Journal of Ancient Egyptian Interconnections

Technical and Analytical Study of One of Tutankhamen's Inlaid Walking Sticks

Eman Nabil
Cheops Boat Museum, Egypt

Naglaa Mahmoud
Conservation Department, Faculty of Archaeology, Fayoum University, Egypt

Shaaban Abdelaal
Conservation Department, Faculty of Archaeology, Fayoum University, Egypt

Abstract
This paper describes the techniques and deterioration of a walking stick from the tomb of Tutankhamen (Carter no. 135e) by examining and analyzing its various decorative layers. Several scientific and analytical methods were applied. A visual assessment was done to understand aspects of its deterioration, which were then scientifically analyzed through means of infrared photography, polarized microscopy, environmental scanning electron microscopy (ESEM), and Fourier transform infrared spectroscopy (FTIR). Identification was undertaken to identify wood, resin layer, binding medium, and previous restoration materials.

Introduction
In a partnership that began with excavations in the Valley of the Kings in 1914,[1] Howard Carter and Lord Carnarvon discovered the tomb of the 18th Dynasty king Tutankhamen in November 1922.[2] The vast treasures it contained has made it the most substantial discovery of an intact royal tomb from pharaonic Egypt to date.[3] The world is still dazzled by these treasures and the ingenuity of the ancient Egyptian artists and craftsmen used in the production of these artifacts.[4]

Among them are many sticks and staves (Fig. 1). Such wooden sticks were commonly an element of tomb furnishings,[5] but this collection, 130 in all, is the largest ever found. Recent medical studies conducted on the mummy of Tutankhamen have revealed a fracture in the king's right leg, which probably explains the exceptional number of decorative walking sticks found in his tomb.[6]

During excavation, Carter assigned a reference number to and wrote a simplified description of each artifact.[7] The collection was transferred to the Egyptian Museum in Tahrir Square after restoration by Alfred Lucas and Arthur Mace.[8] Only a part of the collection from the tomb was displayed in the museum exhibition hall; most of the remainder was kept in warehouse No. 52 until recent transfer of the artifacts to the laboratories of the Grand Egyptian Museum (GEM), where they are being conserved and restored in preparation for exhibition. The wooden stick selected for this study, known as Carter no. 135e, JE 61696, and EM 13975, is currently in the GEM restoration labs. It was one of forty-eight that had been gathered into of a single bundle. It measures 148 cm long and has an average diameter of 13 mm. Its surface is divided into three zones. The

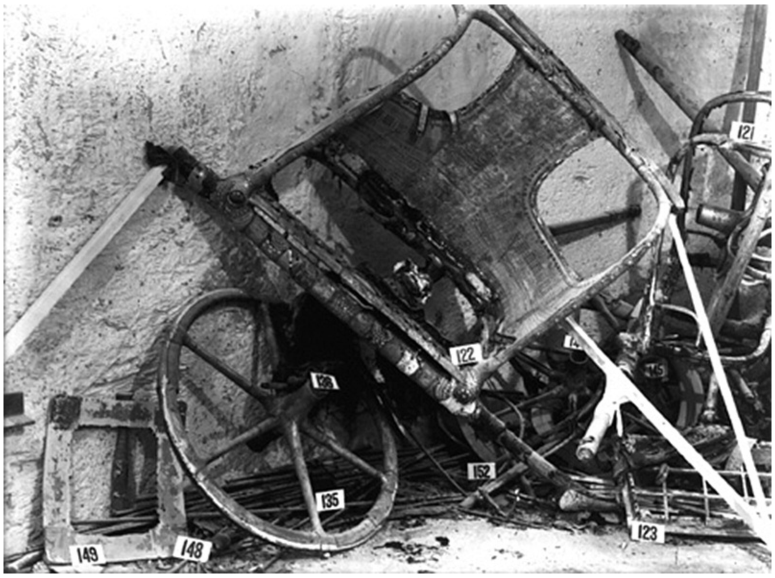

FIGURE 1: Tutankhamen's walking stick 135e at the time of discovery. Reproduced with permission of the Griffith Institute, University of Oxford.

