CONSERVING, RECONSTRUCTING AND DISPLAYING TUTANKHAMUN'S SANDALS: THE GEM-CC'S PROCEDURE

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Abstract

Although the new Grand Egyptian Museum (GEM) near the Giza pyramids is not yet open, the Conservation Centre (CC) is operational and the employees are working full time to prepare the objects for permanent exhibition in the GEM. Among these objects are the 'sewn sandals' that were recovered from the tomb of Tutankhamun, which were moved from the Egyptian Museum at Tahrir to the Organic Material Laboratory of the Conservation Centre in 2010. The present paper explains the cleaning and conservation work done in order to exhibit them properly and preserve them for future generations and allows a glimpse into the work (methodology of treatment and conservation) at the GEM-CC.[1]

Introduction

Discovery

The discovery of the tomb of Tutankhamun in 1922 by Howard Carter is celebrated as one of the biggest archeological discovery of all times. For the first time, humankind could see the wealth Egyptian kings were buried with. Among the many thousands of finds, were the sandals and shoes of the king (Figure 1), which have recently been studied, nearly 90 years after the discovery (Veldmeijer, 2010). It appeared that all footwear are so-called 'sewn sandals' or based on this type of sandals.

The sole of 'sewn sandals' is made of transverse bundles of vegetable materials (usually halfa grass, *Desmostachya bipinnata* or *Imperata cylindrica*, but other grasses were sometimes used too), which are secured with a strip of dom palm leaf (*Hyphaene thebaica*) that wraps the grass bundle and secures it by the sewing. The stitches of the subsequent rows are sewn through the previous row, either through (part of) the bundle, or mainly through its winder. The transverse rows are finished with an edge, which is made in the same technique, i.e. a fibre core, which is wrapped and sewn with palm leaf strips. An edge can have two or three rows. There is considerable variety in the tightness and refinement of the sewing; the

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[1] All images by Nagm El Deen Morshed, courtesy of the Ministry of State for Antiquities unless mentioned otherwise.

Figure 1. Pair of sewn sandals (Carter's 021a, b) as found by Carter and his team. Photograph by Harry Burton. Courtesy of the Griffith Institute, University of Oxford.

expensive C-Type, however, distinguishes itself by the default high quality of manufacturing. All finds from Tutankhamun's tomb are of this type (Veldmeijer, 2009, 2010).

The straps consist of various parts. At the back, a pre-strap, consisting of a strong loop of palm leaf, is clad and secured to the edge of the sandal by additional cladding, which is stitched through the sole. The loop points upward. The pre-strap serves as attachment and reinforcement of the back strap, which is fixed to it with a papyrus strip (*Cyperus papyrus*). Usually, the wrapping extends a few centimetres high and includes the pre- and back strap. Although the pre-strap is made of palm, the back strap is made of various layers of papyrus, which results in an aesthetic pleasing effect. The back strap is rather thick and widens dorsally of the foot. The front strap is attached at the centre of the back strap by means of looping. It usually consists of a core that is clad transversely with strips of palm leaf; in Tutankhamun's sandals they are clad twice. This cladding tightly secures the looping to the back strap. The lower part of the front strap is inserted in the sole off centre in order to fit better between the first and second toe. At the ventral surface of the sole, the strap is secured with a crown sinnet.[2]

[2] See Greiss (1949), Gourlay (1981a, b) and El Hadidi & Hamdy (2011) for additional identification on sewn sandals. The identification of fibre sandals of the Ancient Egyptian Footwear Project is forthcoming (Cartwright & Veldmeijer).

Post-Excavation Treatment

When excavated, the objects were preliminary treated by Carter and his team which consisted in most cases of pouring warm wax over the sandals. Authorities like Flinders Petrie and Alfred Lucas recommended protective beeswax and paraffin coatings. Indeed, using wax was such a popular treatment that, apparently, Howard Carter even claimed to have employed paraffin wax to treat his mange-stricken pet dog (http://conservationblog.hearstmuseum.dreamhosters.com/?p=651).Wax was expected to strengthen the materials and to prevent moisture from affecting them. Oils and waxes were also used to saturate surfaces and colours that appeared dry. There may have been a sort of "feeding of the wood myth" in those days for plant material treatments: paraffin and other wax treatments occur frequently in museum documentation as most common treatments. A common problem with artifacts treated with a wax — and to some extent in those treated with various oils — is that different gradients are created between tissues coated with the wax, restricting moisture vapor permeability: those less affected by the wax or oil will remain more permeable. Therefore, the vegetable materials respond quite differently to changes in relative humidity: the tissues at the margins of the gradient are placed under tension and compression and can therefore fail, causing cracking, splitting, loss of surfaces, and structural damage. The same can be expected with treatments with resins that either partially saturate materials before forming a film or which coat the surface fibers in a treatment procedure. This may be an inherent danger with direct resin adhesion treatments.

Many objects that were coated with wax in the early twentieth century now have dark, dull looking, gray surfaces. Over time, slightly tacky wax attracts minute particles of dirt, dust and grime. The build-up of dirt and grime eventually causes the wax-coated surface to appear dark and opaque, sometimes obscuring painted or carved designs. This is clearly visible in the photographs in the first publications of the sandals by Veldmeijer (2009, 2010), as no cleaning work other than small brushes and blowers were used at the time (compare Figure 1, 2 with Figure 8b). The wax led to the distortion of the surface and in some cases hid some of the technological features, like the sewing structure.

