Archaeological Granite Sarcophagi Restoration and Conservation from The New Kingdom era in Luxor – Egypt: An Investigative and Applied Study

ترميم وصيانة التوابيت الجرانيتية الأثرية من عصر الدولة الحديثة بالأقصر – مصر: دراسة تشخيصية تطبيقية

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Abstract

Archaeological granite sarcophagi are exposed to many deterioration factors in the burial and exposure environments, the chosen granite sarcophagus which belonged to Tjay or Thay (19th dynasty – New Kingdom), Tomb TT23 in Sheikh Abd el-Qurna, Luxor- Egypt, it was subjected to sediments pressure, which resulted in it was breaking into pieces. Samples were taken from the separate parts in the lid, they were examined to identify the components and evaluate the damage condition by usb digital microscope, stereomicroscope, polarized light microscope (PLM) and scanning electron microscope (SEM), they were also analyzed by x-ray diffraction (XRD) , and a Handheld X-Ray Fluorescence (XRF) Analyzer (Portable and Non- Destructive Method), the components of the granite samples are Sanidine , Quartz , Analcime and Iron oxides , the XRF results confirm XRD analysis results, through the examination of the usb digital microscope and stereomicroscope , it is evident the presence of Quartz, Orthoclase and Biotite minerals, the examination using a polarized light microscope (PLM) reveals the presence of Microcline, Alkali feldspar, Quartz, Biotite, Orthoclase, and Pyroxene, in addition to the presence of iron oxides , large stages of deformation in the crystals are very clearly observed , the scanning electron microscope examination (SEM) shows distortions in the crystals in addition to the presence of gaps within the surface's texture, which means that the granite sarcophagus was exposed to many damage processes .

This research aims to shed light on the conservation processes of archaeological granite sarcophagi as applied to the chosen sarcophagus through the following restoration processes: mechanical and chemical cleaning, cracks grouting, assembly of heavy, large and small separate parts, loss-compensation or completion of the lost parts. The authors recommend preserving the granite sarcophagus in air temperature 18-22 ^{o}C, relative humidity 40-45% , away from the air pollution and direct lighting.

Keywords: Granite, Sarcophagi, Restoration, Conservation, New Kingdom, Luxor, Investigative and Applied study.

الملخص:

تتعرض التوابيت الجرانيتية الأثرية للعديد من عوامل التلف في بيئات الدفن والتعريض ، يعود التابوت الجرانيتي المختار للدراسة لـ ثاي عصر الأسرة التاسعة عشر – الدولة الحديثة (المقبرة رقم TT23) في منطقة آثار القرنة - الأقصر – مصر ، تعرض التابوت لضغط الرواسب أثناء الدفن والذي نتج عنه تهشمه إلى أجزاء عديدة (وبخاصة الغطاء) ، حيث

تم أخذ عينات للدراسة من الأجزاء المنفصلة بغطاء التابوت وتم فحصها للتعرف على مكوناتها وتقييم حالة التلف بواسطة الميكروسكوب الرقمي (الديجيتال) ، الميكروسكوب المجسم ، الميكروسكوب المستقطب والميكروسكوب الإلكتروني الماسح ، أيضا تم تحليل العينات بواسطة حيود الأشعة السينية ، جهاز تفلور الأشعة السينية المحمول (طريقة غير متلفة في التحليل) ،وقد وجد أن عينات الجرانيت تتكون من مركبات السانيدين ، الكوارتز ، الأنالسيم وأكاسيد الحديد ، وقد كانت نتائج تفلور الأشعة السينية مؤكدة لنتائج حيود الأشعة السينية ، ومن خلال الفحص بواسطة الميكروسكوب الرقمي (الديجيتال) والميكروسكوب المجسم تبين وجود الكوارتز ، الأرثوكليز ومعادن البيوتيت ، أما الفحص بواسطة الميكروسكوب المستقطب فقد تبين من خلاله وجود معادن الميكروكلين، الفلسبارات القلوية ، الكوارتز ، البيوتيت ، الأرثوكليز والبيروكسين بالإضافة إلى وجود أكاسيد الحديد ، أيضا تبين وجود تشوه ملحوظ في البلورات من خلال الفحص بالميكروسكوب الإلكتروني الماسح ، بالإضافة إلى وجود فجوات في نسيج سطح العينات عند درجات تكبير مختلفة وهذا معناه تعرض التابوت الجرانيتي لعمليات متعددة من التلف.

يهدف هذا البحث إلى إلقاء الضوء على عمليات ترميم التوابيت الجرانيتية الأثرية تطبيقا على التابوت المختار للدراسة من خلال عمليات الترميم التالية: التنظيف الميكانيكي والكيميائي، حقن الشروخ، تجميع الأجزاء المنفصلة الثقيلة كبيرة الحجم والصغيرة، تعويض الفاقد أو إستكمال الأجزاء المفقودة. يوصي الباحثون بحفظ التابوت الجرانيتي بعد الترميم في درجة حرارة 18-22 م°، رطوبة نسبية 40-45% بعيدا عن التلوث الجوي والإضاءة المباشرة.
الكلمات الدالة: جرانيت، توابيت، ترميم، صيانة، عصر الدولة الحديثة، الأقصر، دراسة تشخيصية وتطبيقية.

1. Introduction

The Theban Tomb TT23 is located in Sheikh Abd el-Qurna, part of the Theban Necropolis, on the west bank of the Nile, opposite to Luxor. It is the burial place of the Ancient Egyptian official, Tjay or Thay called to who was a royal scribe of the dispatches of the Lord of the Two Lands, during the 19^{th} Dynasty (The New Kingdom).Thay served during the reign of Merenptah.

Thay was the son of the scribe of soldiers Khaemteri and Tamy. Two wives are mentioned in TT23. Thay is shown with a wife named Raya, who was chief of the harem of Sobek and another wife who is called Nebettawy. Conservation works for the tomb and granite sarcophagus was carried out by Russian Academy of Sciences - Centre for Egyptological Studies (the Russian mission) - Season 2022.

A. Archaeological study of the tomb

The study of the tomb was done in specific areas that were necessary to clarify certain questions. One of them was focused on floors of the inner rooms of the tomb (mainly in the long room 4) with a special attention to chisel marks and the ways to make the floor smooth. Like in majority of Theban tombs, the floors were hewn in the massive of limestone rock and were roughly smoothed with small chisels. The faults of stone or cracks were smoothed with mud plaster, rather similar to the one used during building of the tomb.

This study also included study of architectural fragments coming from the courtyard, that made it possible to precise the shape and dimensions of columns and pillars of the courtyard, as well, parameters of other elements (cornices, architraves, etc.). For example, the main type of columns used in the courtyard was columns with simple cylindrical shafts and a vertical inscription with an offering formula on four sides. Some architectural details were drawn for documentation purposes; these drawings will be used for further architectural reconstructions – Fig (1-2).