FIGURE 2: The decorations of the stick into three parts, **a–b:** decoration in the upper area of the stick in the form of lotus; **c–d:** decoration in the middle area; **e–f:** decoration in the lower area; g-h) cartouche of King Tutankhamen **i–j:** decoration in the form a human face

undecorated middle zone is covered by a layer of bark. The decorated upper end of the stick is carved into the form of a lotus and carries the royal cartouche of King Tutankhamen; the lower end features figures in relief of non-Egyptian prisoners of war (FIG. 2).

MATERIALS AND METHODS

A thorough understanding of the materials and techniques used in the creation of the stick was necessary to ensure that the appropriate conservation procedures would be applied. Thus many methods, both modern and traditional, were utilized in the scientific examination and analysis of the stick, which serves as a good example of several decorative techniques. The specific questions to which answers were sought included: What is the type of wood? How were the different layers adhered? What type of ground layer was used?

For analysis, different layers were chosen carefully from the loosened samples.

VISUAL ASSESSMENT

Certain aspects of the deterioration of the stick could be determined through visual assessment with the unaided eye. It was very effective; causes and effects of deterioration were easily identifiable by an expert.

VISIBLE (VIS) IMAGING AND INFRARED (IR) IMAGING

Infrared images were created using a Nikon D90 digital camera fitted with an 840 IR filter. This method uncovered details indiscernible to the naked eye and revealed the different styles of decoration.[9] Two types of IR filters were employed to allow light to pass from 760 nm and higher, and filters to allow light to pass from 950 nm and higher. The lighting was changed in the camera itself to control the degree of the apparent red color (as it showed one time and was hidden another), in order to achieve the best result for revealing the exact artistic details.

When the stick was photographed under visible light, the exact artistic details did not appear in the resulting image. Use of the aforementioned filters, along with controlling the degree of color from the camera itself, allowed us to obtain the best image, showing details hidden beneath layers of dust and the paraffin wax applied during previous restoration work.

Polarized Microscopy

A Discovery V20 Zeiss polarized microscope with an Axiocam MRC5 camera was used to study the stratigraphic structure of the decorative layers.

Optical microscopy (OM)

A Zeiss Stero DV 20 stereomicroscope equipped with an Axiocam MRC5 camera was used for an optical microscopy examination of the surface. Additionally, identification of the species of wood was undertaken with the aid of an Optika microscope fitted with an Optikam B9 digital camera, used with transmitted light. Thin sections were obtained in the three principal anatomical directions, i.e., transverse (TS), tangential (TLS), and radial (RLS). Observation and description of the anatomical features allowed the taxonomic identification of the wood.

Scanning Electron Microscopy (SEM)

An SEM Quanta 250 FEG (field emission gun) with an energy-dispersive X-ray unit (EDX) attached, with accelerating voltage 30 K.V., magnification of 14x up to 1,000,000 and resolution for Gun.1n was used to create a high-quality image within a short period of time.[10] It was also used to examine the stratigraphic structure, the external surface and aspects of deterioration of the layers.

Fourier Transformed Infrared Spectroscopy (FTIR)

A Shimadzu IRPrestige-21 Fourier transform infrared spectrometer was employed to identify the functional groups characteristic of the organic materials.[11]

Discussion of Results

Aspects of Deterioration

The stick is made of wood, bears ornamentation on both ends, and has a middle section void of decoration aside from bark. Its decoration has suffered from loss in parts of the carved lotiform top, as well as bits of the inlaid geometric motifs (triangles and rhombuses). However, the royal cartouche of King Tutankhamen is well preserved. The middle of the wooden stick has no decoration and suffered from fragility. Additionally, the whole stick is severely fragile as a result of the bad conditions of its conservation.