Pre-Conservation

First Examination and Documentation

Preparing objects for display in the GEM-CC consists of various steps, which are documented visually, by means of photography and annotated Auto-Cad diagrams as well as in a narrative format. The first step is manifold, involving the macroscopic study of the objects and a literature review of the object and object type, as well as discussions with specialists to understand the manufacturing technology and to identify the materials used as these determine the conservation strategy. Furthermore, areas of damage are registered and interpreted: e.g. whether they are ancient or more recent, as well as the type of damage. Previous interventions influence the conservation strategy, which means that, simultaneously to the aforementioned study, excavation records, the archives of the museums and conservation reports (if they exist) are consulted to get insight in previous treatments. The GEM-CC has a wide range of equipment, varying from plain magnifiers and stereo- and optical light microscopes to Scanning Electron Microscope (SEM) and Fourier Transformation Infra Red (FT-IR), but

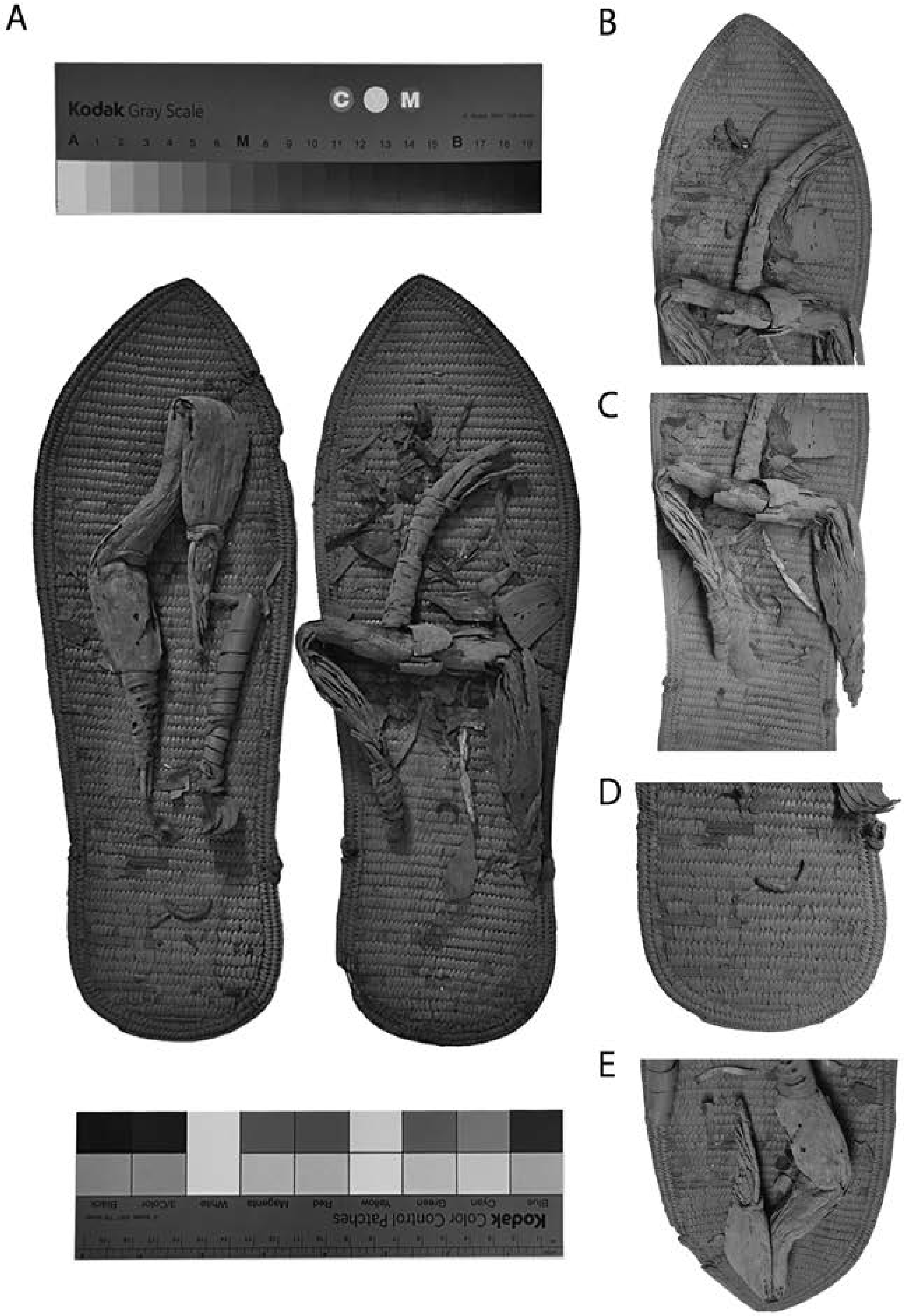

Figure 2. Photographic documentation is the first step upon arrival of the objects in the GEM-CC.

before using these, careful consideration of what actually is needed is paramount. For example, if the material at hand is in such a good state, identification of the material can be done with less expensive and complicated means, such as magnifying glass or stereo-microscope. Consulting other specialists, such as archaeobotanists, secures adequate identification.