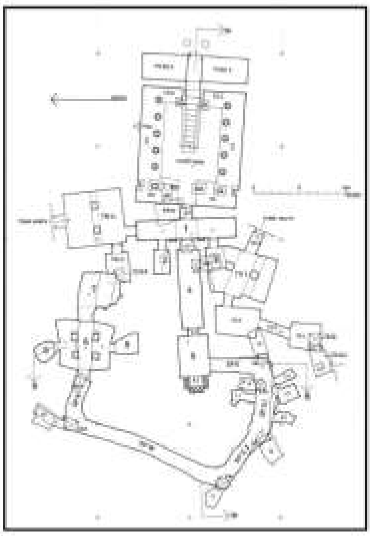

Fig (1) The plan of the tomb TT23

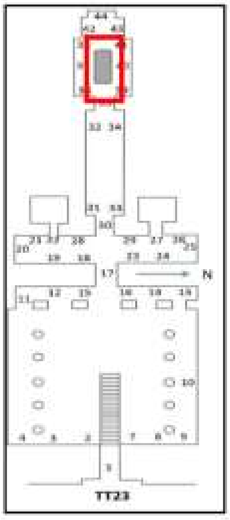

Fig (2) Location of the sarcophagus in the tomb (red rectangle)

B. The chosen sarcophagus description

Tjay commissioned an outer sarcophagus made of granite. It was discovered in 1905 inside the coffin pit of the burial chamber of the tomb. R. Mond, an excavator of the tomb, mentions that the sarcophagus was empty; it is likely that the lid was already broken by robbers. R. Mond ordered to lift the sarcophagus to the tomb proper. For this his workmen had to refill all shafts in the sloping passage; moreover, as far as the sarcophagus was moved upwards the space behind it was also refilled in order to prevent the heavy object from sliding down. Obviously, this operation was not an easy task and resulted in further destruction of the sarcophagus. Its multiple fragments of various sizes were discovered while cleaning the sloping passage in 2008–2013. Some attempts to fix the sarcophagus were made in 1980-s, when complex conservation of the whole tomb was conducted by the Egyptian Antiquities Organization. Several pieces of medium size were joined with epoxide. The base was put on a concrete platform and filled with limestone, and then large fragments of the lid were put atop the fill.

The sarcophagus of Tjay consists of a base and a lid that represents the owner as a mummy with exposed face and hands .The base is ovoid in plenum; it is rounded in the head part and flat at the feet. The maximal length of the base is 265 cm, its maximal width is 110 cm, and its overall height is 131 cm (the base — 100–86 cm, the lid — 30– 45 cm). The size of the sarcophagus fits the format of lager (outer) containers which were c. 5 cubits and 1 palm long.

Outer surface of the sarcophagus is decorated with painted reliefs. The main subjects of these reliefs are guarding the deceased, who is identified with Osiris, by the goddesses Isis and Nephthys, and vignettes and the text of the 'Spell 161' of the 'Book of the Dead'. The closest parallels to the sarcophagus of Tjay are granite sarcophagi of Amenhotep Huy from Mit-Rahina, Amenempope and Djhutimes from Thebes (TT 41 and TT 32). A relatively small number of inscriptions and mentioning of the owner's name only twice are among peculiarities of Tjay's sarcophagus. This can be a sign of speedy production or adaptation of a sarcophagus that was made for sale[1]- Fig (3-4).

Granite is a plutonic and felsic igneous rock؛ it contains 20-60% quartz, plagioclase 10-65% by mode[2]. Its crystals are of quartz, feldspar, mica and hornblende or pyroxene, crystals are generally large (a few mm)[3] .There are many granite quarries in Egypt used in the Egyptian civilization throughout the ages؛ Aswan granite is considered one of the most important granite quarries .Its use for vases, stelae, statues, sarcophagi and buildings commenced from at least the Early Dynastic Period, its largest use was during the Old Kingdom, particularly associated with the 4th Dynasty pyramid complexes at Giza, and again during the New Kingdom for obelisks and colossal statues، the stone was also extensively used during the Greco–Roman era. The most widely used type is the Aswan red or pink granite, which is mainly coarse grained to very coarse grained[4], the granite rocks taken from Aswan were called syenite[5].

[1]Ivanov, S.V., The granite sarcophagus of Tjay , Египет и сопредельные страны / Egypt and Neighbouring Countries(2019) 4 , pp1-14.

[2]Mondal , M.E.A., Modern Trends and Challenges of Classification and Genesis of Granite Rocks , Frontiers of Earth Sciences , 43, 2015, p464.

[3]Myers, J.S., Geology of granite, Journal of the Royal Society of Western Australia, 80, 1997, pp87-100.

[4]Kelany, A., Negem,M., Tohami, A., Heldal, T., Granite quarry survey in the Aswan region, Egypt: shedding new light on ancient quarrying , Geological Survey of Norway Special publication, 12,2009, pp87–98.

[5]Orabi, E.A., The Environment Deterioration Impact on the Granite Rock Art Relief of Seti I in Aswan, Egypt , Journal of Materials Science and Chemical Engineering , 10, 2022, pp20-39.

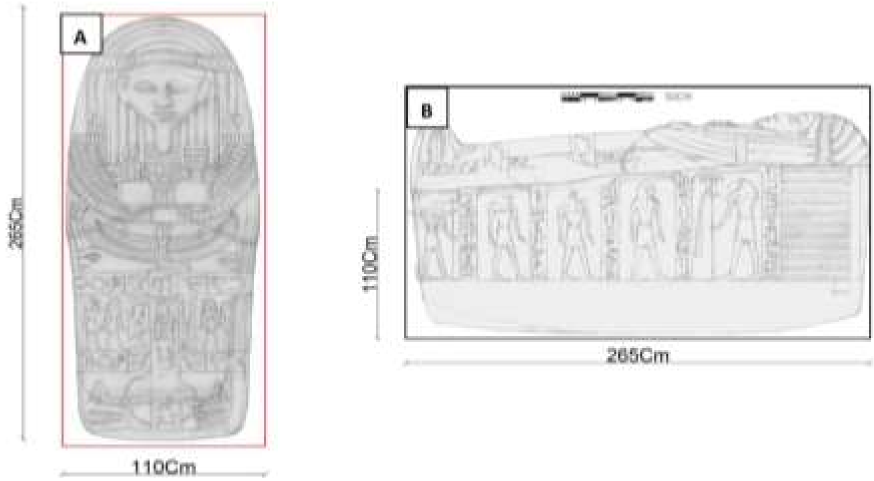

Fig (3) The dimensions of the sarcophagus (A) Lid (B) Base (2D Drawing by AutoCAD 2020 Program)

Fig (4) The granite sarcophagus, the blue arrow indicates the head's direction

C. Deterioration phenomena of the granite sarcophagus

Several deterioration phenomena were observed to assess the condition of the sarcophagus and current situation:

1. There is a layer of dust covering the surface – Fig (5).
2. There were remains of the bats blood stuck to the surface.
3. There is a complete separation into several parts in the front part (head) and the back part (foot) of the lid and some parts in the chest of the sarcophagus – Fig (6-7).
4. The presence of horizontal and vertical cracks in the coffin or sarcophagus- Fig (8).
5. There is a loss in the color layer in some parts – Fig (9).

