USING INTERDISCIPLINARY STUDIES AND ANALYSES IN THE CONSERVATION OF GRECO-ROMAN CARTONNAGE

Firas Alawneh*
Department of Conservation Science, Queen Rania Faculty of Tourism & Heritage, Hashemite University, Zarqa, Jordan.

Abdel Rahman Elserogy
Department of Restoration, Faculty of Archaeology,
Fayoum University, Fayoum, Egypt.

Eyad Almasri
Department of Sustainable Tourism, Queen Rania Faculty of Tourism & Heritage, Hashemite University, Zarqa, Jordan.

Keywords: cartonnage, conservation, mummy, SEM-EDX, Egyptian blue.

1. Introduction

Ancient Egyptians employed various methods for decorating their mummies, such as using plaster or gold leaf, as in the collection of Tutankhamen [1]. They also used wooden coffins with different decorations. Features varied from one period to another. The coffins were decorated with geometric designs, an assortment of deities or inscriptions which included verses from the Book of the Dead, painted in different colors [2, 3 and 4]. The gold-covered plaster masks were cast immediately after death and took on the shape of the deceased's facial details. The forms were flexible enough for molding while wet against the irregular surfaces of the body. This method was used for decorating the mummies, creating funerary costumes, and to produce cases, masks or panels to cover the mummified body.

Egypt has a huge number of cartonnages (mummy masks) in its museums and in storage areas. In many cases, deterioration and damage of these cartonnages can be observed and the linen fabric in the plaster is often exposed. A cartonnage can be defined as a form dedicated to decorating and preserving the mummy consisting of linen and sometimes of papyrus layers bonded together by a layer of mortar or *gesso*. The word *gesso* is the Italian word used for a gypsum (CaSo4, 2H2o) and glue mixture which acts as a primer/ground in painting. A fine layer was applied over a coarse layer to obtain a cohesive painting surface. Egyptian archaeologists also use the same term for a white limestone powder and glue solution mixture [5].

A cartonnage is composed of multiple layers of linen and glue formed in a mold and then covered on one side with a mixture of gum, lime or gypsum, which is then suitable for coloring and gilding, and after drying, is decorated with inscriptions and colors and occasionally painted in part with gold [6].

* Corresponding author: Firas-alawneh@hu.edu.jo

This method has been used since the beginning of the Middle Kingdom [7]. The earliest known examples of cartonnages date back to the 18th Dynasty (1549/1550 - 1292 B.C.) and spread during the Roman period. Linen layers were sometimes replaced by papyrus, which was often written on. Several studies have been conducted on papyrus cartonnage. This process had a specific use in creating burial masks and was also used to cover the bodies of the dead. The main function was to protect and decorate the mummy with personal funerary decorations [8].

The studied artifacts were two first century AD (Greco-Roman) cartonnages of two female mummies displayed in the Ismailia Museum, Ismailia (Egypt). Figure 1a shows the painted plaster cartonnage of a woman wearing a long Egyptian-style wig, a crown of pink flowers on her head, a deep-red tunic with black vertical stripes, and jewelry that includes two rings on her left hand and snake bracelets adorning her right and left arms. At the lower edge of her tunic are two holes which were used to attach the mask to the mummy. Figure 1b shows a female mummy cartonnage with a gilded face that reflects the association of the deceased with the gods. The decoration was applied in layers, with the final layer being the gilding. The eye inlays are made from glass, as well as the gold scarab on the top of the head. The scarab has gilded wings which stretch down to the sides. A colored collar with five vertical stripes and geometric patterns adorns the mask. The golden face of this mask shows no signs of age or emotion.

Due to the bad condition of the studied cartonnages, a rapid intervention for the maintenance and restoration of the artifacts was needed (Figures 1c – f).

To better understand and find a suitable intervention approach, it was important to identify and characterize the components of the cartonnages. Different analytical techniques were used, such as scanning electron microscopy (SEM−EDS), X-ray diffraction analysis (XRD), and Fourier transform infrared spectroscope (FTIR). The obtained results will help to develop a reliable conservation plan for the damaged cartonnages. Furthermore, a microbiological analysis will be conducted aimed at diagnosing any biological hazard that infects the cartonnages. Finally, the cartonnages will be re-displayed in a manner that best serves the methods for their conservation and preservation.

2. Experimental

Preliminary condition assessments of the cartonnages were conducted by visual examination. For better understanding and to find the correct method for treatment, a detailed physical, chemical and biological study was planned. Various techniques were used in order to obtain further information about the nature of the materials employed to execute and color the cartonnages. The analysis was carefully conducted taking the necessary precautions, paying attention to the critical state of the artifact and attempting to minimize the risk of further damage. Representative samples were selected from parts that were already separated from the cartonnages to identify the constituents and degree of deterioration. These samples were representative of the blue, red, green, yellow and gilded layers as well as the linen and preparatory layers. Investigations were performed using optical microscopy (OM); this examination mainly focused on the stratigraphy and thickness of the paint layers, as well as the preparatory layers (Figures 2a, b, and c).

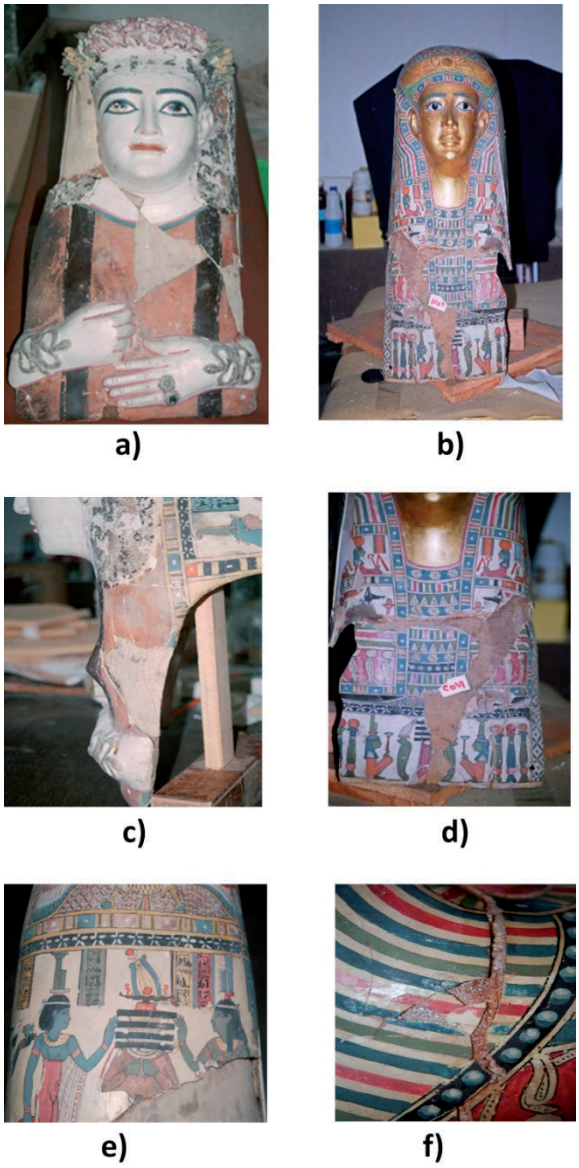

Figure 1. Studied artifacts: a) colored plaster cartonnage of woman with red clothes; b) gilded cartonnage; c) and e) show details of the different deterioration features on the plaster cartonnage; d) and f) show details of the different deterioration features on the gilded cartonnage.