The sandals are documented meticulously, resulting in an exhaustive data file, which allows assessment of the project during and after the conservation process. It can be consulted in the future if new interventions are required so that no conflicting methodology is used.

Photographic documentation in visible light was the first step of the photographic documentation immediately after the sandals entered the GEM-CC and before anything else was done (Figure 2). Visible light is helpful as it can be manipulated by using different light sources or filters to bring out details in the object that may not otherwise be noticed. The photography is done with a digital camera (Canon EOS 50D, Zoom lens 18:200x) with leveler on a tripod or photography stand using daylight lamp, light stand and auto-meter. The object was put on grey background paper, and photographed with a scale bar, colour chart and a label with object ID, the date and stage of conservation included in the frame. This photography is the first and most important visual documentation of the object before treatment, but visual light photography is done at various stages of the conservation process too in order to safeguard and continuously guide the conservation process.

The visual light photography is complemented with Ultra Violet (UV) light examination (some materials absorb UV radiation of around 250 -360 nm and emit fluorescence by excitation). This technique can emphasize colours, reveal stains and signs on the surface of previous interventions that would go unnoticed with other photography techniques (Figure 3). The annotated AutoCad drawing, a visual document of the condition of the object in which the different types of deterioration and damage are marked in different colours and/or codes helps to locate the different types of damages (Figure 4).

Preparation for Conservation

The next phase in the conservation process is to assess the condition of the object and determine an appropriate treatment. This includes methods such as identifying the acidity (pH), and intensified visual research with high power microscopes.

Measuring the pH value (Figure 5), i.e. the acidity of a material, is important as low pH (high acidity) attacks the cellulosic and other components of plant tissues. The result is a much weaker and more brittle material, which is more susceptible to further deterioration. If, on the other hand, the material is alkaline it may be due to degradation from hydrolysis or oxidation.

Stereomicroscopes allow magnification of up to several hundreds times (Figure 6), where layers of wax, to which dust and other types of dirt adheres, can be seen in detail: it revealed that the condition of the strips of dom palm leaf, which were used to sew the bundles together, was relatively good but simultaneously showed that the condition of both the grass and papyrus was much worse. Comparison with newly harvested plant fibres was done to record changes and further interpret the condition.

Scanning Electron Microscopy (SEM) allows magnification up to several million (Figure 7). The sample is irradiated with an electron beam from above and the reflected electrons are computerized into an image to observe surface information. This technique can also help to