Fig (5) A dust layer covering the surface

Fig (6) The separated parts of the sarcophagus

Fig (7) The separated parts of the lid (2D Drawing by AutoCAD 2020 Program)

Fig (8) Cracks on the sarcophagus lid

Fig (9) Colors loss at the base

2. Materials and Methods

The granite samples were taken from the separated broken parts in the sarcophagus lid, There was difficulty in taking pigments samples from the sarcophagus due to their loss and rarity and the necessity of preserving what was left of them without damaging the monument, the granite samples were examined and analyzed to identify the components and evaluate the current situation as following:

A. USB Digital Microscope Examination

An USB digital microscope ((50× – 1600×) RoHS Company) at Faculty of Archaeology, Luxor University , Luxor – Egypt, was used to examine the surface with many magnification powers to do the initial evaluation of the surface's condition.

B. Stereomicroscope Examination

The Stereomicroscope is used for low-magnification applications, allowing high-quality, 3D observation of subjects that are normally visible to the naked eye, a stereo microscope (Discovery.V20 – ZEISS Company) at Faculty of Archaeology , Luxor University , Luxor – Egypt, was used to examine the samples in 3D images to assess the surface status and identify the deterioration phenomena.

C. Polarized Light Microscope Examination (PLM)

Polarized Light Microscope is used to identify the minerals of the sample and their transformations, crystals shape, distribution and deformation, (Nikon Eclipse LV100 Pol) microscope at Geology department, Faculty of Science, Cairo University, Giza – Egypt, was used to identify the minerals and their transformations in the samples.

D. Scanning Electron Microscope Examination (SEM)

Scanning Electron Microscope is a very important method in the damage products identification of the surface with magnification powers; it is also used in the evaluation of the treatment materials and methods, (JEOL) Microscope at Faculty of Nanotechnology Postgraduate at Cairo University – Giza – Egypt, was used to examine the samples surface with different magnification powers.

E. X-Ray Diffraction analysis (XRD)

X-ray diffraction (XRD) is the laboratory technique that accurately obtains information such as chemical composition, crystal structure, crystal orientation, crystallite size, and layer thickness. Materials researchers therefore use XRD to analyze a wide range of crystallized materials like: stones, metals, pottery and ceramics, BRUKER D8 ADVANCE device at Physical Research Division , National Research Centre (NRC) – Giza – Egypt was used to identify the samples components and deterioration products.

F. A Handheld X-Ray Fluorescence (XRF) Analyzer (Portable and Non-Destructive Method)

XRF spectroscopy is a qualitative and a quantitative method for non-destructive material analysis (NDT), and enables the measurement of powders and solid compact samples as well as liquids[6]; NDT (Non- Destructive) methods are based on different physical phenomena. They are usually divided into different groups depending on their scientific background: Geophysical methods; measure mechanical and electrical Properties of the material .Spectral analytical methods; analyze surface properties by the use of electromagnetic radiation that is absorbed or emitted by the material. Tactile and visual assessment[7]. A Handheld X-Ray Fluorescence (XRF) Analyzer is a non-destructive elemental analysis method (Spectro xSort - Heritage Aid Mobile Lab - Faculty of Archaeology – Fayoum University – Fayoum - Egypt) was used for the elemental analysis of granite samples without damaging it.

3. Results and Discussion

3.1. USB Digital Microscope Examination

It is evident through the microscopic examination of samples surfaces, the presence of Quartz, Orthoclase and Biotite minerals, also there are many gaps on the surface at magnification power 200× - Fig (10).

3.2. Stereomicroscope Examination

Through the surface examination with a stereo microscope, it is clear that there are Quartz, Orthoclase, Biotite minerals, and iron oxides in addition to many burrs on the surface due to the deterioration factors which impacted on it in the burial environment – Fig (11).

[7]Svahn, H., Non-Destructive Field Tests in Stone Conservation (Field and Laboratory Tests) , Final Report for the Research and Development Project , Riksantikvarieämbetet, Sweden , 2006, p18.

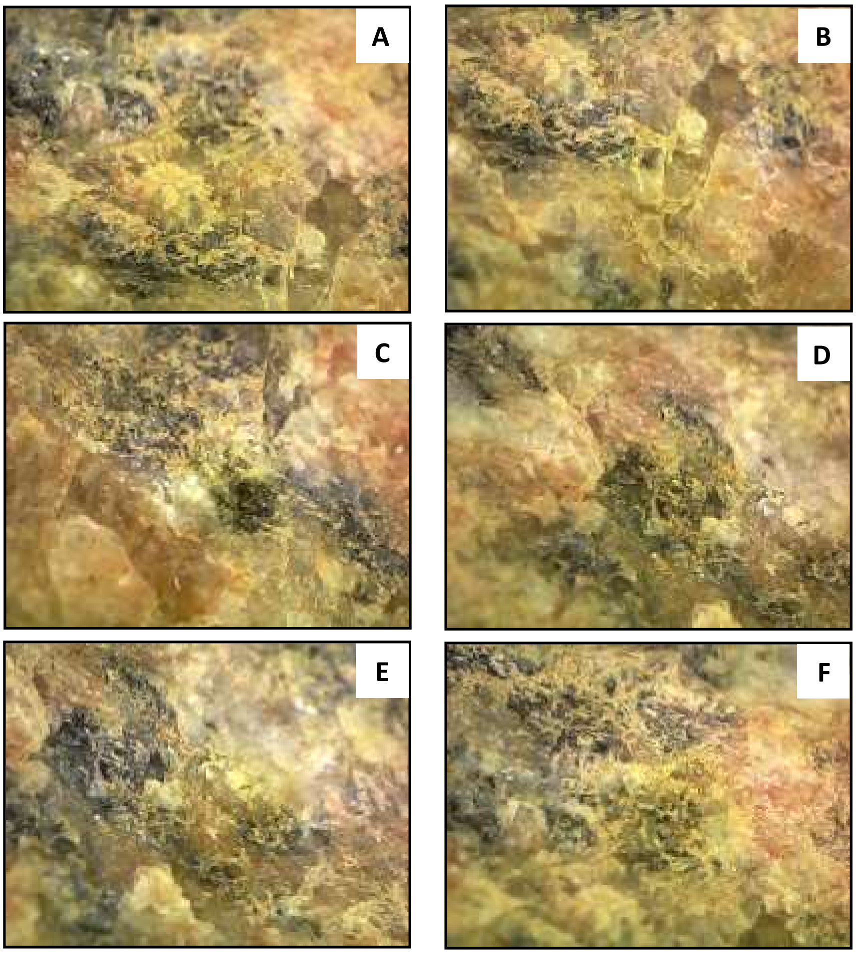

Fig (10) (A-F) The USB digital microscope examination of the granite samples (it is noted that there are many gaps on the surface), magnification power 200×.