Another aspect was to study the microstructure of the cartonnage components of both artifacts, such as the pigments, pigment size, inclusions and porosity. Samples were prepared, coated with gold and then examined under a scanning electron mi-

croscope. The SEM/EDX investigation was carried out using a high-resolution field emission electron microscope JSM-6300 F, combined with a microprobe analyzer JXA-8800 L (JEOL, Japan). The beam voltage for the quantitative determination of elements was set to 25 kV, in order to obtain better excitation of the low-energy and low-concentration compounds. Finally, the distribution of the elements (mapping) in cross sections was determined by simultaneous acquisition of X-ray data from each pixel of the secondary electron (SE) image areas.

The mineralogical composition of the different parts of the cartonnages (e.g. colors, plaster, basic layer and other components) was determined using a Shimadzu LabX, XRD-6000 X-ray diffractometer. Using monochromatic CuK radiation operating at 30 kV and 15 Ma, spectra were collected in the range of 2–80o 2θ, with a step size of 0.03o/s. Selected samples were examined using X-ray fluorescence (XRF) to obtain total element content qualitatively and quantitatively. XRF measurements were performed in situ (non-destructive analysis). An XRF spectrometer was used for elemental analysis (JSX- 3222) equipped with end window type X-ray tube, tube voltage 5 to 50 Kv (in 1Kv steps), tube current 0.01 to 1.0mA, using Rh anode as target, window Be, 127μm thick. X-ray fluorescence was detected by an X Flash silicon drift detector with high speed electronics and an energy resolution of 149 eV at Fe Kα spectral line (5.9 keV, 4000cps).

In order to confirm the chemical analysis by SEM-EDS regarding the identification of pigments, selected paint layers were analyzed by Fourier-transform infrared spectroscopy (FTIR). The FTIR analysis was performed in a Bruker, Equinox 55/S spectrometer. Transmittance spectra were collected in the range 4000–650 cm−1 with a spectral resolution of 4 cm−1 and acquiring 400 scans.

A microbiological study was also carried out aimed at identifying the most important fungi present on the cartonnages and thereby finding the means and materials to treat the infected area.

3. Results and discussion

The purpose of the analysis was to identify the basic components of the cartonnages, characterize the materials used in their preparation and to diagnose the nature of the damage to the cartonnages before treatment and restoration. Prior to discussing and interpreting the resulting spectrum, it is worth mentioning that the selected spectrums are the most significant.

The preliminary examination, done by naked eye, light microscope and a hand-held magnifying lens (x I0) indicated that both cartonnages were composed of more than one material in a single installation. It consists of the following: color layer, gesso layer and linen. These materials differ in their physical and chemical properties. According to the examination of the two cartonnages inside the museum, it was possible to observe many damaged features.

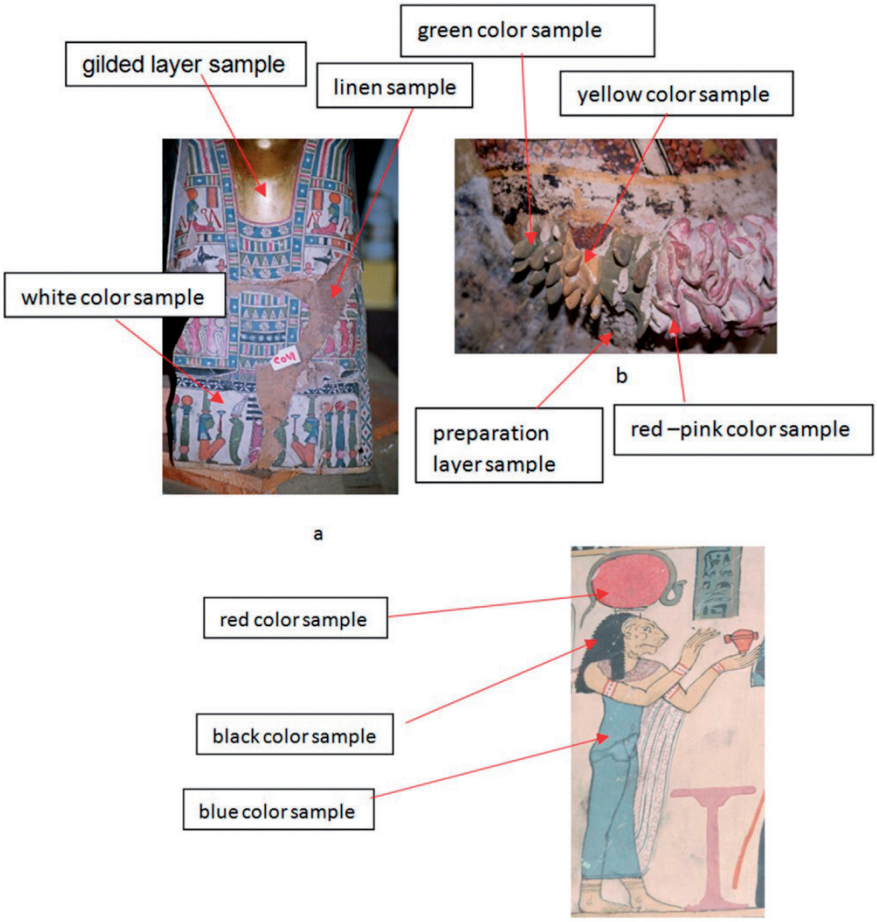

Figure 2. a) Image of the gilded cartonnage; b) and c) images of the plaster cartonnage showing location of the analyzed samples.

The factors responsible for the damage can be summarized as follows:

High relative humidity in the storage area, which exceeded 70% as a result of the regular cleaning process of the museum. This led to increased water content in the cartonnages, especially in the hygroscopic components such as flax, glue and colors. It also caused the loss of the medium (used as a color bond), thus changing the mechanical and physical properties of the colors, turning blue to green in some parts of the colored plaster cartonnage. Also, it caused the dissolution of the glue with separation and splitting of the base layer, which deformed the area of the head in the plaster cartonnage, as well as the chest in the gilded cartonnage. Due to the growth of microorganisms, brown spots can be seen in different areas on the cartonnages.