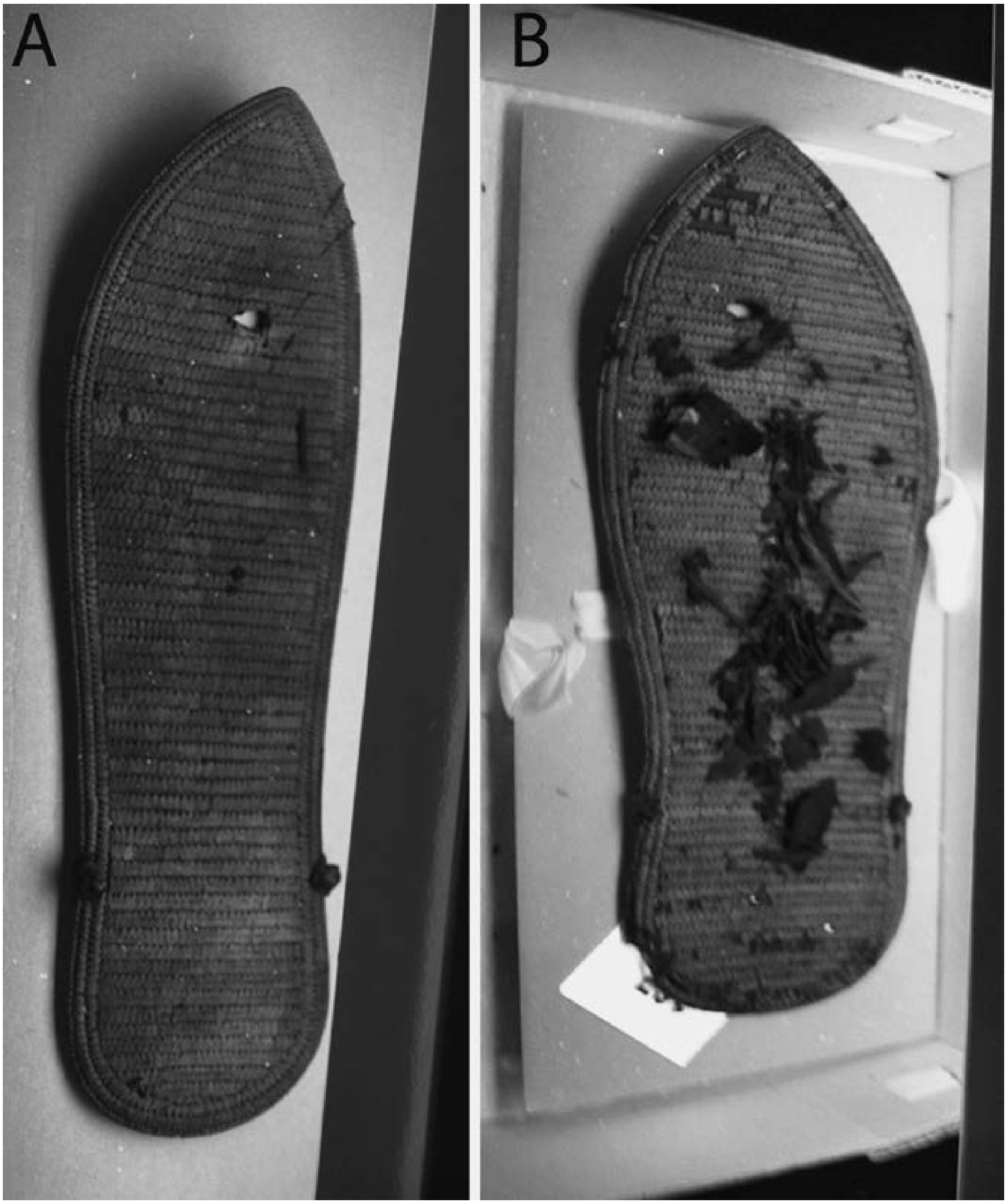

Figure 3. UV light was used as this shows spots that would go unnoticed otherwise.

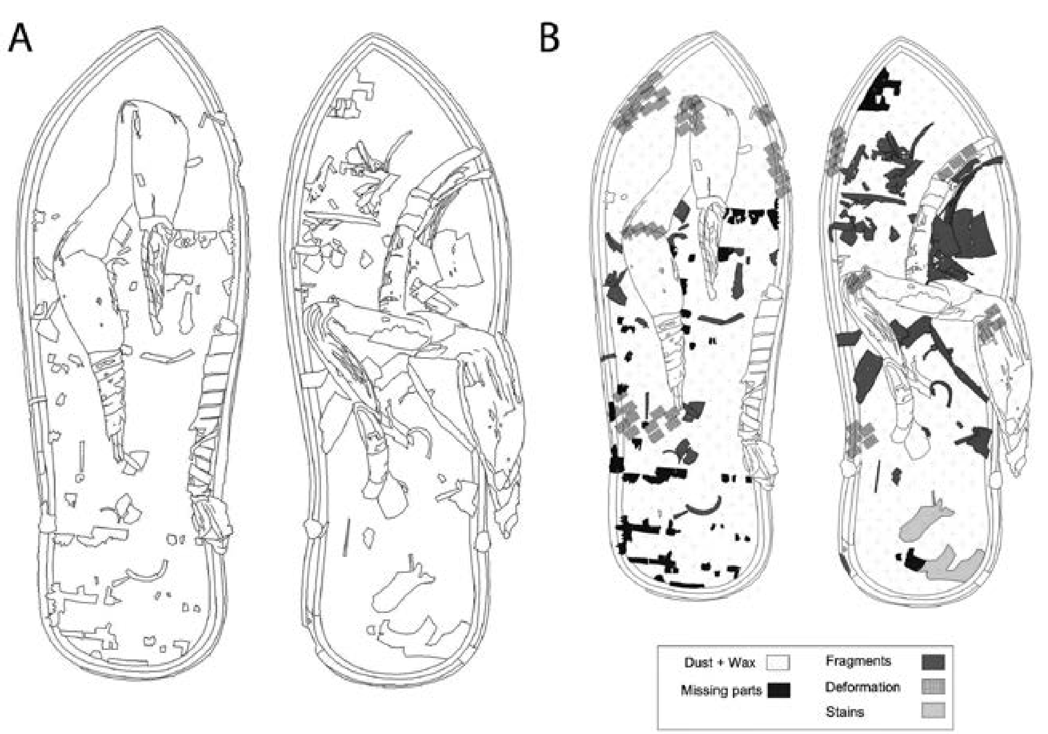

Figure 4. AutoCad drawing with various types of damage indicated in different colours.

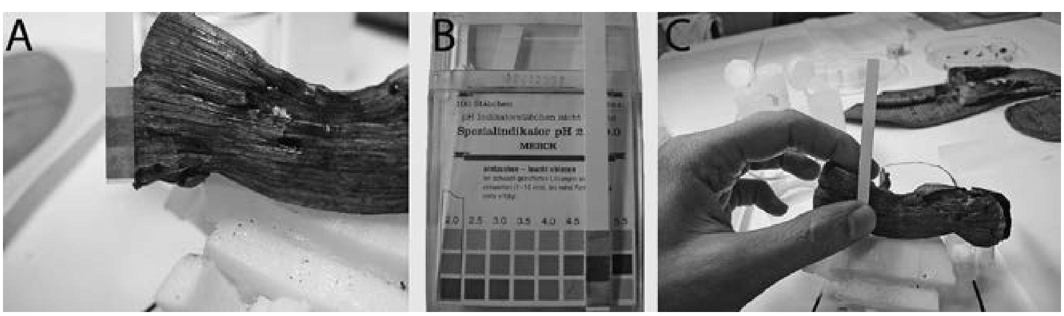

Figure 5. Measuring the pH value (using pH colour indicator test strips) is important as a too low or too high value will destroy the material more rapidly.