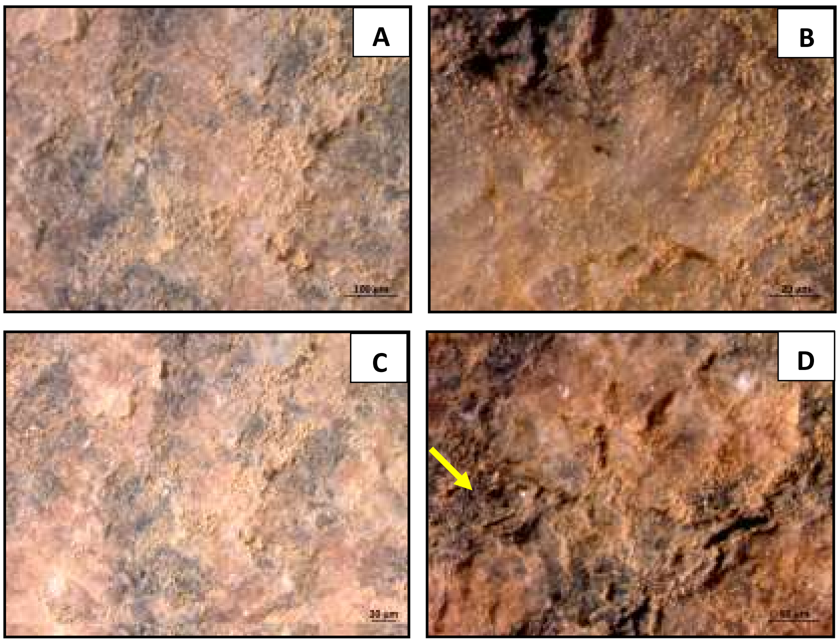

Fig (11) (A-D) Stereomicroscope's examination of the samples (it is clear that there are many burrs on the surface and iron oxides (as yellow arrow refers)).

3.3.Polarized Light Microscope Examination (PLM)

Granite samples were examined using a polarized light microscope (PLM) , the examination revealed the presence of mineral crystals of Microcline, Alkali feldspar, Quartz, Biotite, Orthoclase, and Pyroxene, in addition to the presence of iron oxides , the presence of large stages of deformation in the crystals was very clearly observed due to the deterioration factors effect- Fig (12).

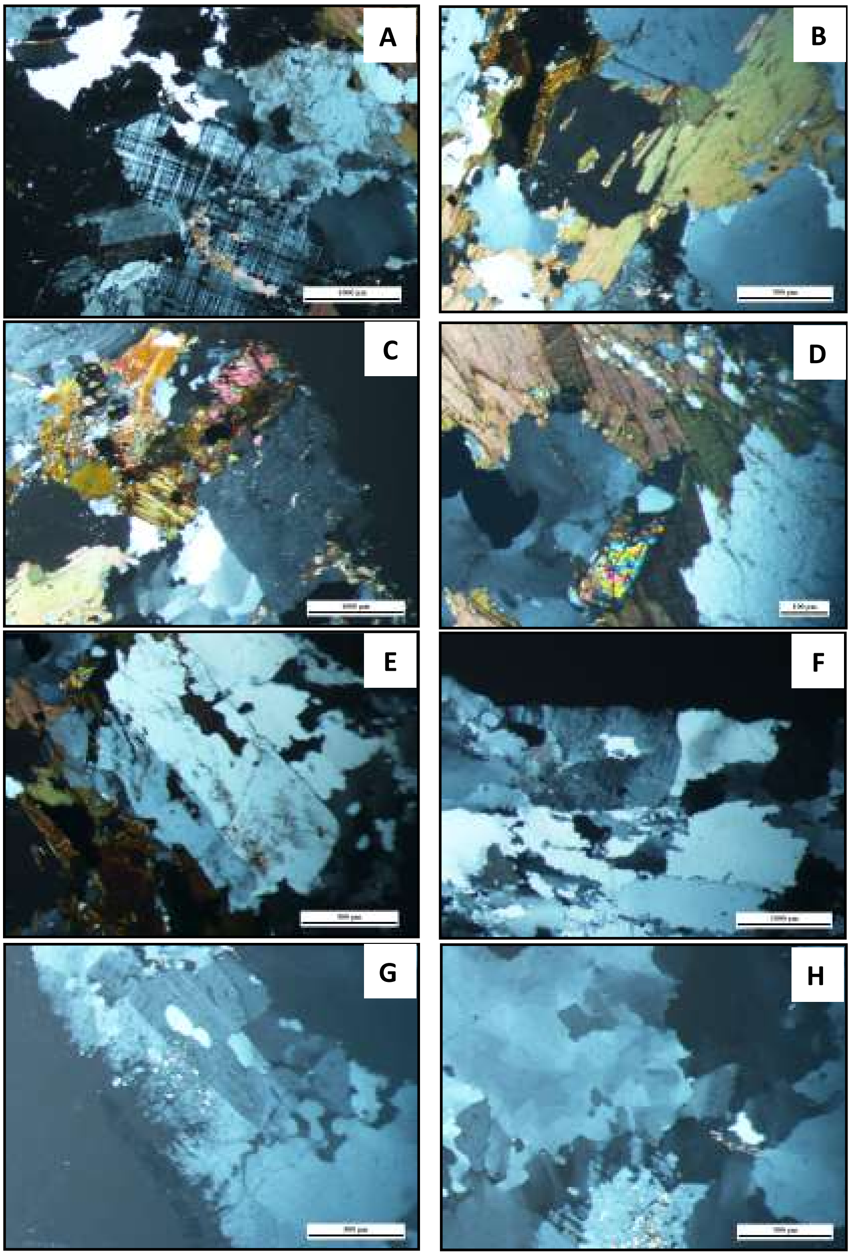

Fig (12) (A-H) Polarized Light Microscope examination of granite samples (there are Microcline, Alkali feldspar, Quartz, Biotite, Orthoclase, and Pyroxene, in addition to iron oxides).