The most significant aspect of the temperature was its effect on relative humidity (RH). Ismailia Museum is characterized by high indoor temperature and is considered

an inappropriate place for keeping archaeological artifacts. The poor indoor climate conditions of the museum, direct exposure to sunlight and bad air circulation make it an inappropriate place for preserving the cartonnages (Figure 3). The lighting system, moreover, accentuates the poor indoor conditions and leads to loss of water content. This has led to the cracking and destruction of the cellulose chains, the main component of the flax, as well as twisting, in some of the interior and edges of the preparatory layer.

Dust and dirt are solid particles which can absorb sulfur dioxide, which later turns into sulfuric acid and may lead to the destruction of the artifacts. Dust can also carry insect eggs which helps in the spread of biological damage and deterioration [9]. Dust and dirt are hygroscopic and will attract additional dust and dirt to the cartonnages, which can cause further damage. Accumulated dust and dirt were held loosely to the surface of the cartonnage by electrostatic forces or weak chemical bonds; deposited in the cracks dust and dirt can stain the surface of the cartonnages.

Both humidity and heat, as well as poor ventilation in the museum environment has encouraged the growth of fungi. The presence of some components, such as animal glue in the basic layer or in the linen, are considered to be suitable nutrition for micro-organisms.

Figure 3. Photograph showing the direct impact of sunlight on stored cartonnages.

3.1 Results of color analysis

All the color samples from both cartonnages (plaster and gilded) were analyzed, with particular focus on the pigment layer. In the case of the plaster cartonnage, analysis of the blue sample using an X-ray diffraction device (RD Philips Analytical X.Ray BV) revealed that Egyptian blue (Ca Cu Si_4 O_{10}) was used consisting of copper silicate and calcium (Figure 4a)). In order to confirm the XRD result, the same blue samples were also analyzed using SEM (EDX). It is clear from the spectra obtained that the blue colored sample is Egyptian blue (Ca Cu Si_4 O_{10}), as seen in Figure 4 b.

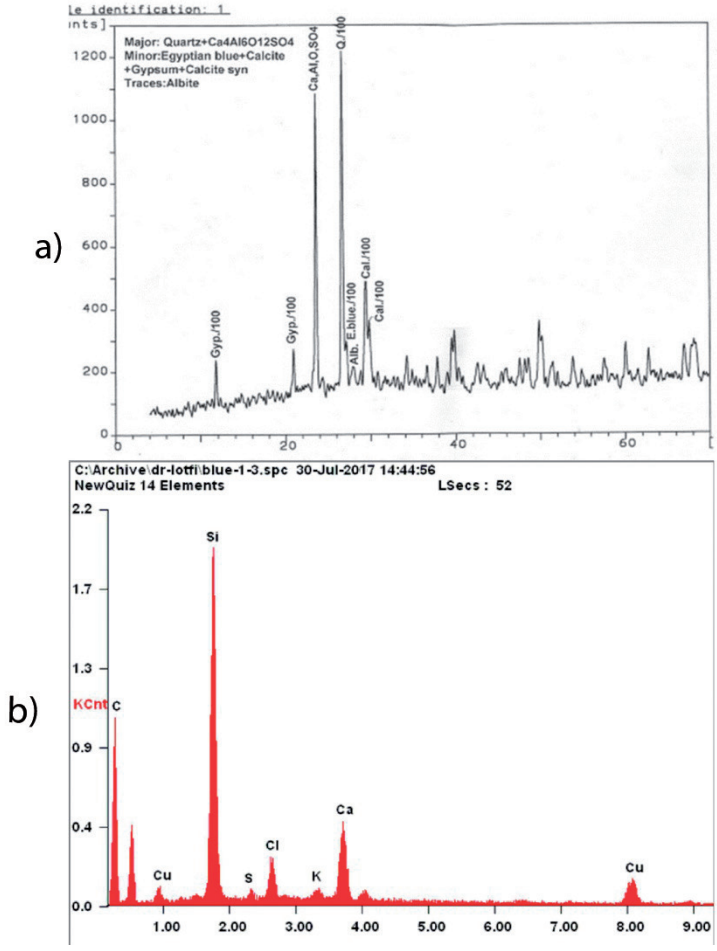

Figure 4. Color analysis; a) XRD spectrum for the blue color; b) EDX spectrum for blue color sample.

XRD and EDX analyses were conducted for identification of the red pigment from

the crown of pink flowers in the plaster cartonnage (Figure 2c). The majority of red pigments used in ancient Egypt were earthen based colors containing iron oxide. Hematite (αFe_2O_3) was very common [10]. The spectrum of the red sample contained bands at 222, 292, 407, 492, 607, 662 and 1320 cm−1 (Figure 5), that is, the typical bands of hematite (Fe_2O_3). This means that the dark red of the sample comes from this mineral. As expected, the presence of hematite was found as the main component for the red pigment, while for the red-pink sample of the corneal cornea above the head of the plaster cartonnage (Figure 2b), XRD analysis revealed that it is red-lead Pb_3O_4.

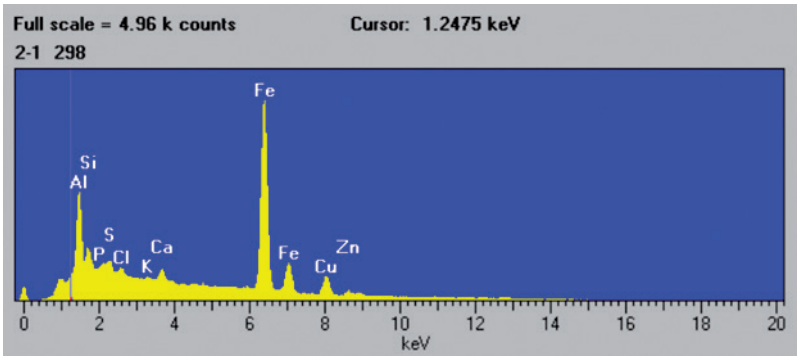

Figure 5. EDX spectrum for the red color.