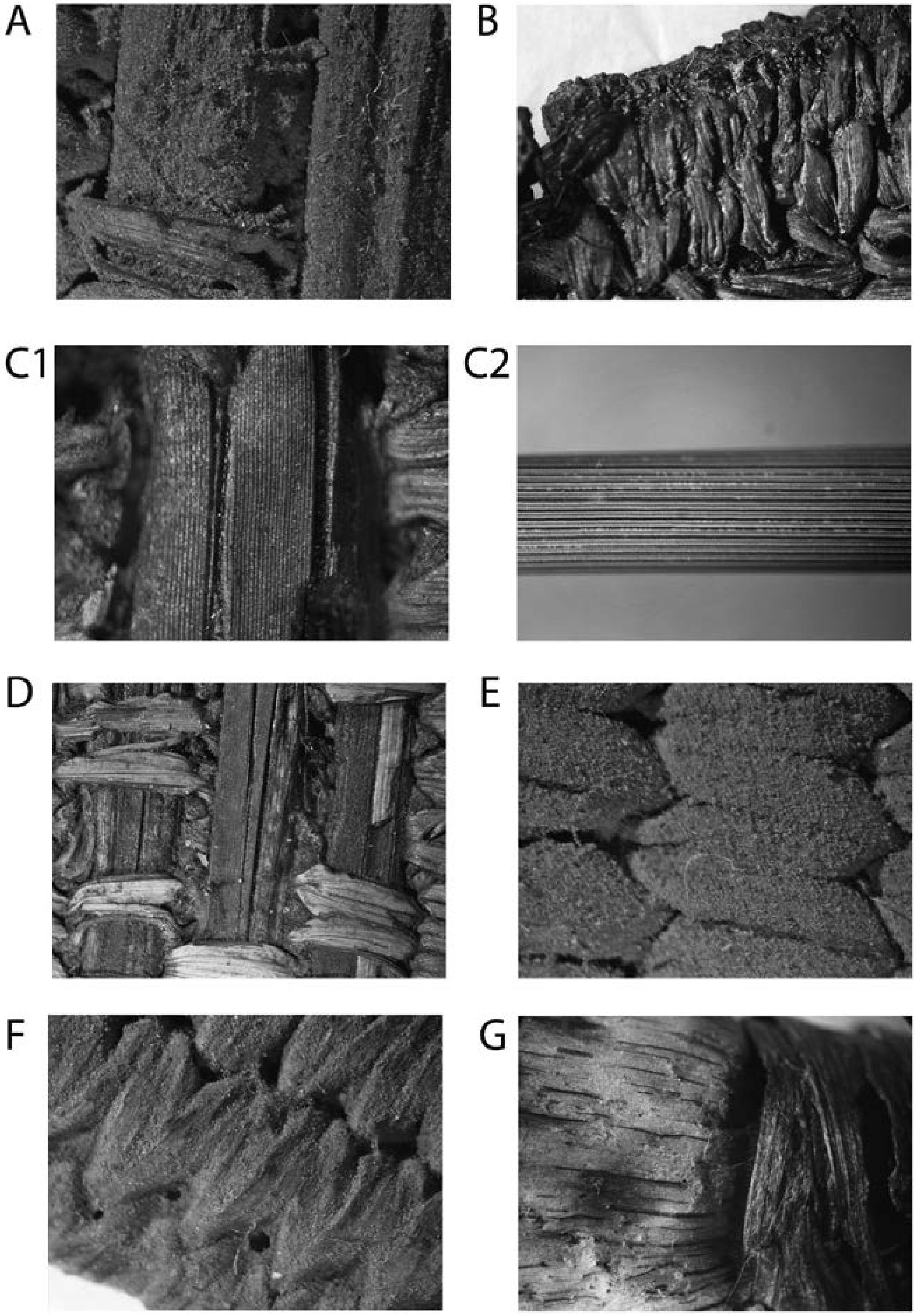

Figure 6. The excellent preservation of the material allows for identification of the plant fibres by stereomicroscope, aided by comparison with newly harvested plants (c2).

