195 kg/cm^2 for Wacker (OH 100) while it was 222 kg/cm^2 for Wacker (OH 100) enhanced by nanosilica sample (Table.7).

In order to obtain an integrated evaluation of the treated stone samples, they were examined after aging using a scanning electron microscope (SEM), the examination with SEM showed for sandstone samples treated with Wacker (OH 100), a slight fading of the polymer material in some parts and the appearance of some salts on the surface sporadically (Fig.18,19).

The treated sample with Wacker (OH 100) enhanced by nanosilica gave the best result, as well as showed a large degree of stability for weathering cycles, and also showed a high degree of resistance to artificial aging, it recorded density 1.58 g/cm^3, porosity 4.70%, and water absorption 7.0% , compressive strength value 222 kg/cm^2 and no color change occurred.

Through the previous results, it was found that the Wacker (OH 100) material enhanced by nanosilica is the best consolidation material, which can be used to consolidate the deteriorated sandstone statues in the Sphinxes avenue, as it has the property of repelling water and thus doing the isolation in addition to the consolidation , followed by the Wacker (OH 100) material in the second place, as for the other consolidation materials : Paraloid B72 enhanced by nanosilica , Kemtekt , Addicon, and Paraloid B72 were excluded from the beginning, as color changes appeared in the treated samples with the occurrence of glossiness in the visual examination and were less in measuring the physical and mechanical properties compared to the selected samples in addition to assessing their efficiency using a scanning electron microscope (SEM), acrylic resins like: Paraloid B72 and Addicon yellow after a period of time due to the photo oxidation and thermal decomposition besides, a film is formed on the surface[14].

It was also noticeable that the addition of nano-materials to acrylic and silicate compounds improved their properties in consolidation processes. It was noted that the results of adding nanosilica to Wacker (OH 100) were better than Wacker (OH 100) alone, and adding nanosilica to Paraloid B72 gave better results than Paraloid B72 alone.

Nanoparticles are used to improve the mechanical and the wetting properties of OH 100 and Paraloid B72, The addition of the nanoparticles is a standard method to enhance the

[14]Ibrahim , M.M., *etal*.(2021).EXPERIMENTAL STUDY FOR EVALUATION OF PARALOID® B72 AND ITS NANOCOMPOSITE WITH NANO TiO2 AND NANO ZnO FOR CONSOLIDATION OF POTTERY SAMPLES , SCIENTIFIC CULTURE, Vol. 7, No. 2, 101-111.

hydrophobic character of the aforementioned polymers[15, 16, 17].

It is demonstrated that the Superhydrophobic and water-repellent siloxane surfaces exhibit self-cleaning properties, good durability, and furthermore do not practically affect the optical transparency of glass substrates after thermal weathering , the siloxane materials , also transform from hydrophobic to superhydrophobic in high temperatures[18,19,20], and this is very suitable in the consolidation of sandstone statutes in sphinxes avenue at Luxor , Egypt Where high temperatures degree in the summer and hot climate[21, 22].

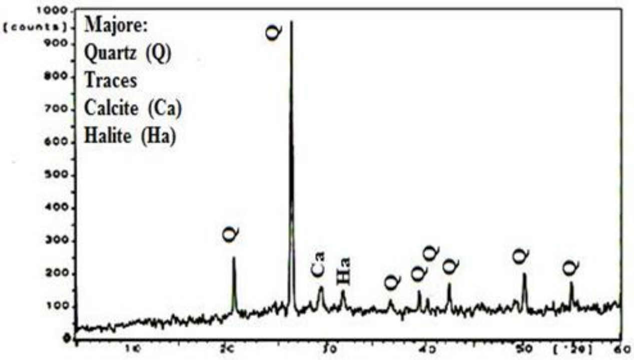

Figure 6. X-Ray Diffraction pattern of the sandstone's sample

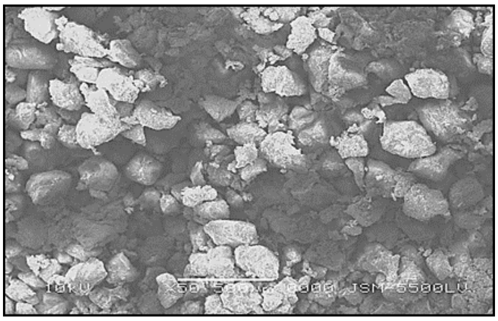

Figure 7. Examination by Scanning Electron Microscopy (SEM) of the sandstone's sample (50X)