3.4. Scanning Electron Microscope Examination (SEM)

Through the examination with a high-magnification scanning electron microscope (SEM), there are distortions in the crystals in addition to the presence of gaps within the surface's texture, which means that the granite sarcophagus was exposed to many damage processes – Fig (13).

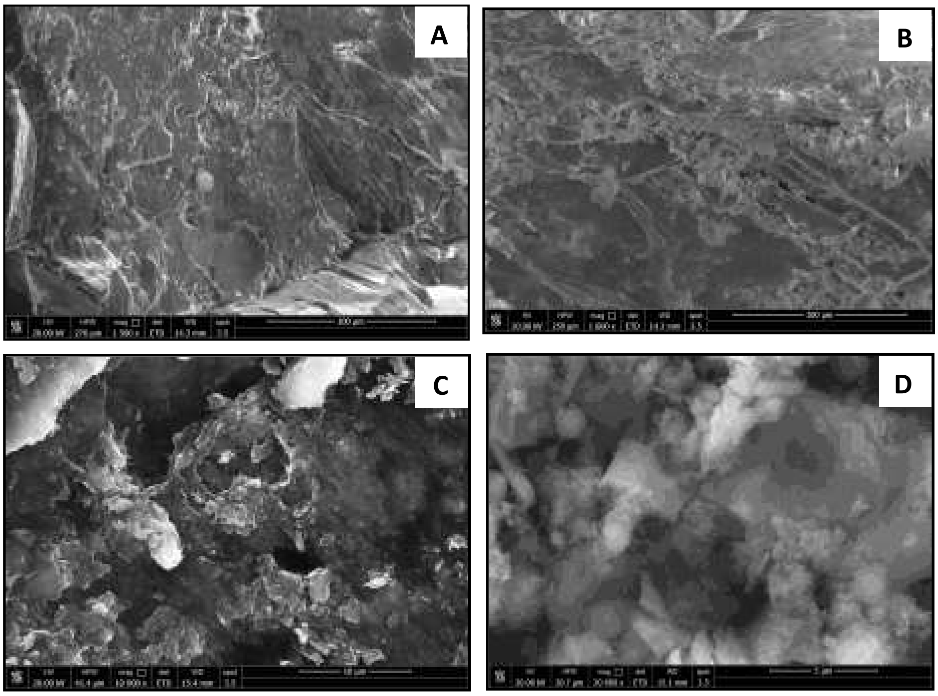

Fig (13) (A-D) Scanning Electron Microscope (SEM) examination of granite samples, with magnification powers (A) 1500× , (B) 1600× , (C) 10000× and (D) 20000× , there are distortions in the crystals and gaps in the surface's texture

3.5. X-Ray Diffraction analysis (XRD)

The granite sample was analyzed by X-ray diffraction (XRD) to identify the mineral compounds as well as the most important deterioration products. It was found that the essential compound is Sanidine with 84% , it is the high temperature form of Potassium feldspar with a general formula $K(AlSi_3O_8)$. Quartz 9% , Analcime 5% which consists of hydrated Sodium Aluminum Silicate in cubic crystalline form. Its chemical formula is $NaAlSi_2O_6 \cdot H_2O$, also there are iron oxides in the sample with percentage of 2% , there are no mineral transformations in the stone, which means that the impact of damage factors is only a physical effect - Fig (14),Table (1).

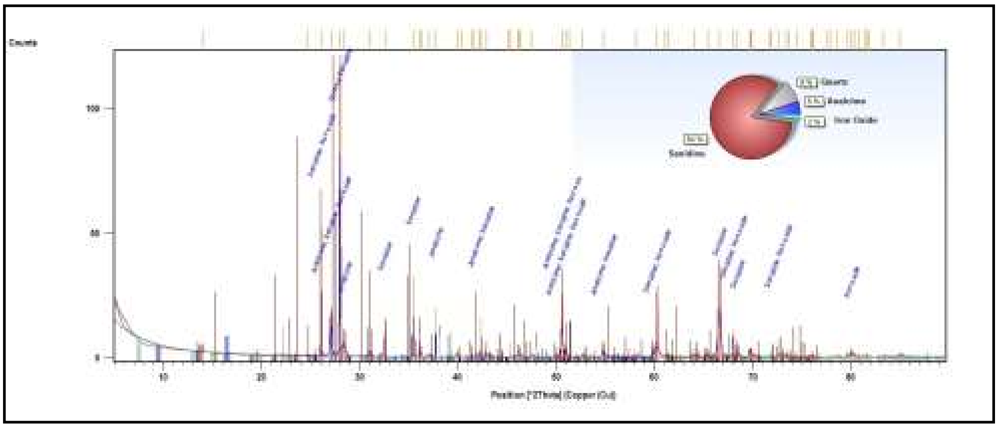

Table (1) Granite sample components and their percentages (XRD Diffraction analysis)

Component	Percentage %
Sanidine	84
Quartz	9
Analcime	5
Iron oxides	2

3.6. A Handheld X-Ray Fluorescence (XRF) Analyzer (Portable and Non-Destructive Method)

Three granite samples were analyzed by XRF because the device sometimes has an error rate, the following elements were found in the samples: (Sample No.1) Silicon (Si) 34.68% , Aluminium (Al) 5.96% , Calcium (Ca) 4.055% , Iron (Fe) 3.575% , and Potassium (K) 3.242%, (Sample No.2) Silicon (Si) 33.07% , Aluminium (Al) 7.212% , Calcium (Ca) 4.239% , Iron (Fe) 3.050% , Chlorine (CL) 1.688% , Sulfur (S) 1.574% , and Potassium (K) 1.553% , (Sample No.3) Silicon (Si) 31.31% , Aluminium (Al) 5.829% , Potassium (K) 4.061% , Iron (Fe) 2.471% , Calcium (Ca) 2.176% , Sulfur (S) 1.613% , and other elements in low percentages in the three samples, while the device does not recognize some elements like : Sodium (Na), Carbon(C) , and Oxygen (O). The three granite samples results confirm the XRD analysis results (The presence of Sanidine , Quartz , Analcime and Iron oxides in the granite samples) - Table(2-4) , Fig (15-17).