For the gilded cartonnage, the composition of the white pigment appears as a combination of calcite and as calcium silicate mixed with aluminum silicate. The XRF analysis of the sample showed the distinctive peaks of gypsum and dolomite. In the case of the plaster cartonnage, XRD results for the yellow color of the corneal cornea above the head turned out to be composed of Goethite $Fe_2O_3H_2O$ while the green color of the corneal lobes above the head proved to be Paratacamite Cu_2 (OH) $_3$CL. The results of the Fourier transform infrared spectroscopy (FTIR) analysis were compared with the reference spectra of well-known organic adhesives. In this respect, the FTIR spectra evidenced the C=O bond stretching and NH bond bending bands found between 700 and 1500 cm-1, both of them characteristic of the amide groups of proteins. This finding is confirmed by the presence, between 1500 and 1700 cm-1 of the CH2 bond of the methylene group as well as by the -CH3 methyl group band at about 2900 cm-1, all of them suggesting the presence of animal glue [11]. In Figure 6, the use of animal glue is also shown in this IR spectrum by the presence of a band at 1540 cm-1 associated with the deformation vibration of the N-H link in the protein. The bands that appear in the IR spectrum can be attributed to animal glue. This band includes multiple bands made up of multiple N-H groups (its primary amides), both in the solid state and in the presence of hydrogen bonding.

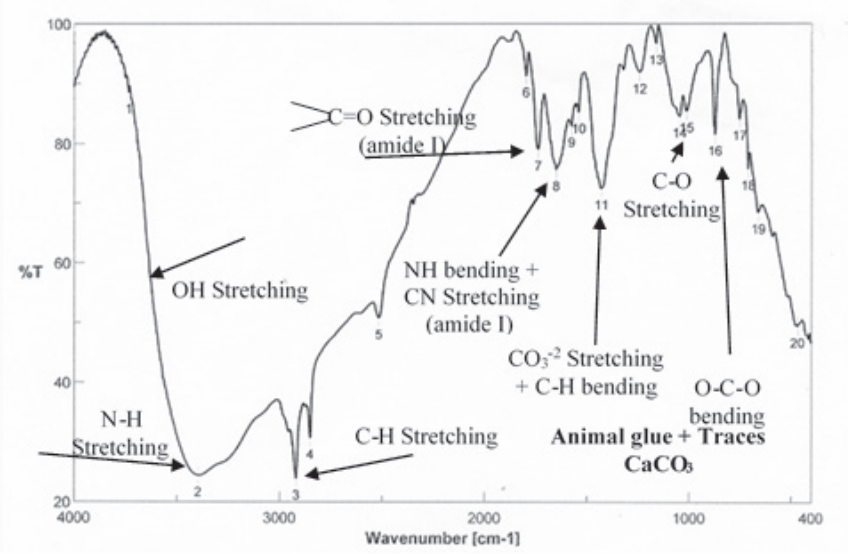

Figure 6. FTIR spectra of the blue color medium.

In order to determine cartonnage components a scanning electron microscopy of cartonnage tissue lining was conducted on both artifacts. It appears that a flax fabric was used (Figure 7a). The basic layer is often made up of calcium carbonate or calcium sulfate with a glue medium. This layer is very important as it prevents absorption of the paint layer and also facilitates the movement of the brush during painting. The results of the electron microscopy and FTIR revealed the presence of three canvas layers consisting of a linen textile. Cracks and holes were seen on the basic layer and the linen fabric (Figure 7b).

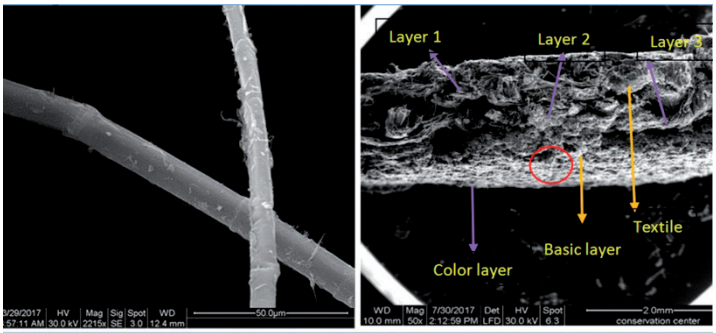

Figure 7. SEM microscopy; a) SEM image showing the identified textile fabric; b) SEM image showing a cross section of the cartonnage components

Scanning electron microscope of the linen fiber shows progressive damage, roughened surface, cracking and longitudinal splitting. Some fibers are damaged with a brush–like fracture (Figure 8a, b and c). In the longitudinal section, the length of the cells varies from 27.4 to 36.1 microns and their diameter from 17.8 to 21.6 microns. Fibers were in the shape of a cylinder divided by thick-walled cross-sections. When examining the linen used in the cartonnages, and as a result of the various damage factors already mentioned, the fibers were fragmented and incomplete, the linen surface is extremely rough. The damage is evident in the form of scratches, holes and transverse cracking of fibers (Figure 8).

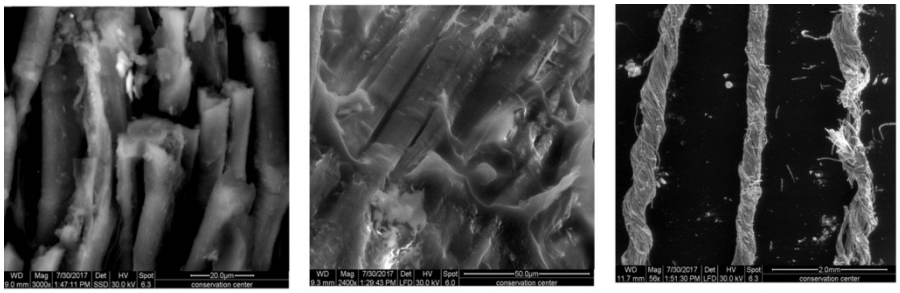

Figure 8. a) SEM images showing the fibers are fragmented and incomplete and separated into small lobes; b) SEM images showing the roughened surface, cracking and longitudinal splitting ; c) Images showing the brush-like fracture of the linen fiber.

3.2. Biological test results

To establish or confirm the diagnosis of a fungal infection, swabs were taken from different areas of both cartonnages. The samples collected depended upon the suspected location of the infection from different areas where biological damage was visible. Fungal testing was used to detect infection, determine which specific fungus or fungi were present and to help establish proper treatment [10]. For fungi, microbial samples were cultured on Czapek–Dox agar plates (30 g sucrose, 1 g K_2HPO_4, 0.5 g $MgSO_4.7H_2O$, 0.5 g KC, 0.01 g $FeSO_4$, 15 g agar, distilled water 1000 ml at pH7.3) (Figure 9). Composition of the various media used are given in Table 1. The fungi were grown in static culture in the dark at *25* degrees Celsius for 4 weeks to maximize the recovery of slowly growing fungi.