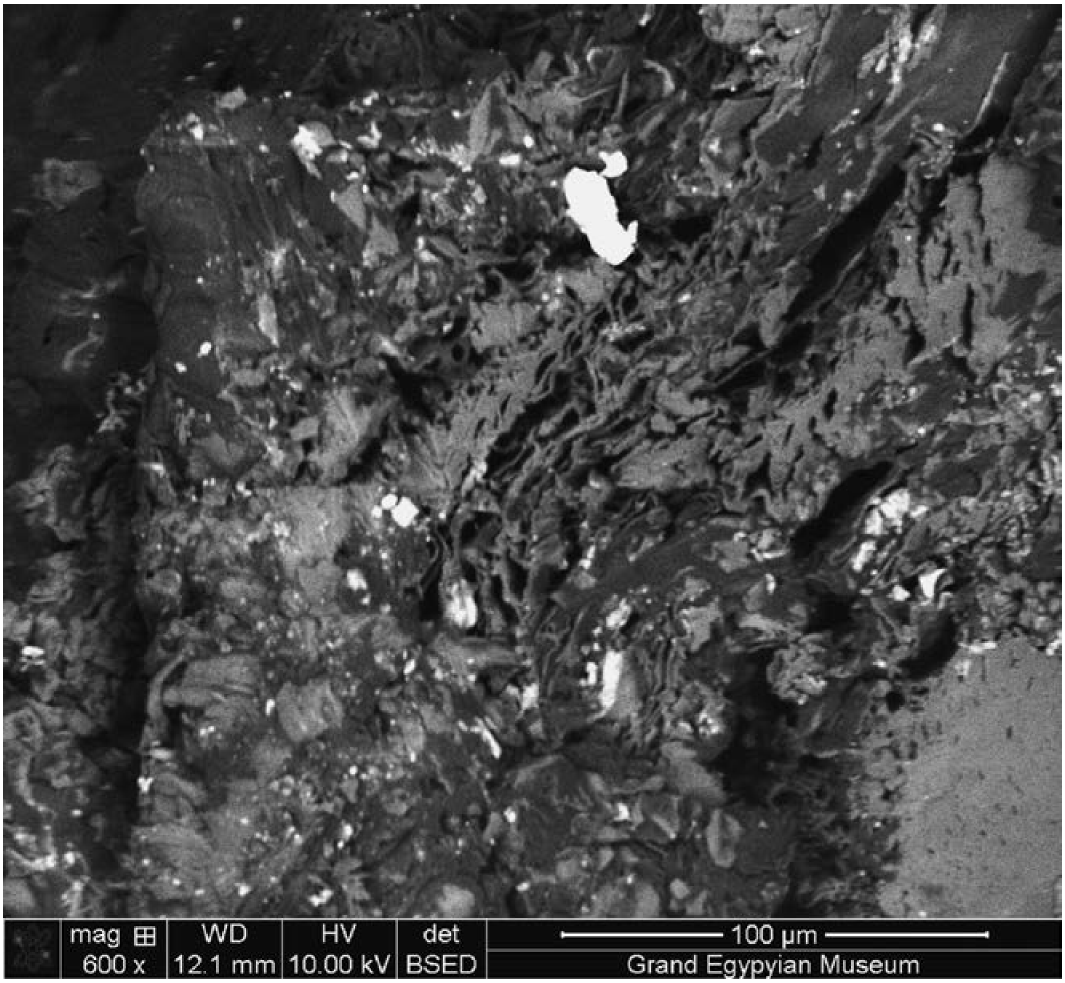

Figure 7. Longitudinal section under SEM.

investigate the plant fibre and identify species; three samples of plant fibres were investigated under magnification between 50 X and 2500 X (see above for the identification of the materials). The study of the surface morphology, cross section and longitudinal section not only identified plant species but also showed a high degree of degradation and damage. The surface of the fibres was extremely rough and had wax on the surface and inside the pores (see below). The damage is also evident from the deformation noticeable in the cross section and the calcifications of salt.

The three type of plant fibres (papyrus, halfa grass, palm) were analyzed by Fourier Transform Infrared Spectroscopy (FTIR) Spectrum Analasis. The spectrum was measured at a resolution of 4 cm^{-1} and 50 scans were recorded per sample. From the main characteristics of IR absorption bands for the three types of plant fibres were the O-H stretching bands about

3500-3200 cm^{-1}, the C-H stretching bands about 2954-2800 cm^{-1}, the C=O stretching band about 1800- 1627 cm^{-1}, the C=C stretching band about 1620 cm^{-1}, the CH2 bending band about 1462 cm^{-1} , the CH3 bending band about 1377 cm^{-1}, and, finally, the CH2 bend band about 721 cm^{-1}. Paraffin wax is mainly composed of hydrocarbons, and the IR spectra should only show the C-H stretching vibrations of saturated hydrocarbons located at 3000 cm^{-1}, the -CH3,and C-H deformation at about 1460 and 1380 cm^{-1} respectively, and the rocking and wagging of –CH2 , at 720 cm^{-1}. Beeswax include the same long hydrocarbon chain as mineral waxes but also contain free carboxylic acid and esters groups illustrated by the specific IR bands around 1700 cm^{-1}, corresponding to the carbonyl (C=O) stretching vibrations. These fundamentals help to underscore the difficulty in distinguishing aged waxes (with a high percentage of branched hydrocarbons and cycloalkanes) by means of oxidation, which can eventually produce carboxyl and ester byproducts. This makes it very challenging to differentiate it from a natural ester-containing wax, such as beeswax. From the characteristic of IR absorption bands we can confirm and identify the presence of bees wax and not paraffin wax with the samples (see conserving outdoor sculpture, the stark collection at the Getty center, Derrick et al., 1999: 133, 184).

Condition Assessment

The afore-mentioned techniques allow us to make a detailed condition assessment. Plant fibre is composed of carbohydrates (cellulose, hemi-cellulose, and lignin) and protein; the vascular bundles are primarily lignin, and the surrounding tissue, cellulose. While cellulose is a stable material, it is vulnerable to degradation from oxidation, hydrolysis, and acidosis. Organic material, plant fibres such as papyrus, halfa grass and dom palm leaf, are subject to chemical processes induced by acid, air, and water. Acid is of particular concern, as mentioned previously, and plant fibres’ naural acidity is in the range of 4.0-5.5 pH.

Oxidation, or ‘slow burn’, makes plant fibre brittle. Hydrolysis, a chemical reaction with water, turns the fibre from its original ivory white to a yellow-brown. This is particularly noticeable in the case of papyrus fibre.