The following types of deterioration were noticed. The surface was covered with dust and previous material used for consolidation; the latter obscured the decoration due to the accumulation of wax among the layers.[12] Morphological investigation of the wood using SEM identified various forms of damage. These examinations showed weakness and erosion in the wood tissue, as well as the effects of previous restoration processes on the wood, as shown in Figure 3. Examination by stereoscopic microscopy revealed various forms of damage: dirty surface, dust pockets between the decorative units, cracks, loss in the decorative layers, separations, and accumulations from previous restorations (Fig. 4).

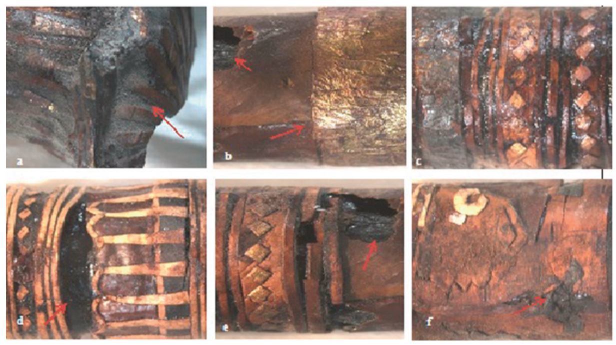

Figure 3: Detailed images of different areas of the decorated layers, showing aspects of deterioration revealed by stereomicroscopy); **a–b:** upper area; **c–d**: middle area; **e-f:** lower area.

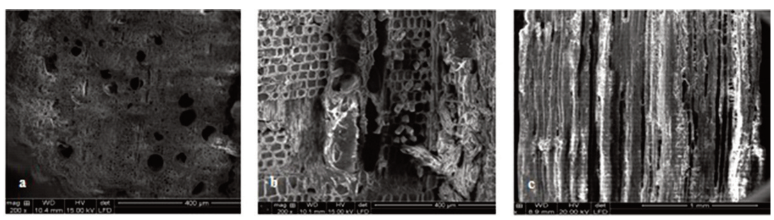

Figure 4: SEM. **a:** showing the extent of the penetration of the remnants of the previous preservation material used in the tissues, vessels; **b:** showing cell wall degradation in the middle lamella, primary wall and secondary wall; **c:** rupturing of different cell walls with the remnants of the previous preservation material

Identification of the Decorative Shapes

The precise details of the decorative units and the missing parts were identified through infrared inspection, which unveiled artistic details that could not be observed by the naked eye.[13] The style of the decoration using tree bark was rendered visible. When using only visual light, we could not see the details of the geometric units and of the human figures, nor how the ancient Egyptian artist carved multiple layers of bark to portray the human face and details of the robes, as well as the geometric units. Lucas and Harris reported that a number of objects from Tutankhamun's tomb, such as bows, a bow box, sticks, a fan handle, and a chariot axle were covered with bark probably obtained from birch (*Betula* sp.). IR photography (Fig. 5) brought out all of these details, as well as decorative features hidden as a result of the accumulation of dust and waxes. It revealed what could not be seen: the use of more than one layer of wood bark in a manner that suggested the carving of the wood in relief, with paint for the human face and other details. It also revealed the areas of loss and fragility.

Identification of the Layer Structure

The examination by polarized microscopy and SEM of the lateral layers of parts that had separated from the stick determined that the decoration consisted of more than one layer. Additionally, the number of layers varied from one area to another according to the method of decoration, as follows:

The first part of the gilded rings consisted of four layers (Fig. 6a–b). The first layer, which directly covered the surface of the wooden stick as a ground layer, was covered by a second layer, which was wood bark. Then came a third layer, composed of an adhesive material, which was topped by the fourth layer, which was gilding.

The second part of the triangular geometric units consisted of four layers (Fig. 6c–3). The first layer covered the surface of the wooden stick as a ground layer; this was topped by a second layer, wood bark. Next was a third layer that was made up of an adhesive material, which was covered by the fourth layer, which was gilding. The gilding of this unit was done in two layers, one on top of the other.