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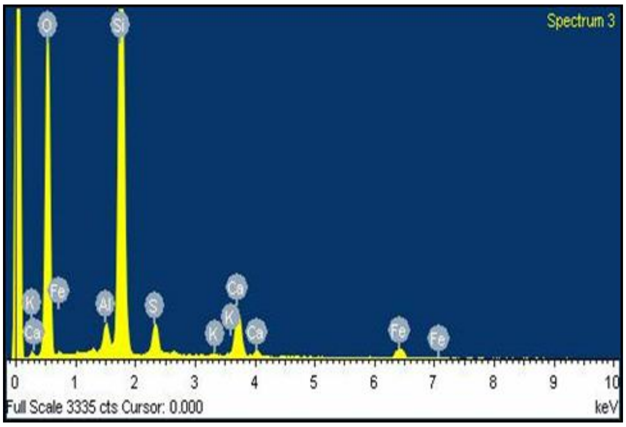


Figure 8. Elemental analysis by EDX of the sandstone's sample.

Table 2. Elements of the sandstone's sample (EDX analysis).

Element	Weight %	Atomic %
O K	37.66	53.16
Al K	1.35	1.13
Si K	46.15	37.11
S K	3.31	2.33
K K	0.55	0.32
Ca K	9.53	5.37
Fe L	1.46	0.59
Total	100.00	

A B C D E F

Figure 9. The Treated samples after drying (visual examination before artificial aging)

A B C D E F

Figure 10 . The consolidation materials effect on water repellence properties of the sandstone samples

Table 3. Visual examination (effect on appearance) of the consolidated samples

Effect on appearance	Consolidation Material	Code of samples
No surface changes	Wacker (OH100)	A
Slight colour change	Kemtekt	B
The appearance of a weak luster	Paraloid B72	C
Intense darkening and glossy	Addicon	D
No surface changes	Wacker (OH 100) enhanced by Nanosilica	E
Darkening and pallor	Paraloid B72 enhanced by Nanosilica	F

Table 4. Physical properties values of the consolidated samples

Porosity%	Water Absorption %	Density g/cm^3	Consolidation Materials	Code of samples
25.80	18.15	1.50	Untreated sample	-
2.85	1.25	1.74	Wacker (OH100)	A
15.70	1.23	1.54	Kemtekt	B
17.20	9.15	1.52	Paraloid B72	C
13.80	10.47	1.85	Addicon	D
2.80	1.20	1.64	Wacker (OH 100) enhanced by Nanosilica	E
14.30	9.10	1.55	Paraloid B72 enhanced by Nanosilica	F

Table 5. The values of compressive strength of the untreated and treated samples

Compressive strength kg/cm^2	Consolidation materials	Code of samples
107	Untreated sample	———
204	Wacker (OH 100)	A
187	Kemtekt	B
190	Paraloid B72	C
199	Addicon	D
230	Wacker (OH 100) enhanced by Nanosilica	E
200	Paraloid B72 enhanced by Nanosilica	F