The various types of damage that were recorded can be summarized here:

- Mechanical damage, caused by use, rough handling (e.g. by the robbers and/or the priests alike).
- The condition of the sandals suggests that fluctuations in relative humidity during post-excavation and while in the tomb over a long period of time have had a negative impact on the sandals: plant fibres are hygroscopic materials which lose water easily in a dry environment, making the fibres extremely brittle. Moreover, if humidity rises, it absorbs water too easily, which leads to the most important aspects of damage and deformation on the shape of the sandals. These rather specific features, therefore, might indicate different areas within the tomb with different environmental conditions.
- The wax, used by the excavators, protected the sandal after they were excavated but also resulted in accumulated dirt, giving the sandals a gray/dark patina.

Practical Conservation Work

Treatment Procedures

The conservation work starts with designing a Treatment Procedure (TP), which consists of various components (note that the order of the components might differ from sandal to sandal; moreover, not all sandals have to go through all components), discussed below.

The plant fibres are friable, highly fragmented and splintered which required preliminary consolidation to prevent loss of fibres during conservation. Consolidation was done with Japanese tissue 9.3 G/M that was secured to the plant fibre with a 2% solution of "Klucel G" (Hydroxy propyl cellulose H.P.C). This type of consolidation is essentially a mending technique as the old wax closed the pores of the fibre completely, which reduced penetration of adhesive solution inside the fibre, due to which the Japanese tissue does not adhering strongly, allowing for easy removal after finishing the conservation process.

Despite the drawbacks of the use of wax, as mentioned above, it also assisted the sandals to remain in the shape and condition in which they were found by Carter and his team, as it strengthened the structure and sealed the material from outside environmental factors. Nevertheless, this layer of wax had to be removed first before new conservation work could be done.

Cleaning is a non-reversible treatment and once dirt and dust is removed, it can never be replaced again. Thus examining it before removal is of importance too. The sandals were cleaned using mechanical and chemical methods. Mechanical cleaning means physically picking up or removing dirt particles (Figure 8). The surface of the sandals were very dusty and

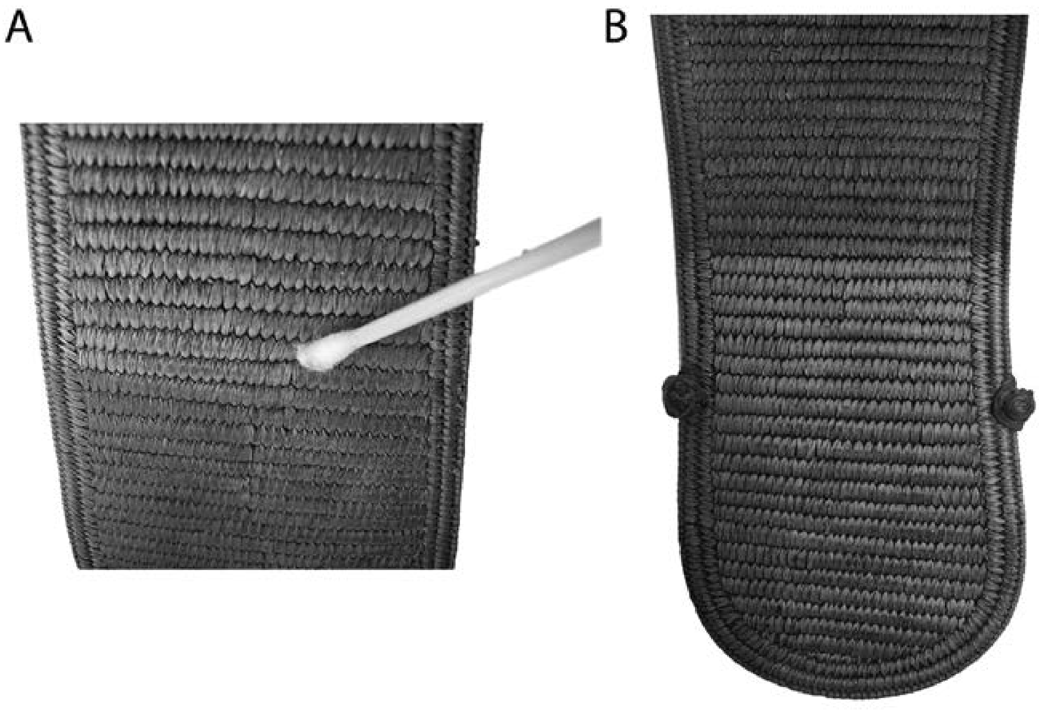

Figure 8. Removing the wax, poured on it by Carter and his team, with a mixture of benzene and alcohol (1:1).

stained so it was necessary to remove it together with the wax layer that attracted it. Soft flat brushes were used for first cleaning of the loose lying dust. Needles were used to remove the wax in narrow areas, such as the space between the rows of sewing as well as between the individual stitches themselves. The mechanical cleaning was followed by chemical cleaning, using different types of solution to dissolve the wax. Tests were carried out first to determine the most efficient solvent, and to determine if the solvent may be used on the object without adversely affecting the sandals fibres or appearance. A mixture of white spirit and Ethyl alcohol absolute was applied using swabs of cotton rolling them back and forth over the surface of the sandals. The mixture successfully removed the uppermost surface of the wax to clear the view of the sandals: the entire wax layer was not removed because if the solvent was allowed to penetrate inside the pores of the fibres it would cause additional damage to the fibre.