The third part of the middle area comprised three

Figure 5: Technical images of the lower area of the stick (the figures of foreign enemies) made by **a:** visible light (VIS) imaging and **b–c:** infrared (IR) imaging.

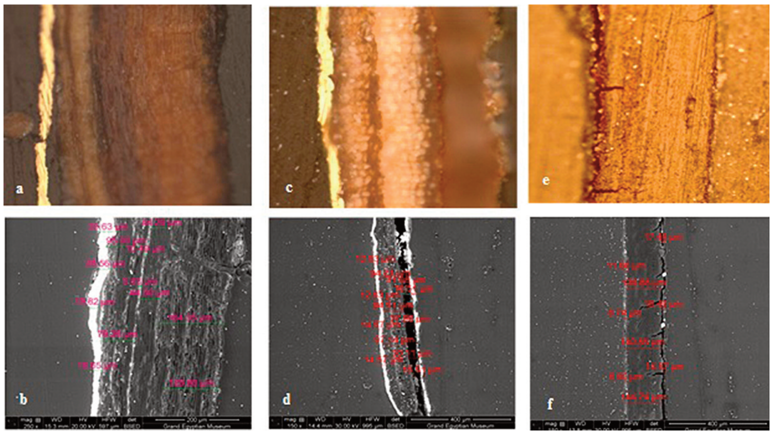

Figure 6: Microscopic examination of the loose decorated samples from different areas, showing the stratigraphic structure of the decorated layers: **a–b:** sample 1; **c–d:** sample 2; **e–f:** sample 3.

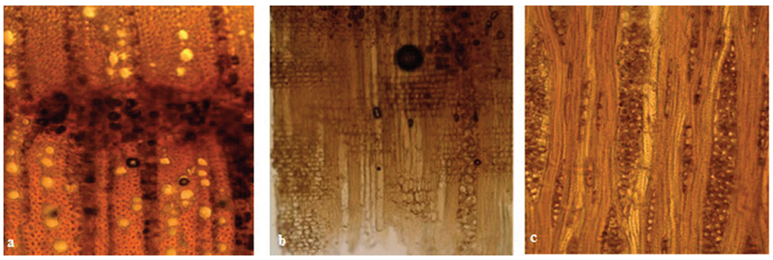

Figure 7: Microphotographs of thin wood sections under the optical microscope in transmitted light, showing the anatomical characteristics of *Prunus dulcis*: **a:** transverse section (TS); **b:** radial longitudinal section (RLS); **c:** tangential longitudinal section (TLS); **d:** detail of tangential longitudinal section (TLS) (40× magnification).

layers (Fig. 6e–f). The first was the ground layer, which was topped by a second layer, an adhesive material. The third (i.e., surface) layer, consisted of wood bark. It was noticed that the layers differed in thickness from one sample to another. Examination of the same fragments illustrated the fine thickness of the different decoration layers. For example, the thickness of the gilding started at 25.5 μm and varied from one point to another. Some measurements of the thickness of the layers were recorded on the SEM images. Identification through such readings allowed determination of the average thickness of the layers as follows. The thickness of the layer below the gilding was an average of 85.5 μm, while the layer underneath was of the average thickness of 44.5 μm. The bark layer had an average thickness of 155.5 μm. In the second part, the average thickness of the bark layer was 13.5 μm, while the layer beneath had an average thickness of 85.5 μm, the layer beneath had an average thickness of 15.5mu, and the ground layer ground had an average thickness of 16.5 μm. SEM of the third part showed that the average thickness of the bark layer was 9.5 μm, and that of the layer beneath was 145.5 μm. The ground layer was of an average thickness of 16.5 μm.