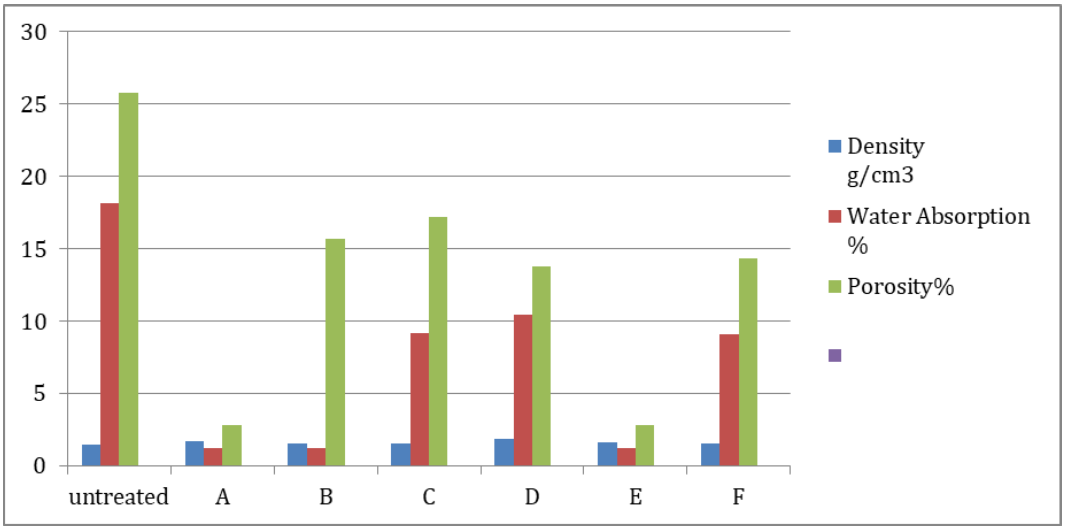


Figure 11. A diagram represents physical properties values of the consolidated materials

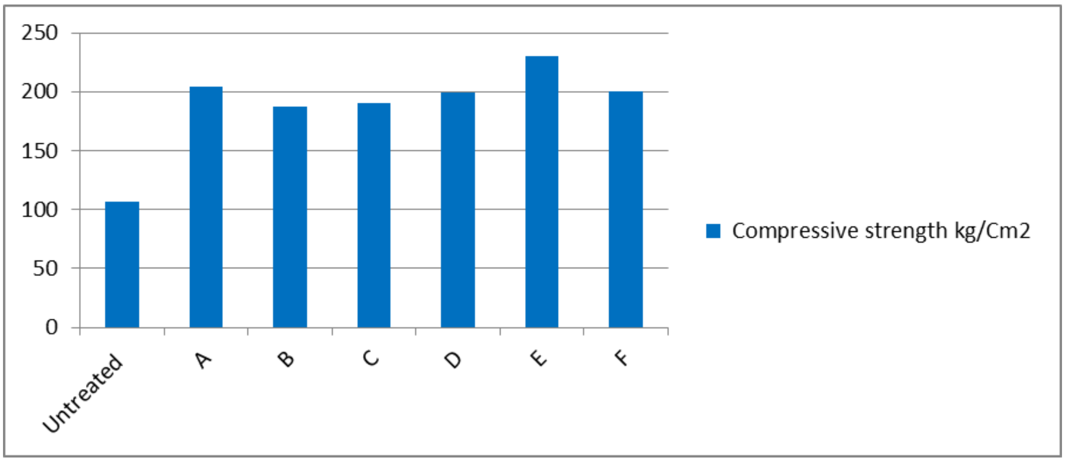


Figure 12. A diagram represents compressive strength values of the consolidated materials