Table 1. Showing media used for growing fungal culture

Formula (in /gl)	
Potato extract	4.00
Glucose	20.00
Agar	15.00
pH	5.6 $\pm$ 0.2

A pure fungus was isolated from the isolates taken from the cartonnages; classification of these fungi was done on the basis of color and shape according to Raper & Fennell, 1965, the color and shape of the forms being examined with the naked eye; microscopy was then used to determine their type. These cultures were classified according to Domsch, Gams and Anderson 1980, [11, 12, 13 and 14]. The species characteristics, such as colony color, colony appearance, mycelial texture and pigmentation on both obverse and reverse, on plates, were observed after 3–7 days of incubation under standard incubation conditions. Results revealed the most common fungi to be found on the cartonnages were: *Aspergillus flavus, Aspergillius sulphureus, Aspergillius terreus, Aspergillius fumigatus, Penicillium citrinum, Penicillium chrysogenum*, and *Rhizopus oryzae*. In addition, *Micrococcales* and *Bacillales*, were the most abundant orders among the Actinobacteria to be found (Figures 9 and 10).

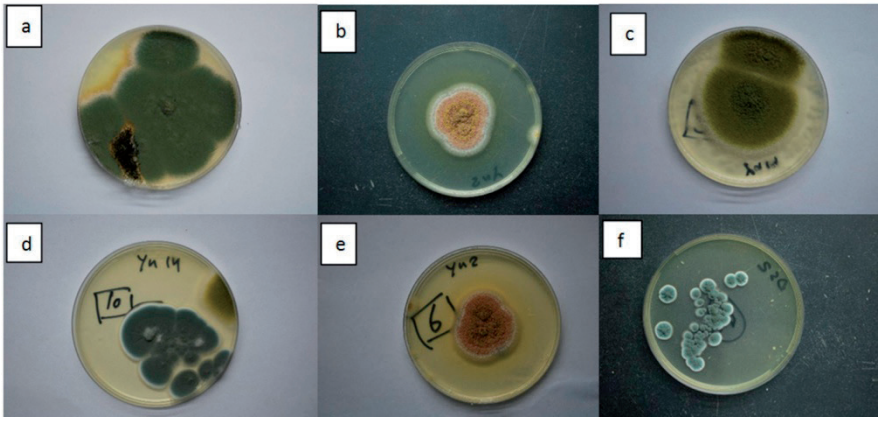

Figure 9. Fungi isolates inside Petri dishes before purification.
a) Aspergillus; b) Rhizopus oryzae; c) Aculeatus; d) Aspergillius; e) Alternaria; f) Penicillium

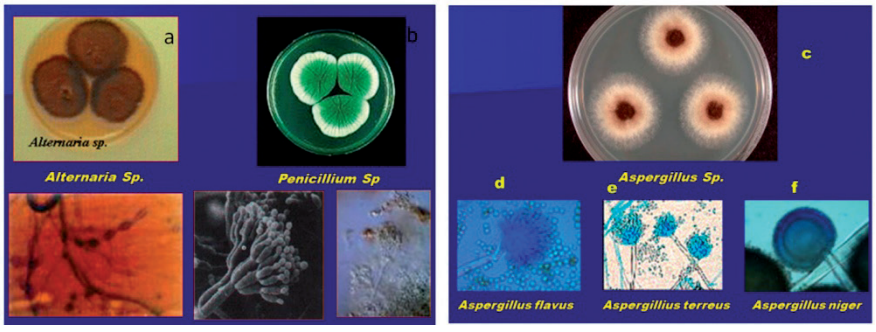

Figure 10. Identified fungi species. a) Alternaria Sp.; b) Penicillium Sp,; c)Aspergillus Sp.; d) Aspergillus flavus; e) Aspergillius terreus; f) Aspergillus niger.

4. State of conservation - cleaning

The objective of the cartonnages' conservation was to maintain their stability and structural cohesion. Apart from considering aesthetic reintegration, a conservator may perform partial or complete restoration on an artifact. This decision is based on results previously obtained from an understanding and knowledge of the materials employed. The use of materials which may become so intractable that their future removal could endanger the physical safety of the cartonnage is to be avoided. In general, all treatments should be reversible.

Cleaning is the first step before starting any remedial action on the cartonnages. The process was conducted by using soft brushes to remove dust and dirt. A sterilization process and treatment with different phenols (e.g. thymol, cymol) was then conducted in a closed glass box and kept for one week to ensure sublimation within the cracks and gaps.

The adherent deposits on the pictorial layer were removed quite easily. The 10 ml acetone, 20ml n-butyl alcohol, and 5 ml ethylene glycol-based solutions gave good results, thinning the blackened surface without negatively impacting on the colors. Support reinforcing was installed after removing previous grouting interventions, where various incompatible materials had been used. Cleaning the reverse side was carried out through physicochemical methods, with compatible substances.

Each phase of the conservation and restoration was tracked and monitored through photographic documentation and surveys, supplemented by a detailed list of the intervention procedures. The old adhesive was removed very gently and slowly by applying small amounts of acetone with a Pasteur pipette. This method permitted the accurate application of the acetone and allowed the conservator to regularly check that the acetone was not affecting the painted part of the front of the mask.

4.1 Previous restoration

The first step is to remove the remains of any previous restoration materials from the internal parts of the cartonnages. To repair the broken parts, cotton strips applied with animal glue were used. All old tapes and cotton strips were removed by using warm water and alcohol (1:1) without excess, so that the solvent did not seep into the inside [5]. Cleaning was performed using diluted organic solvent to prevent dissolving the color or the white preparatory layer [15]. Warm water was used to remove the animal glue in the cotton bands. Scalpels and medical tweezers were also used to help in the removal process. In the case of solid dirt, a solution of ethyl alcohol and turpentine (1: 2) was first used to dilute it and it was then removed. This method gave good results. Some colored parts were cleaned by eraser which was safe and gave good results. A new lining of mild flax was made as a posterior reinforcement for the mask using 15% Paraloid B72 with a xylene [16].

4.2 Filling the gaps in both cartonnages

Gaps were filled before starting the cleaning and repairing processes. Due to the extreme sensitivity of the cartonnage parts, 5% Paraloid B72 dissolved in xylene was

used to strengthen these parts and to prevent their separation. After fixing the separated and weak parts on the back side of the cartonnage and to avoid separation or cracking of the filler material, missing parts and wide gaps were filled with strips of linen using a 10% polyvinyl alcohol adhesive and alkoxide 2000 (Figure 11) [17].

Figure 11. Image showing the process of filling the gaps in the gilded cartonnage.