Identification of the Wood

The optical microscope was used to identify the type of wood used to make the stick. Microphotographs of thin sections of the wood showed that it was almond (*Prunus dulcis).* The anatomical characteristics of the transversal section revealed growth-ring boundaries made distinct by differences in the vessel size of the latewood and of the early wood, by semi-ring-porous to ring-porous wood, by solitary vessels, and by radial multiples of four or more, as well as axial parenchyma diffuse and scanty paratracheal (Fig. 7). The wood was characterized by a high percentage of fibers and narrow vessels,[14] which gave the wood hardness, strength, density, and durability.[15]

Identification of Gold-Leaf Composition

SEM-EDX analysis of the loose parts of the gilded square units and the gilded triangular decorative units demonstrated that there was a high percentage of gold (Au), at 81%/75,38%. It also contained silver (Ag), 14.78%/21.37%, and copper (Cu), 3.99%/3.25%, added in order to improve the properties of gold and give the metal the required flexibility. Tables 1–2 summarize the composition of the gold leaf from different areas of the stick as shown in Figures 8 and 9. It corresponded to the composition of samples of gold leaf dated to different periods published by Hatchfield and Newman[16] and to the composition of

Table 1: EDX results from loose parts of the gilded square units.

Element	Weight %	Atomic %
Cu K	3.99	10.26
Ag L	14.78	22.38
Au L	81.23	67.36
Total	100.00	

Table 2: EDX results from loose parts of the gilded triangular units.

Element	Weight %	Atomic %
Cu K	3.25	8.08
Ag L	21.37	31.35
Au L	75.38	60.57
Total	100.00	

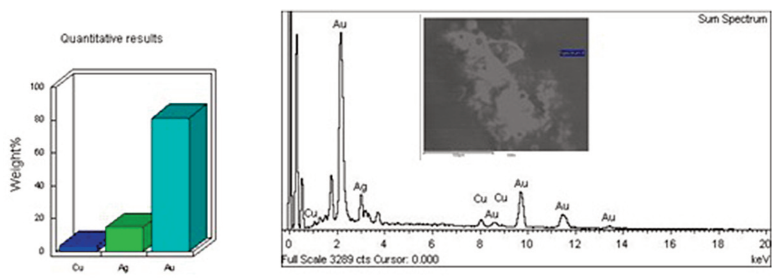

Figure 8: EDX results from loose parts of the gilded square units.

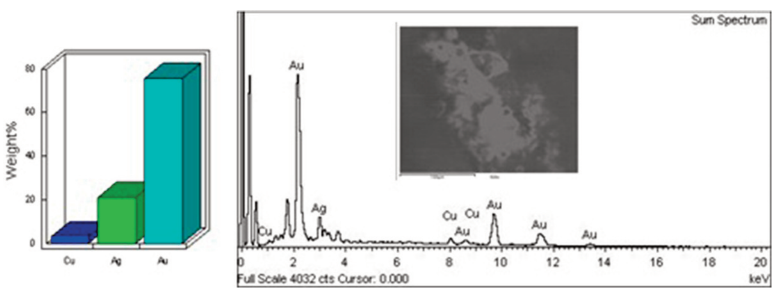

Figure 9: EDX results from the loose parts of the gilded triangular units.

gold leaf of sample 2 from the tomb of Tutankhamun published by Rifai and El Hadidi.[17]

Identification of the Black Resinous Layer

Infrared spectrum analysis was used to analyze the black resinous layer that was used as a base to affix the bark decorations. This was an unusual practice in ancient Egypt.[18] Recent analyses have shown that the black resinous layers or coatings applied to artifacts had a complex composition, with diverse materials including oils, resins, fats, bitumen, and wax.[19] The sample from the stick showed the characteristic peaks of C-C stretching mode at 1597–1509 cm^{-1}, C-H stretching mode at 2937 cm^{-1}, and C-O stretching mode at 1275 cm^{-1}, O-H stretching mode at 3420.14 cm^{-1}, and C-H Stretching mode at 2937.08 cm^{-1}, with other peaks at 2917 cm^{-1} and 3200 cm^{-1}.