Table (2) XRF elemental analysis of the granite sample No.1

Element			Concentration		Abs. Error
13	Al	Aluminium	5.96	%	0.19
14	Si	Silicon	34.68	%	0.12
15	P	Phosphorus	0.851	%	0.023
16	S	Sulfur	0.725	%	0.011
19	K	Potassium	3.242	%	0.014
20	Ca	Calcium	4.055	%	0.015
22	Ti	Titanium	0.7444	%	0.0094
25	Mn	Manganese	0.0745	%	0.0015
26	Fe	Iron	3.575	%	0.006
28	Ni	Nickel	0.00582	%	0.00017
30	Zn	Zinc	0.00724	%	0.00016
37	Rb	Rubidium	0.00976	%	0.00010
38	Sr	Strontium	0.01733	%	0.00012
39	Y	Yttrium	0.00451	%	0.00010
40	Zr	Zirconium	0.01225	%	0.00014
41	Nb	Niobium	0.00501	%	0.00014
51	Sb	Antimony	0.00104	%	0.00052
56	Ba	Barium	0.1411	%	0.0027

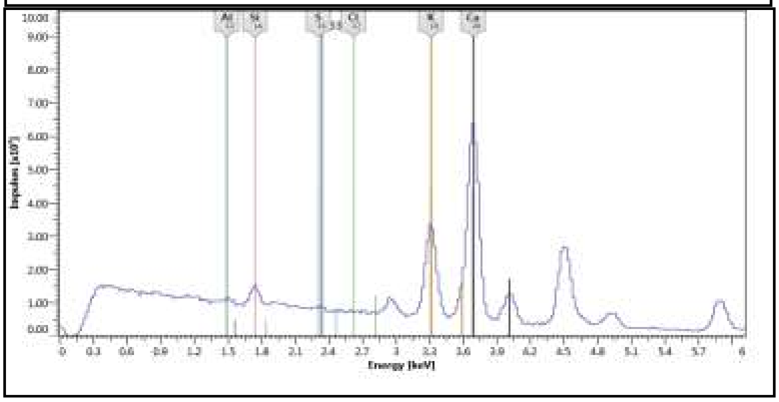

Fig (15) XRF Spectrum of the granite sample No.1

Table (3) XRF elemental analysis of the granite sample No.2

Element			Concentration		Abs. Error
13	Al	Aluminium	7.212	%	0.093
14	Si	Silicon	33.07	%	0.06
15	P	Phosphorus	0.626	%	0.011
16	S	Sulfur	1.574	%	0.007
17	Cl	Chlorine	1.688	%	0.009
19	K	Potassium	1.553	%	0.005
20	Ca	Calcium	4.239	%	0.007
22	Ti	Titanium	0.6297	%	0.0080
23	V	Vanadium	0.0089	%	0.0023
24	Cr	Chromium	0.0057	%	0.0014
25	Mn	Manganese	0.0626	%	0.0014
26	Fe	Iron	3.050	%	0.005
28	Ni	Nickel	0.00443	%	0.00016
30	Zn	Zinc	0.00625	%	0.00015
37	Rb	Rubidium	0.00533	%	0.00009
38	Sr	Strontium	0.02454	%	0.00013
39	Y	Yttrium	0.00724	%	0.00011
40	Zr	Zirconium	0.03766	%	0.00018
41	Nb	Niobium	0.00489	%	0.00015
56	Ba	Barium	0.1130	%	0.0030
90	Th	Thorium	0.00258	%	0.00015

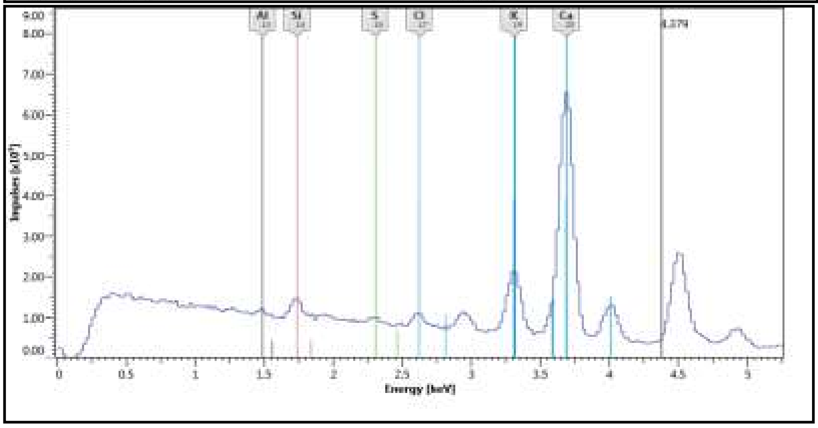

Fig (16) XRF Spectrum of the granite sample No.2

Table (4) XRF elemental analysis of the granite sample No.3

Element			Concentration		Abs. Error
13	Al	Aluminium	5.829	%	0.073
14	Si	Silicon	31.31	%	0.05
15	P	Phosphorus	0.4815	%	0.0086
16	S	Sulfur	1.613	%	0.007
17	Cl	Chlorine	0.3848	%	0.0060
19	K	Potassium	4.061	%	0.007
20	Ca	Calcium	2.176	%	0.005
22	Ti	Titanium	0.3530	%	0.0067
25	Mn	Manganese	0.0551	%	0.0013
26	Fe	Iron	2.471	%	0.005
28	Ni	Nickel	0.00324	%	0.00013
30	Zn	Zinc	0.00464	%	0.00013
37	Rb	Rubidium	0.01114	%	0.00010
38	Sr	Strontium	0.01718	%	0.00011
39	Y	Yttrium	0.00314	%	0.00009
40	Zr	Zirconium	0.03522	%	0.00016
41	Nb	Niobium	0.00297	%	0.00013
56	Ba	Barium	0.1704	%	0.0027
58	Ce	Cerium	0.0077	%	0.0033
60	Nd	Neodymium	0.0102	%	0.0050
73	Ta	Tantalum	0.00257	%	0.00014
82	Pb	Lead	0.00125	%	0.00021

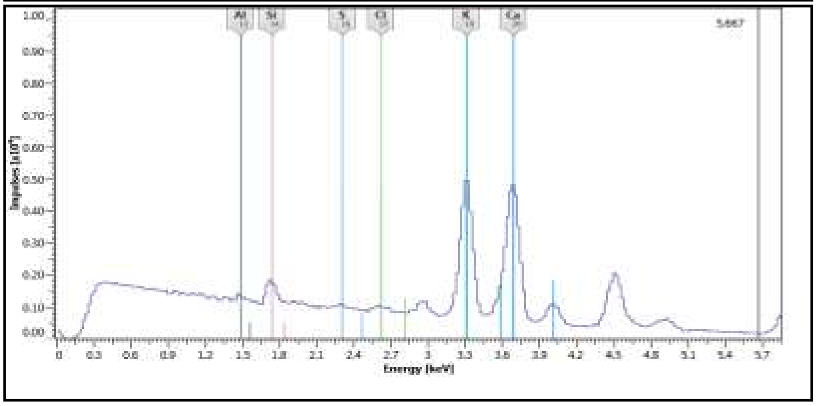

Fig (17) XRF Spectrum of the granite sample No.3

3.7. Conservation Processes of the Granite Sarcophagus

3.7.1. Mechanical cleaning

The dust accumulated on the granite sarcophagus was removed using soft brushes and an air blower to remove the dust[8], this process was carried out from top to bottom, and toothbrushes were used to remove the clay calcifications[9]– Fig (18).