4.3 Completing the preparatory layer

The preparatory layer was completed using clean brushes and spatulas (Figure 12a). This was completed in three stages so that each layer was lighter in texture than the previous one, using a low glue concentration. The first layer consists of coarse calcium sulfate, as well as a 10% polyvinyl alcohol adhesive. This layer was left to dry to ensure easy and complete bonding with the subsequent layer. The second layer contained fine calcium sulfate with 7% adhesive ensuring that the thickness of each layer did not exceed 1 mm. Thick layers increase the probability of separation and cracking of the preparatory layer [18]. The second layer was left to dry at room temperature. Then a third layer with a concentration of 5% glue and a thin texture was applied. After this layer was completely dried, the surface was smoothed with fine sandpaper till the surface was ready for coloring [19]. Following standard conservation practices, the method chosen must be reversible so that in the future any interventions can be removed easily. All the completed parts were covered by Japanese paper and Paraloid B72, dissolved in xylene at a concentration of 5% (Figure 12b).

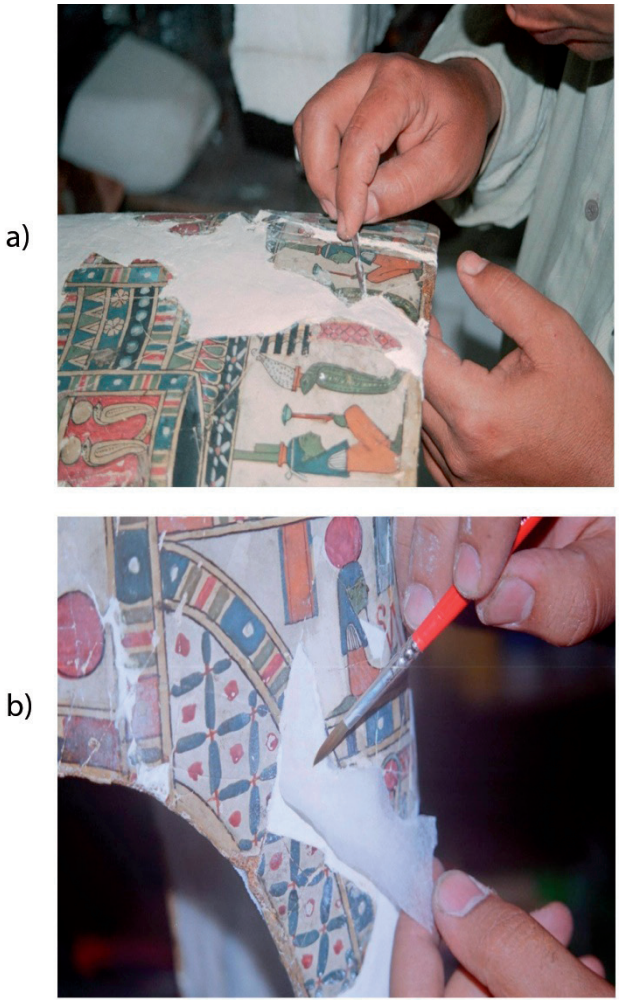

Figure 12. a) Image showing the process used for the preparatory layer;
b) image showing the process of applying the Japanese paper as a base for coloring.

4.4 Missing text and color

Due to the loss of many large parts and the absence of knowledge of the scripts and drawings, it was decided not to color or complete the texts. Therefore, a single color, consistent with the general background color was used [20]. Acrylic paints were used to complete the missing parts of the red and brown on the chest area as well as a black color for the right eye [21]. Acrylic paint differs from oil paint in both its quick drying time, and in the way the paint dries. Acrylic paint dries in as little as thirty minutes and dries by the evaporation of water solvent. Acrylic colors are characterized by reversibility and transparency which make them consistent with the background color.

4.5 Cartonnage protection

From a preservation viewpoint, it is essential to protect the cartonnages from the surrounding atmospheric conditions. The cartonnages were completely isolated using 3% Paraloid B72 dissolved in xylene by brushing both sides (i.e. outside and inside) [22]. During the isolation process, we ensured that all material surfaces were completely dry and clean. During application of the coating layer of Paraloid B72, the direction of the brush strokes was taken into account, so one direction was used to eliminate the appearance of brush marks on the surface. All processes were conducted in a closed and clean environment [23].

The final step was to create two holders for the cartonnages to provide a better display option. A piece of sponge was placed to serve as a cushion for the cartonnage head on the inside to avoid friction between the wooden stand and the cartonnage itself. A wooden holder made of beech wood was designed in terms of size and shape and was coated with a shellac solution to ensure proper homogeneity and uniform weight load distribution on all parts of the cartonnage (Figure 13). The cartonnages were then able to be easily and safely carried and moved, together with the new holders. The cartonnages after conservation are shown in the photos below (Figure 14).