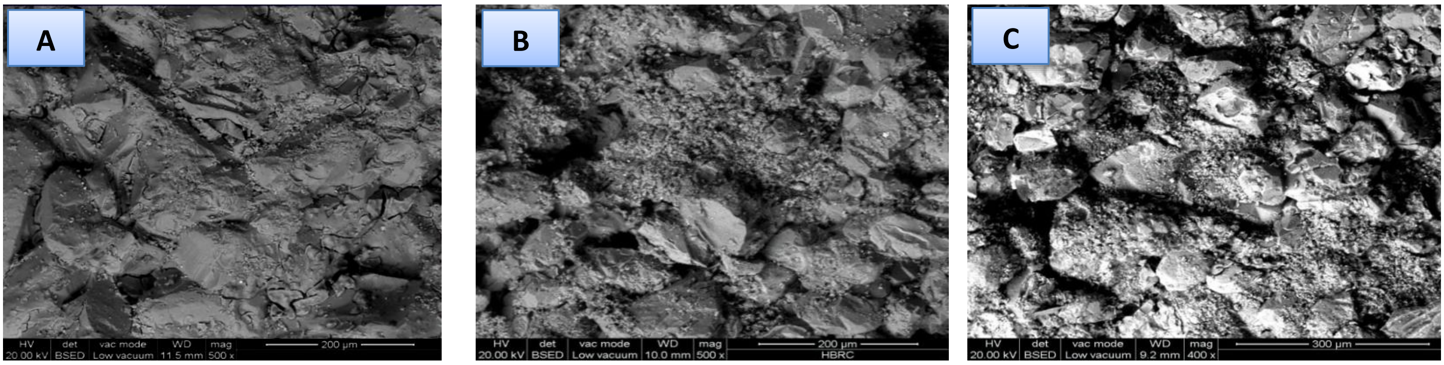


Figure 13. Scanning electron microscope (SEM) examination of the treated sample (500X) , (A) Wacker (OH 100) , (B) Kemtekt, (C) Paraloid B 72

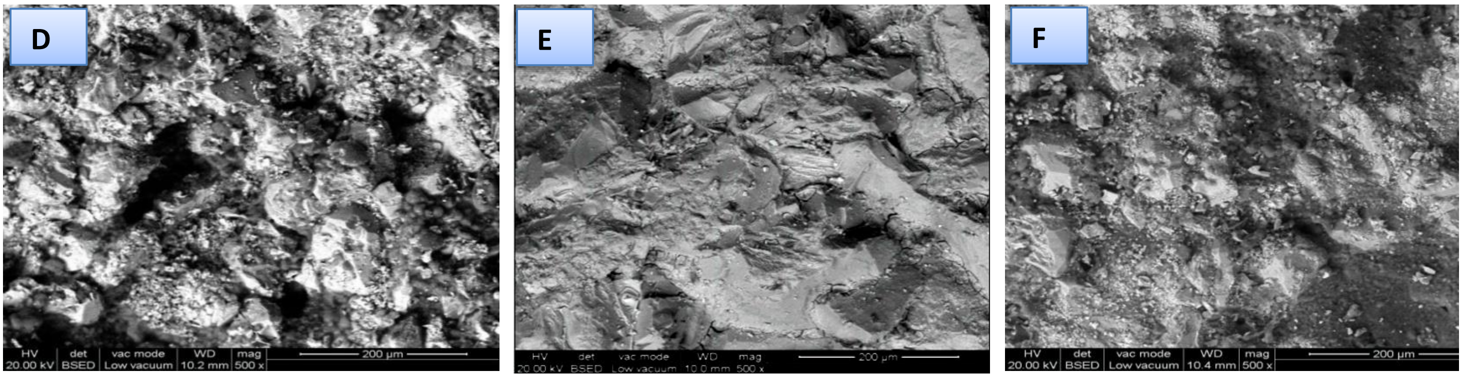
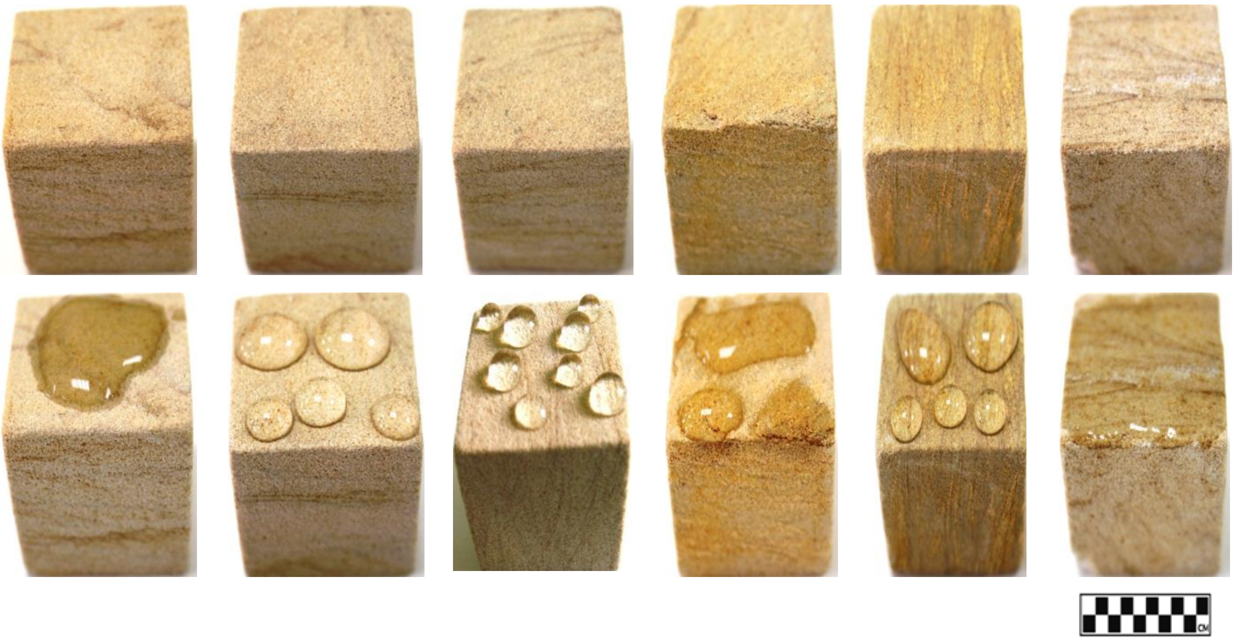