After a comparison with the control sample that might be assigned to the presence of shellac resins, these analyses showed that the ancient Egyptians used shellac in the ground layer with an adhesive material, i.e., animal glue (Table 3;[20] Fig. 10). Based on the results of the analyses, it is clear that, even for high-quality works of art, the ancient Egyptians used an unpretentious base that required a special second ground layer to receive, with the use of strong adhesives, different decorative layers. Thus, the techniques used to create the wooden stick present a good model for the quality of ancient techniques that have been generally recognized.

Table 3: FITIR spectrum of shellac mixed with animal glue.

Sample	Animal Glue	Functional Group of Animal Glue	Shellac	Functional Group of Shellac
3288	3400–3200 cm^{-1}	N-H stretching band	3600–3200 cm^{-1}	O-H stretching band
3078	3100–2800 cm^{-1}	C-H stretching bands	3100–2800 cm^{-1}	C-H stretching bands
1633	1660–1600 cm^{-1}	C=O stretching band	1740–1640 cm^{-1}	C=O stretching band
1540	1565–1500 cm^{-1}	N-H bending bands	1650-1600 cm^{-1}	C-C stretching band
1400	1480–1300 cm^{-1}	C-H bending band	1480–1300 cm^{-1}	C-H bending band
12400	—	—	1300–900 cm^{-1}	C-O bending bands (189)

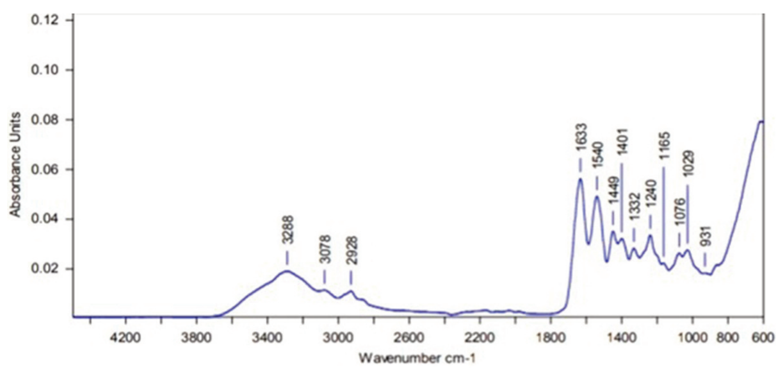

Figure 10: FTIR spectrum of shellac mixed with animal glue.

Identification of the Previous Consolidating Material

The material covering the surface of the wooden stick was analyzed as an old restoration material. After comparison with the control sample (Table 4), it was determined to be paraffin wax. It is known that Alfred Lucas and his assistants restored and conserved objects from the tomb of King Tutankhamen, including the sticks, using paraffin wax.[21] This was confirmed for this object by infrared analysis, which revealed the presence of characteristic peaks of C-H stretching mode at 2916 cm^{-1}, C-H bending mode at 1463 cm^{-1}, and C-H torsion mode at 728 cm^{-1}, describing paraffin wax (Fig. 11). This result agrees with the Carter's notes on the object.

Identification of Adhesives

The decorative units were affixed to the bark layer with an adhesive that analyses and comparison with a control sample (Table 5) determined to be animal glue (Fig. 12). Animal glue is characterized by the presence of N-H 1500-1565 cm^{-1}, which was confirmed by the N-H stretching band at 3200–3500 cm^{-1} and bands corresponding to the stretching frequencies of carbonate (1490–1370 cm^{-1}, 910–870 cm^{-1}).

Conclusions

- Stick Carter no. 135e, one of many found in the tomb of Tutankhamen, is extremely important.
- Examination by the unaided eye reveals that the

Table 4: FTIR spectrum of previous consolidating material.

Paraffin Wax	Sample	Functional Group
3000–2800 cm^{-1}	2965	C-H stretching bands
1480–1300 cm^{-1}	1472	C-H stretching band
750–700 cm^{-1}	720	C-H torsion band

Table 5: FTIR spectrum of the adhesives.