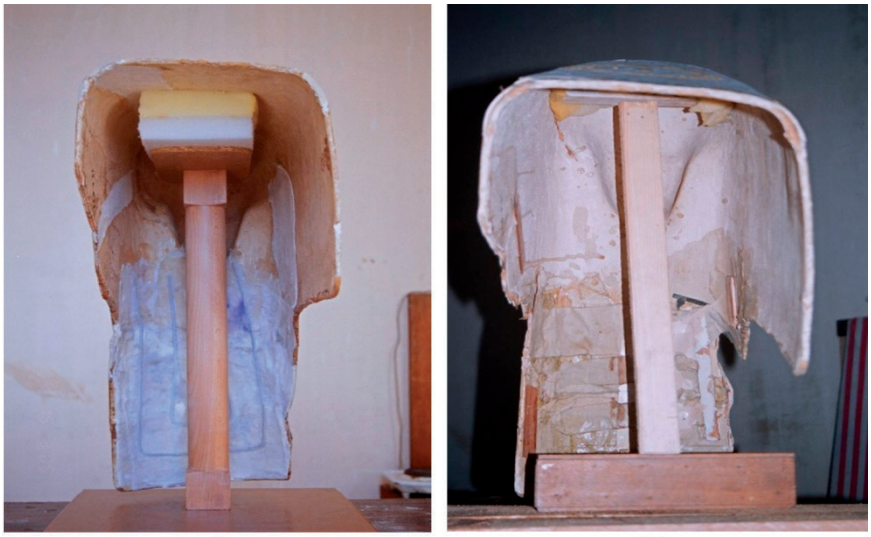

Figure 13. Images showing: a) the new display holder; b) the old display holder

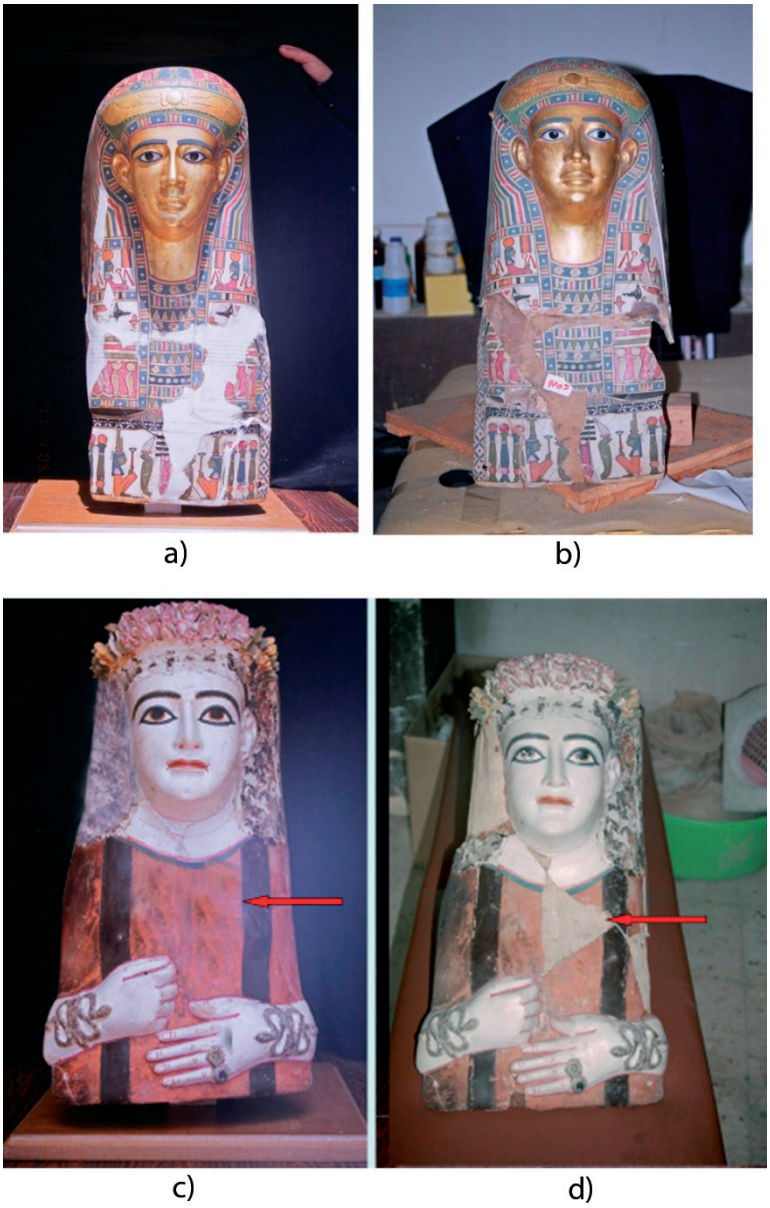

Figure 14. Images showing: a) and c) cartonnages after conservation; b) and d) cartonnages before conservation.

5. Conclusion

An improper display setting is one of the major factors that significantly contribute to cartonnage damage. The major environmental factors that affect the stability of cartonnages are light, temperature, relative humidity, air pollution and microorganisms. Closed glass cases or cupboards create a harmful environment for the cartonnages rather than protecting them. The results of electron microscopy and FTIR revealed the presence of three layers of linen textile made of layers of linen, and sometimes of papyrus, and mounted with animal glue. The preparatory layer consists of calcium carbonate or calcium sulfate with an animal glue medium. The blue pigment was identified as Egyptian blue; the red pigment was identified as hematite. The gilded layer was gold leaf. Results identified the adhesive/binder which was used in the linen layers as animal glue. The study showed the existence of biological infection from bacteria and fungi on the masks. They included several types of fungi, such as: *Aspergillus niger, Aspergillus flavus, Aspergillius sulphureus, Aspergillius terreus, Aspergillius fumigatus, Penicillium citrinum, Penicillium chrysogenum, Rhizopus oryzae* and many types of bacteria such as: *Bacillus subtilis, Bacillus alvei, Bacillus coagulans*

References

[1] Teeter, E., (1994). Egyptian art, ancient art at the art institute of Chicago, *Museum Studies*, Vol. 20 (1), pp. 1 - 96.

[2] Picton, J., Quirke, S., Roberts, P., (2007). Living Images. Egyptian funerary portraits in the Petrie museum. Walnut creek, California.

[3] Bagnall, R. & Reading P., (1995). Writing ancient history, Routledge Press, NY.

[4] Redford, B., 2001. The Oxford Encyclopedia of Ancient Egypt, Th American University in Cairo Press, Vol. 2.

[5] Chizheve, T.D., (1981). Methods of egg tempera panel painting conservation employed in the state Hermitage, the state Hermitage Museum Leningrad U.S.S.R , pp. 1-5.

[6] Wendelbo, Q., (1975). The Freeing of Papyri From Cartonnage", Restaurator press vol. 2 nº 2, Denmark, pp. 41-53.

[7] Wright, M.,(1983). A method of Extracting Papyrus from Cartonnage, Studies in Conservation, 28, p.122.

[8] Jaeschke, L., (1995). A Method of Reshaping Cartonnage without Water Conservation in ancient Egyptian collections, Archetype Publication, Conference held by UKIC Archaeology Section, International Academy Projects Editors: Brown, C., Macalister, F., Wright. London 20-21 July: Archetype Publications. pp. 23-28

[9] Moehler, H., (1980). A New Method of Dismounting Papyrus Cartonnage, Bulletin of the Institute of Classical Studies 27, p.120.

[10] Green, L. (2001). Colour transformations of ancient Egyptian pigments. In: W.V. Davies (Ed.), Colour and Painting in Ancient Egypt, Oxbow Books, London, pp. 43-48.

[11] Derrick M.R., Stulik D., Landry J.M. (1999). Infrared Spectroscopy in Conservation Science, The Getty Conservation Institute, Los Angeles, pp. 97-98.

[12] Domsch, K. H. & Gams, W. & Anderson, T.H. (1980). Compendium of Soil Fungi, I and 2, Academic Press, Inc., London.