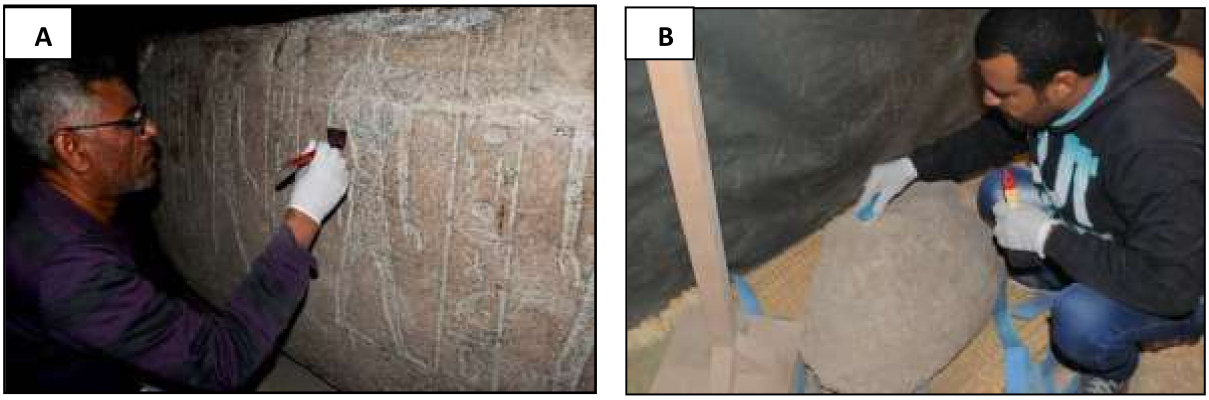

Fig (18) (A-B) Mechanical cleaning of the sarcophagus using soft brushes

3.7.2. Chemical cleaning

The remains of clay calcifications were removed using ethyl alcohol at 65% concentration by using swabs to save the remnants of pigments on the surface, the blood bats were removed using vulpex liquid soap[10], it is regarded as a safe cleaner for many surfaces and materials, non-acidic, non-foaming, non-corrosive, non-hazardous and germicidal making, it ideal for a large variety of uses[11], the color sensitivity was tested before use.

3.7.3. Cracks grouting

The deep cracks in the granite sarcophagus were injected, as follows: hoses were installed in the cracks and joints after cleaning them well, and then they were fixed well and the cracks around the hose were covered with a reversible and repair mortar (Gypsum) to ensure that the injected material did not leak out during the injection. The material was injected by syringes using Araldite 1092 – Figure (19-20), Araldite 1092 is an epoxy resin and adhesive .Epoxy resins were candidates of high interest as stone adhesive materials, consolidates, and gap-fillers because of their durability,

[9] Abdel-Maksoud , G., Awad, H., Rashed, U.M., Different Cleaning Techniques for Removal of Iron stain from Archaeological Bone Artifacts: A Review, Egyptian Journal of Chemistry , Vol.65, No.5,2022, p74 .

[10] Gherardi, F., Current and Future Trends in Protective Treatments for Stone Heritage , in Conserving Stone Heritage - Traditional and Innovative Materials and Techniques , Springer Nature Switzerland AG , 2022, p147.

[11] Al-Emam , E., Motawea, A.G., Caen, J., Janssens , K., Soot removal from ancient Egyptian complex painted surfaces using a double network gel: empirical tests on the ceiling of the sanctuary of Osiris in the temple of Seti I—Abydos , Heritage science , 9:1, 2021, pp1-10.

good adhesion, and exceptional mechanical strength, the weight ratio of the epoxy resin to the hardener was 1:2 as grouting and gap filler[12,13,14].

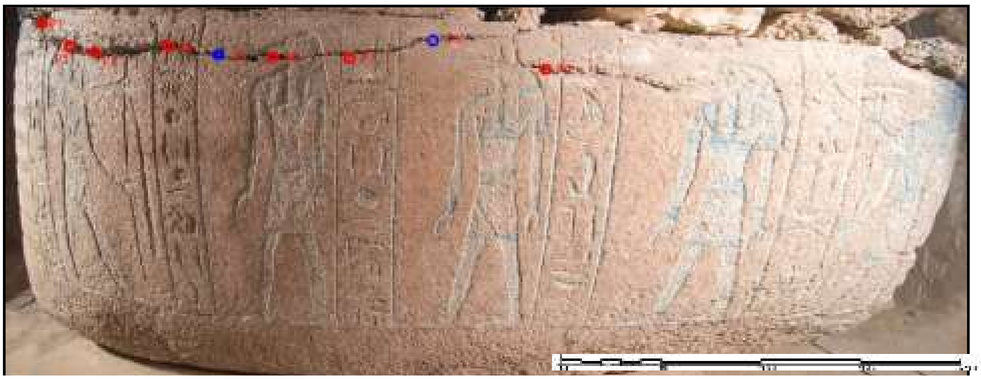

Fig (19) Determining the areas through which the injection is performed

Fig (20) Cracks grouting using Araldite 1092 with fixed injection hoses

3.7.4. Assembly of large and heavy separate parts

The assembly process was carried out for the large and heavy separate parts of the lid and base of the granite sarcophagus which located at piece of head, north, south and west side of the base and lid , first , lifting machine carried the heavy parts, then accesses were made by using drill device and cleaning them by air composers attached with tube[15] . Stainless steel bars 6Ml, 8 Ml and 30 CM were selected for joining the large and heavy separate parts , Araldite 1092 was the injection material with ratio 1

[12]Aldosari, M.A., Darwish , S.S., Adam, M.A., Elmarzugi, N.A., Ahmed, S.M., Re-Assembly of Archaeological Massive Limestones Using Epoxy Resin Modified with Nanomaterials—Part 1: Experimental , Green and Sustainable Chemistry, 10, 2020, p25.

[13]Rodrigues, J.D., Conservation Of Stone Monuments. From Diagnostic To Practice, Minbar Al Jamiaa nº7, Actes de la RIPAM 2005, Meknès, Maroc -2007, pp287-295.

[14]Bader, N.A.E., Experimental Tests Used For Treatment Of Disintegrated Granite In Valley Temple Of Khafre – Egypt, International Journal of Conservation Science , Volume 10, Issue 2, April-June 2019, p221.

[15]Terlikowski, W., Wasilewski, K., Sobczyńska, E., Szczepaniak , M.G., Approach to conservation of irregular stone masonry based on archaeological excavations in the Black Sea basin, E3S Web of Conferences 49, 00117 , SOLINA , 2018, https://doi.org/10.1051/e3sconf/20184900117

(resin) : 2 (hardener) applied by syringe[16,17] in the base and lid - Table (5-7), Fig (21-24).