Figure 14. Scanning electron microscope (SEM) examination of the treated sample (500X) , (D)Addicon , (E) Wacker (OH 100) enhanced by nanosilica , (F) Paraloid B72 enhanced by Nanosilica

Table 6. Physical properties values of the consolidated samples after artificial aging

Water absorption %	Porosity %	Density g/cm^3	Consolidation materials	Code of samples
10.80	14.80	1.42	Untreated sample	——
7.10	10.70	1.55	Wacker (OH 100)	A
2.84	3.44	1.53	Kemtekt	B
8.95	12.80	1.50	Paraloid B72	C
1.80	3.50	1.52	Addicon	D
7.0	4.70	1.58	Wacker (OH 100) enhanced by Nanosilica	E
8.90	13.20	1.51	Paraloid B72enhanced by Nanosilica	F



A B C D E F

Figure 15 . The appearance of the treated samples and their water repellence after artificial aging

Table 7. Compressive strength values of the consolidated samples after aging

Compressive strength (kg/cm2)	Consolidation materials	Code of samples
95	Untreated sample	——
195	Wacker OH 100	A
171	Kemtekt	B
132	Paraloid B72	C
167	Addicon	D
222	Wacker (OH 100) enhanced by Nanosilica	E
185	Paraloid B72 enhanced by Nanosilica	F