The sandals were humidified in order to restore some of the original flexibility of the plant fibres and allow distortions in the shape to be removed. When humidified, hygroscopic materials such as plant fibres swell and relax, thus becoming more flexible. The plant fibres were severely desiccated, and although this is the main reason the object survived for such a long period of time, it also made the fibre extremely brittle and fragile. The wax complicated the humidification process as the absorption of moisture was limited because the wax closed the pores of fibres. The different types of vegetable fibres (papyrus for the straps, halfa grass for the bundles and dom palm leaf for the sewing) absorbed the wax differently, which caused a different response to the humidification too.

An Ultrasonic Steam Cleaner Scalpel was used for humidification, which allows slow introduction of water into the fibre in extremely small quantity. The carefully managed heat of the vapor solved a thin layer of wax, thus making it possible for the fibre to absorb the moisture, restoring part of the original flexibility of the fibre. During the process misplaced fibres were repositioned before drying and continuing with the next step of the treatment. In preparation for the reconstruction, an Ethafoam (closed cell polyethylene foam) model was made to support the sandal.

After cleaning and stabilizing, the sandals were finally consolidated. Paraloid B72 5 % in acetone was used only to connect the loose fibres and fix them to the sandals. For reshaping the paraloid was, assisted by Japanese tissue paper (Figure 9). This solution is much stronger than the one used in the preliminary consolidation and the adhesion is faster; the higher the concentration, the faster the adhesion will be. A high concentration was therefore used. The GEM-CC opts for the minimal amount of intervention, thus the work is more a process of reducing the previous intervention by Carter and his team.

Post-Conservation

After conservation and reconstruction, preparations were made for the proper display or long-term storage of the sandal.

Long-Term Storage / Display

The organic sandals are stored in special rooms designated for Tutankhamun's antiquities, which have suitable conditions for the preservation of organic materials, most notably a regulated climate (temperature and relative humidity). The relative humidity remains between

Figure 9. After cleaning and stabilizing, the sandals were finally consolidated with Paraloid B72 5 % in acetone and Japanese tissue paper.

Figure 10. A mold was made to display the sandal appropriately.

45-55%, with a temperature between 18-22º C. The light levels are kept at a level less than 50 lux, without ultraviolet. The sandals are stored in acid free boxes, wrapped in and fully supported with acid free tissue paper. Not all sandals that have been conserved will be put on display: some will remain in the storage. If the sandal is to be displayed, a holder was made that fully supports the sandal to avoid stress on the structure. Moreover, a material needs to be used that is chemically stable in the long-term and inert so that it does not interact with the materials of the sandal. Thus in this case a mold was made of Plexi-glass (Acrylic sheet or glazing) in the shape of the sole as well as a support for the reconstructed straps (Figure 10). This was done after a prototype was made of ethafoam to create the perfect shape.

The Tutankhamun objects have various numbers: besides the Carter number, they might have a Journal d'Entrée-number, given when entering the Egyptian Museum, a Special Registry Number, Temporary Registry Number and/or a Catalogue Général Number. However, all objects that enters the GEM gets a new number (so-called GEM number), which is added to the older numbers but only the GEM and Special Registry number are used for labels on display. The labels are attached to the sandals with threads of a transparent plastic, avoiding the danger of losing the label.

Discussion

The GEM-CC procedure is one of minimal intervention for several reasons: stabilising and consolidation is the main goal of the conservation strategy, particularly with the view in mind that new techniques in the future might have better results. The most important principles that must be considered during the conservation is that the object should be retreatable, because if a new material is developed in the future which is more effective, the old material should be easy to replace or at least not damage original material. In choosing materials to be used, these should be clearly distinguishable from the original, in order to allow future conservators to easily recognise this intervention. The use of fresh plant fiber is avoided because in due course aging may occur for these new fibres as well, making them indistinguishable from the old fibre, which will mislead the scientific research or a conservator in the future. Not putting any ancient fibre from fragments of sandals back without making absolutely sure that this is the right place; if there is the slightest doubt, placing fragments back should not be undertaken. The whole procedure is monitored in detail and an extensive file is made with all relevant information.

As a rule, conservation intervention has both positive and negative effects. Thus, before starting the work, a strategy should be made based on the study of the condition of each piece at hand in order to decide on the type of interventions. Furthermore, the aim of conservation is to show the object as much as possible in its pre-damaged state and prevent future deterioration, with the minimum of intervention, and in such a way that additional future investigation is not prohibited by it. The conservation of the sandals includes an evaluation of the previous interventions conducted by the excavators or conservators. For example - Mace and Lucas used wax, which had the effect of limiting the treatment process and the options available for conservation, although it has also protected the sandals from further mechanical damage.

Acknowledgements

We are grateful to the Ministry of State for Antiquities as well as the Authorities of the GEM-CC for their collaboration, access to the material and approval of publishing this paper. We are indebted to Mr. Moamen Othman, head of organic lab, and Mr. Ahmed Orabi, head of technical preparation area, and all our colleagues of the GEM-CC for feedback, collaboration and suggestions. Furthermore, we would like to thank Safwat Mohamed, Osama Mahdy, Ali Koriem, Islam Abd Elmaksod, Maggie Efat Adeeb and Afaf Hassan (organic lab college) for their generosity and cooperation. Salima Ikram and Lucy Skinner are thanked for their critical review and correcting the English. We thank Erno Endenburg for preparing the images for publication.

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