[13] Mandelstam, J., (1982). Biochemistry of bacterial growth, Third Edition Edinburgh, London.
[14] Atlas, R., (2010). Handbook of Microbiological Media, fourth Edition, Taylor and Francis Group, CRC Press, Boca Raton.
[15] Bock, E. Sand, W., (1993). The microbiology of masonry biodeterioration. J. Appl. Bacteriol. Second edition, volume 1, the Rockefeller University, New York 74:503-514.
[16] Jullia, P., Natalie, N., (1986). Microbiological degradation of lead containing pigments in mural painting. Studies in conservation, Vol, 31.
[17] Romer, B., (1979). The technology, examination and conservation of the Fayoum portraits in the Petrie Museum, Studies in conservation, Vol, 24.
[18] Podany, J.,Garland, K. Freeman, W. Rogers, J., (2001). Paraloid B-72 as a structural adhesive and as a barrier within structural adhesive bonds, evaluations of strength and reversibility, Journal of the American Institute for Conservation 40 (1), pp. 15-33.
[19] Cyril A., (1998). Mummy coffin and Cartonnage of Lady Teshat, Minneopolis Insititute of Art, No. 125.
[20] Jaeschke, L., (1997). Mechanical cleaning and the conservation of portraits from the Petrie Museum of Egyptian archaeology, From Portraits and masks, London: Published for the Trustees of the British Museum by British Museum Press, London.
[21] Vaticani, M. Egizio, G., (2007). The restoration of the funerary cartonnage of Ny Maat-Re, Decorated Surfaces on Ancient Egyptian Objects: Technology, Deterioration and Conservation, ICON Archaeology Group and Fitzwilliam Museum, Cambridge 6-9 September 2007.
[22] Johnson, C. Gill, A. Miller, E. Hignett, K., (1997). Aspects of consolidation, From Portraits and Masks, British Museum Press.248.
[23] Adams, C., (1996). The manufacture of ancient Egyptian cartonnage cases, The Smithsonian Journal of History, Vol. 1, pp. 55- 66
[24] David A. Scott, M., Narayan, K., Keeney, D. & Dodd, L., (2003). An Egyptian cartonnage of the Greco-Roman period examination and discoveries, Studies in Conservation, Vol. 48 (1), pp. 41-56.
[25] El Hadidi, N, Darwish, S., (2008). The Use of Acids and Bases in Cleaning archaeological Wood in Giza Through Ages, Studies in Conservation, Environment and Tourism, Faculty of Archaeology Cairo University, vol. 2, pp.43-60.

Biographical notes

Firas Alawneh is an Associate Professor of conservation science at the Hashemite University; in 2006 he obtained a PhD in material science and engineering at Arizona State University. He is Dean's assistant at Queen Rania Faculty of Tourism and Heritage, as well as being the head of the Department of Conservation Science since 2016. He has participated in several archaeological excavations, international projects, workshops and training courses. He teaches conservation science, including conservation and restoration theory and practice, materials characterization, history of architecture, documentation, and other courses. His research interests include conservation, resto-

ration, material analysis and the history of architecture. He is the author of more than 30 publications in these areas.

Abdel Rahman Elserogy is a Professor of monuments conservation. He obtained his PhD in Conservation and Investigation of oil panting in 2002, Department of Restoration, Faculty of Archaeology, Cairo University, Egypt. He worked as Assistant Professor at the Department of Restoration, Faculty of Archaeology, Fayuom University, Egypt from 2005-2008. He now works as a faculty member at the Department of Conservation, Faculty of Archaeology and Anthropology, Yarmouk University, Jordan. He was head of the Department of Conservation in the lower Egyptian museums, Sinai and Northern coast of Egypt from 1995-2003. Since 2003 he has taught practical courses in the treatment and conservation of various organic materials such as wooden coffins, icons, oil paintings, textiles, carpets, manuscripts, bone, basketry, feathers and preventive conservation in museums.

Eyad Al Masri studied fine art in Jordan receiving a Bachelor's degree in Art from Yarmouk University in 1987, a Master's degree in Archaeology at the same University in 1991. In 1997 he obtained a PhD in Art History from Baghdad University, Iraq. He became Assistant Professor in 2003 and associated Professor in 2013 (to date), teaching courses in the fields of art, archeology, civilizations and cultural resources management. His research interests and publications are in art history with a focus on Nabataean Art. He has participated in Archaeological excavations at three sites in Jordan. He is a very active artist; his works abound with ancient symbols, seal inscriptions and contemporary images, a visual interplay that fuses the past and present. His medium and technique emphasize the spirit of the ancients as his works are not just painted, but carved and sculptural in appearance.

Summary

This paper describes the multi-analytical techniques and treatment processes that were undertaken in the conservation of two deteriorated cartonnages of the Greek-Roman period. Due to the lack of cartonnage specialists and the complicated nature of the restoration process, cartonnages within Egyptian museums and storage areas suffer from neglect and various other problems. The issue of cartonnage restoration is, so far, still a subject of scientific controversy. The research described in this paper dealt with the conservation and restoration of two mummy cartonnages found in Saqqara. Damage factors were identified and a biological study was conducted aimed at identifying the microorganisms that had led to biological infection. Furthermore, spot-stains caused by using resin in the mummification process were also inspected. Scanning electron microscopy (SEM-EDX), X-ray diffraction and Infrared (FTIR) results revealed the cartonnage components. It is clear from the spectra obtained with the blue colored sample that Egyptian blue was used. The white pigment composition appears as a combination of calcite and as calcium silicate mixed with aluminum silicate. FTIR revealed the presence of three layers of linen textile, which were made of layers of linen, and sometimes of papyrus, and mounted using animal glue. After examining the condition of the cartonnages and studying the results of the previous analysis, a treatment and restoration plan was developed and applied. Treatments included: strengthening the colors and weak parts, cleaning, removal of previous restoration materials and replacing the missing parts as well as preparing two new display holders.

Riassunto

Questo documento descrive le tecniche multi-analitiche e i trattamenti che sono stati intrapresi nella conservazione di due cartonaggi deteriorati del periodo greco-romano. A causa della mancanza di specialisti di cartonnage e della natura complicata del processo di restauro, i cartonnages all'interno dei musei e delle aree di stoccaggio egiziani sono in cattivo stato di conservazione. La questione del restauro del cartonnage è, finora, ancora oggetto di controversie scientifiche. La ricerca descritta in questo documento ha riguardato la conservazione e il restauro di due mummie di cartonaggi trovati a Saqqara. Sono stati identificati i fattori di danno e uno studio biologico è stato condotto per identificare i microrganismi che avevano portato all'infezione biologica. Inoltre, sono state ispezionate anche macchie di macchie causate dall'uso di resina nel processo di mummificazione. La microscopia elettronica a scansione (SEM-EDX), i risultati della diffrazione ai raggi X e dell'infrarosso (FTIR) hanno rivelato i componenti del cartonnage. È chiaro dagli spettri ottenuti con il campione di colore blu che è stato utilizzato il blu egiziano. La composizione del pigmento bianco appare come una combinazione di calcite e come silicato di calcio mescolato con silicato di alluminio. FTIR ha rivelato la presenza di tre strati di tessuto di lino, che erano fatti di strati di lino e talvolta di papiro e montati con colla animale. Dopo aver esaminato le condizioni dei cartonnages e studiato i risultati dell'analisi precedente, è stato sviluppato e applicato un piano di trattamento e ripristino. Trattamenti: rinforzo dei colori e parti deboli, pulizia, rimozione dei materiali di restauro precedenti, sostituzione delle parti mancanti e preparazione di due nuovi supporti.