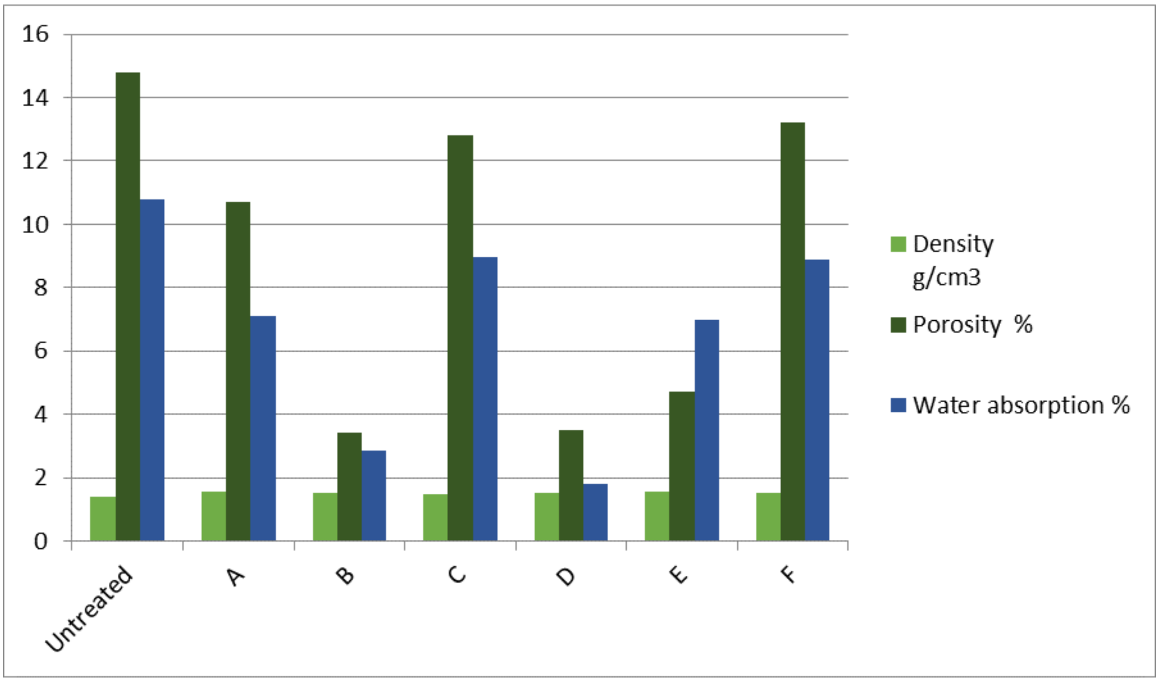


Figure 16. A diagram represents physical properties values of the consolidated materials (after artificial aging)

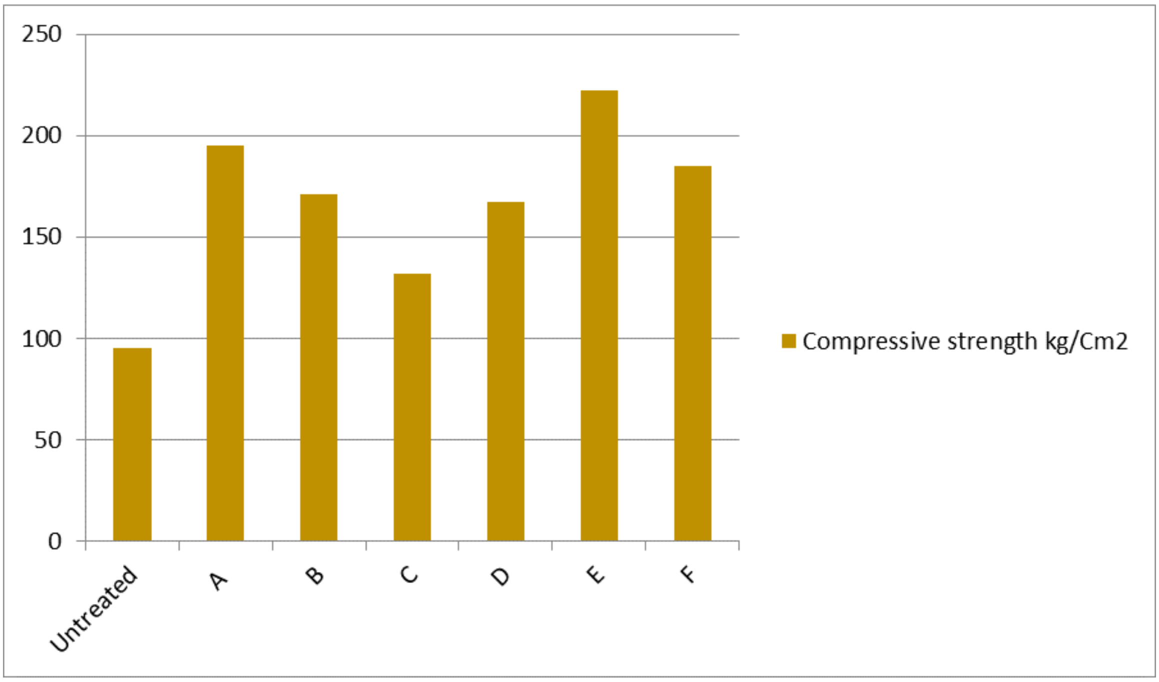


Figure 17. A diagram represents compressive strength values of the consolidated materials

(after artificial aging)