Animal Glue	Sample	Functional Group
3400–3200 cm^{-1}	3373	N-H stretching band
3100–2800 cm^{-1}	2919	C-H stretching bands
1660–1600 cm^{-1}	1634	C=O stretching bands
1565–1500 cm^{-1}	1543	N-H bending bands
1480–1300 cm^{-1}	1368	C-H bending band

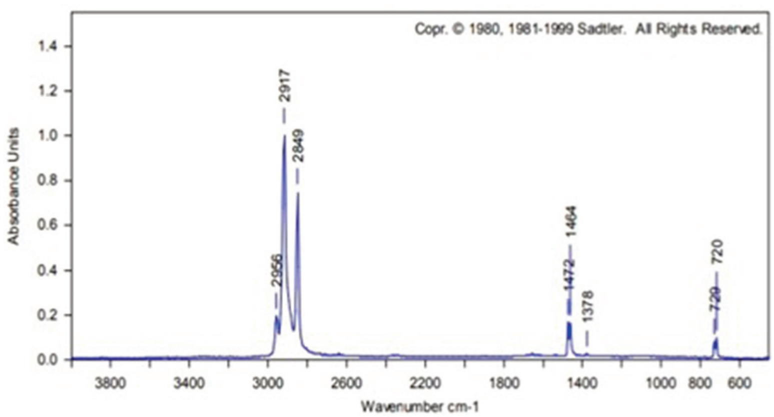

Figure 11: FTIR spectrum of previous consolidating material.

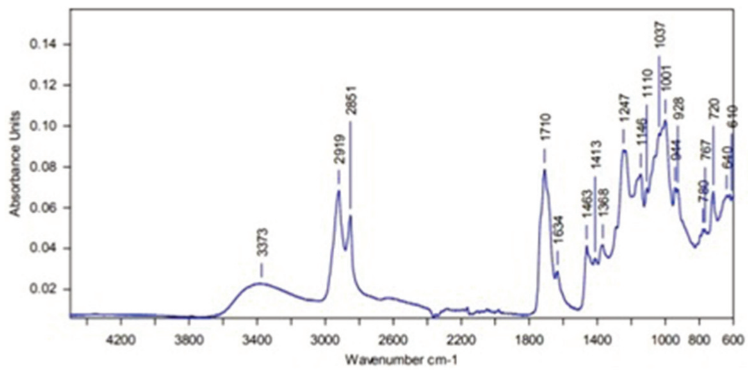

Figure 12: FTIR spectrum of the adhesives.

stick is wood, embellished on both ends, and has suffered various types of damage (cracks, breaks losses, etc.) caused by pressure, friction, and improper storage.

- Infrared camera imaging with two types of filters revealed precise details that are indistinct to the naked eye.
- Morphological examination of the surface of the wood by SEM aided in the identification of various aspects of damage to the wood, manifest as weakness and erosion in the wood tissue, in addition to the materials used in previous conservation treatments.
- Stereoscopic microscopic imagery disclosed fine details of various forms of damage (dirt, pockets of dust, cracks, incisions, and old restoration). This assisted the development of the restoration plan.
- Polarized microscopy revealed the number of layers (3–5) used in the creation of different areas.
- SEM determined precisely the thickness of each layer in micrometers. Generally, they differed in thickness, with an average of 25.5 μm.
- Optical microscope examination facilitated the identification of the wood used as almond (*Prunus dulcis*).
- The percentages of the elements of the decorative units were recognized using EDX scanner microscopy.
- The infrared analyses revealed that the ancient artisans used shellac in the layer ground, mixed with an adhesive material, i.e., animal glue. The material covering the surface of the stick from previous restoration/conservation efforts was found to be paraffin wax.
- The use of different layers provided a versatility that was an artistic advantage for the artisan's creative process but also a detriment to the object in the longer term. The significant differences between the organic materials (wood, glue, and shellac, with the additional complication of modern paraffin wax) and the inorganic materials (gold, silver, and copper) were the main causes of damage to the stick, in addition to environmental factors to which the stick was subjected. All these led to the separation and loss of parts in different areas of the stick. This necessitated an intervention to carry out various repairs and maintenance of this magnificent and finely crafted object.