Table (5) Assembling of north side of the sarcophagus

Hole No.	diameter	Product	Length	Injection material	Total quantity of injection
1	8 Ml	Stainless bar 6 Ml	24 CM	Araldite 1092	20 Ml
2	8 Ml	Stainless bar 6 Ml	24 CM	Araldite 1092	20 Ml

Table (6) Assembling of west side of the sarcophagus

Hole No.	diameter	Product	Length	Injection material	Total quantity of injection
1	8 Ml	Stainless bar 6 Ml	25 CM	Araldite 1092	15 Ml
2	8 Ml	Stainless bar 6 Ml	40 CM	Araldite 1092	30 Ml
3	8 Ml	Stainless bar 8 Ml	20 CM	Araldite 1092	20 Ml

Table (7) Assembling of south side of the sarcophagus

Hole No.	diameter	Product	Length	Injection material	Total quantity of injection
1	8 Ml	Stainless bar 6 Ml	30 CM	Araldite 1092	25 Ml
2	8 Ml	Stainless bar 8 Ml	30 CM	Araldite 1092	35 Ml

Fig (21) Lifting of separate parts of the lid

Fig (22) Using the drill device to make accesses for stainless steel bars

[16] Aldoasri, M.A., Darwish, S.S., Adam, M.A., Elmarzugi, N.A., Ahmed, S.M., Re-Assembly of Archaeological Massive Limestones Using Epoxy Resin Modified with Nanomaterials—Part 2: Applied , Green and Sustainable Chemistry, 10, 2020, pp72-90.

[17]El- Sayed , S.S.M., Maky , A.Y., Study of The Processes of Loss - Completion and Reconstruction of The Archaeological Stone Statues on The Rams Road - Luxor - Egypt, Applying on Selected Models, Heritage and Design Journal , Vol.2 , No.11, 2022, p375.

Fig (23) Araldite 1092 injection by syringes

Fig (24) Joining the separate parts of the lid

3.7.5. Assembly of small separate parts

The small parts of the granite sarcophagus were joined using Araldite AW 106 / HV 953U , resin and hardener were mixed well together in a ratio of 1:1 by a wooden stick and put in the separate parts by spatula after cleaning them. Araldite AW 106 / HV 953U is an efficient adhesive، it has a good resistance to dynamic loads , low shrinkage and high strength and toughness[18]– Fig (25).

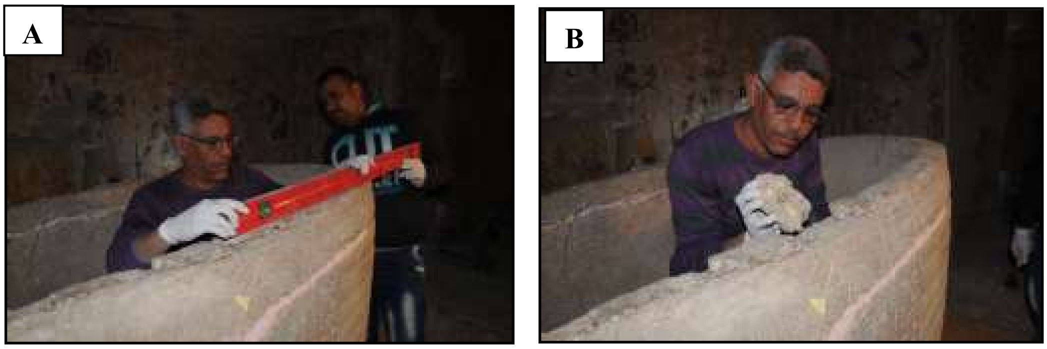

Fig (25) (A-B) Joining small separate parts of the base

3.7.6. Loss - compensation or completion of the lost parts

After completing the assembly operations for the separate parts of the lid and base of the sarcophagus, a survey of the missing parts of the lid and base was made.

[18]Araldite ®AW 106 / HV 953 U structural adhesives (Technical Data Sheet), HUNTSMAN Advanced Materials , Switzerland GmbH , November 2010.

[19] Doehne , E., Price , C.A., Stone Conservation : An Overview of Current Research , Second Edition , Getty Conservation Institute , U.S.A, 2010, p58.

[20]Khallaf, M.K., Mohamed, R.A., Treatment and Conservation of Six Egyptian Archaeological Stone Sarcophagi , SHEDET , Volume.1 , Issue.1 , 2014, p37.

[21]Price, C.A., Stone Conservation: An Overview of Current Research, J.Paul Getty Trust, U.S.A, 1996, p20.

[22]Rodrigues, J.D., Costa, D., The conservation of granite in Évora Cathedral. From laboratory to practice , Proceedings Int. Symp. "Stone Consolidation in Cultural Heritage. Research and Practice", Lisbon, May 2008, pp101-110.

According to international conventions and conferences, completing the missing parts cannot be done unless there is a structural and aesthetic goal without this being a falsification of archaeological facts and evidence[19,20], the compensation of the missing parts was done indirectly by molding where isolation was done first and silicone molds[21,22] were made on the missing parts. Completion mortar was made from crushed granite and Araldite 1092, it was poured in the silicone molds and wait until it dried completely, the granite molds were installed after settling them in their places, and the installation was done using Araldite AW 106 / HV 953U– Fig (26-28).

Fig (26) (A-D) loss – compensation process of missing parts of the granite sarcophagus

Fig (27) The granite lid after the loss-compensation processes

Fig (28) The granite sarcophagus before and after conservation processes

4. Conclusion

Granite sarcophagi are exposed to many deterioration factors in the burial and exposure environments, as these sarcophagi were broken as a result of the deposits pressure. The chosen granite sarcophagus was found by the Russian mission excavations at Qurna area in Luxor, it was found in poor condition, as the lid was found broken into several parts, as well as the base, granite samples were taken from separate parts in the lid that did not affect the sarcophagus integrity and were examined using USB digital microscope, stereomicroscope, polarized light microscope and scanning electron microscope. Quartz, Microcline, Biotite, Alkali feldspar , Orthoclase , Pyroxene and iron oxides were found and it was noted that the surface had many gaps and burrs due to the deterioration processes , the samples were also analyzed using XRD analysis and a handheld x-ray fluorescence (XRF) analyzer (portable and non- destructive method). Conservation processes were carried out for the chosen sarcophagus like: mechanical and chemical cleaning, cracks grouting, assembly of heavy, large and small separate parts and completion of the lost parts. The authors recommend preserving the chosen granite sarcophagus after the conservation processes in air temperature 18-22 ^{o} C, relative humidity 40-45%, away from the air pollution and direct lighting [23,24,25].

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