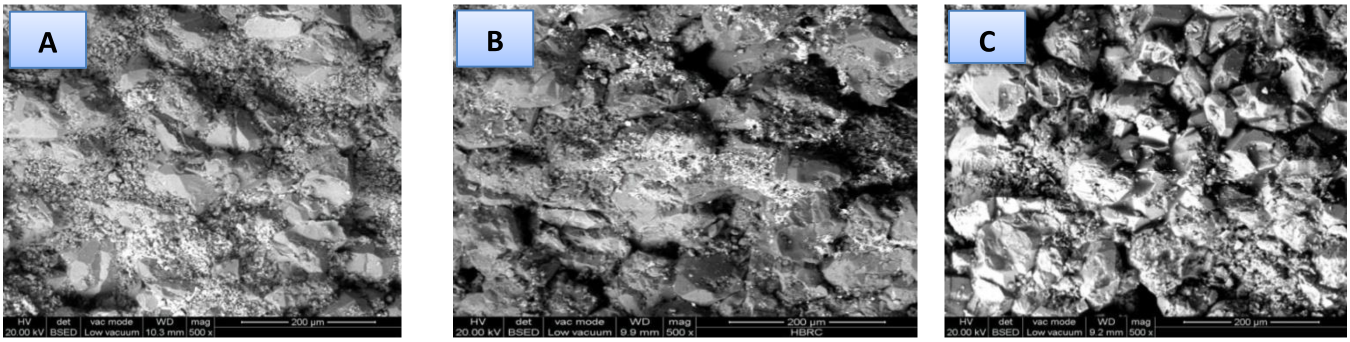


Figure 18. Scanning electron microscope (SEM) examination of the treated sample after artificial aging (500X) , (A) Wacker (OH 100) , (B) Kemtekt, (C) Paraloid B 72

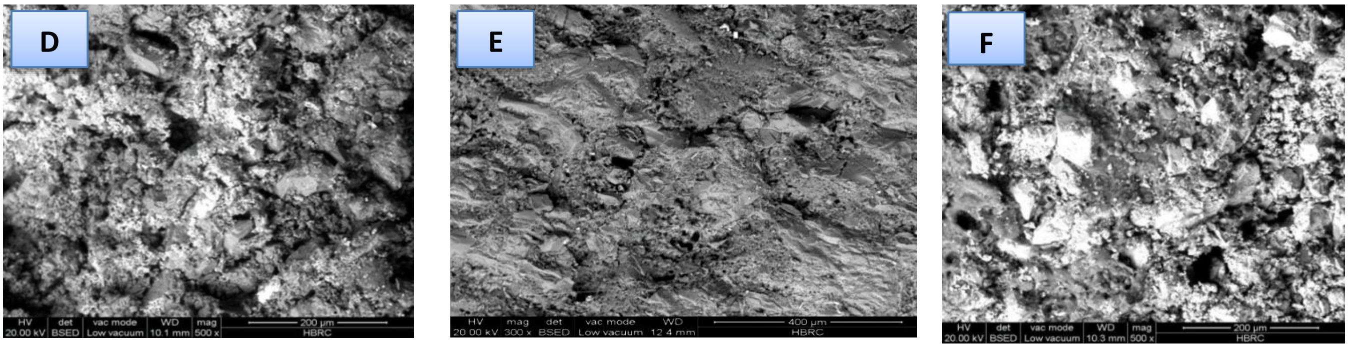


Figure 19. Scanning electron microscope (SEM) examination of the treated sample after artificial aging (500X) , (D)Addicon , (E) Wacker (OH 100) enhanced by nanosilica, (F) Paraloid B72 enhanced by nanosilica

Conclusion

Consolidation processes are very important to save the deteriorated statues [23]in Sphinxes Avenue at Luxor; six materials were selected and used to consolidate sandstones (Wacker (OH 100), Kemtekt , Paraloid B72 , Addicon, Wacker (OH 100) enhanced by nanosilica and Paraloid B72 enhanced by nanosilica) with concentrations 2-5% , they were tested and evaluated to reach the best chosen material to conserve the selected statue using some evaluation methods like : visual examination , physical and mechanical properties measurement and scanning electron microscope (SEM) examination before and after artificial aging .(Wacker (OH 100) enhanced by nanosilica recorded the best results in visual examination, physical and mechanical properties measurement and scanning electron

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microscope examination (SEM). This material consists mainly of silica[24,25,26], which is the same as the sandstone component and it has achieved an important condition of consolidation (convergence in the components and physical and mechanical properties)[27,28], followed by Wacker (OH 100) , Paraloid B72 enhanced by nanosilica , Kemtekt , Addicon and Paraloid B72 at the latest.

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