References

Abdrabou. A, M. Abdallah, E. Nabil, Y. Matsuda, and H. Kamal. 2019. "Preliminary Investigation of the Materials and Techniques Used in a Decorated Wooden Stick of King Tutankhamun." *Conservar Património* 30:9–19.

Carter, H. 1963. *The Tomb of Tutankhamen*, 3 vols. Reprint. New York: Cooper Square.

Cartwright, C. R., C. Ward, J. Tubb, and H. Delaunay. 2009. "The Middle Bronze Age Furniture from Tomb P19 at Jericho: Wood Identification and Conservation Challenges."

The British Museum Technical Research Bulletin 3, 111–120.

Colom, X., F. Carrillo, F. Nogues, and P. Garriga. 2003. "Structural Analysis of Photodegraded Wood by Means of FTIR Spectroscopy." *Polymer Degradation and Stability* 80(3): 543–549.

Darque-Ceretti, E. D., E. Felder, and M. Aucouturier. 2011. "Foil and Leaf Gilding on Cultural Artifacts: Forming and Adhesion." *Revista Matéria* 16(1): 540–559.

Derrik, R. M., D. Stulik, and M. J. Landy. 1999. *Infrared Spectroscopy in Conservation Science*. Los Angeles: The Getty Conservation Institute.

Gale, R., P. Gasson, and N. Hepper. 2000. "Wood." In T. Nicholson and I. Shaw (eds.), *Ancient Egyptian Materials and Technology*, 334–371. Cambridge: Cambridge University Press.

Gänsicke, S., (2010) "The Conservation of Decorated Organic Egyptian Surfaces: A Literature Review." In J. Dawson, C. Rozeik, and M. M. Wright (eds.), *Decorated Surfaces on Ancient Egyptian Objects: Technology, Deterioration and Conservation*, 67–77. London: Archetype Publications.

Gilberg, M. 1997. "Alfred Lucas: Egypt's Sherlock Holmes." *Journal of the American Institute for Conservation* 36(1): 31–48.

Griffith Institute. 2018. "Griffith Institute: Carter Archives—135e." *Tutankhamun: Anatomy of an Excavation*, The Griffith Institute, University of Oxford, http://www.griffith.ox.ac.uk/gri/ carter/ 135e.html, accessed 31 January 2019.

Hatchfield, P., and R. Newman. 1991. "Ancient Egyptian Gilding Methods." In D. Bigelow, E. Cornu, G. Landre, and C. van Home (eds.), *Gilded Wood Conservation and History*, 291–299. Madison, CT: Sound View Press.

Hepper, N. 1990. *Pharaoh Flowers: The Botanical Treasures of Tutankhamun*. London: HMSO.

Ismail, Y., A. Abdrabou, and M. Abdallah. 2016. "A Non-destructive Analytical Study and the Conservation Processes of Pharaoh Tutankhamun's Painted Boat Model." I*nternational Journal of Conservation Science* 7(1): 15–28.

Korkut, D. S., and B. Guller. 2008. "The Effects of Heat Treatment on Physical Properties and Surface Roughness of Red-bud Maple (*Acer trautvetteri* Medw.) Wood." *Bioresource Technology* 99(8): 2846–2851.

Lucas, A, and J. R. Harris. 1962. *Ancient Egyptian Materials and Industries*, 4th ed. London: Edward Arnold.

Nabil, E., N. Mahmoud, and S. Kamel. 2017. "Investigation and Analysis Study of an Old Kingdom Cheops First Boat Oar Blade." *Journal of Ancient Egyptian Interconnections* 16: 87–98.

Newman, R., and M. S. Halpine. 2001. "The Binding Media of Ancient Egyptian Painting." In W. V. Davies (ed.), *Colour and Painting in Ancient Egypt*, 22–32. London: British Museum Press.

Reeves, N. 1990. *The Complete Tutankhamun: The King, the Tomb, the Royal Treasure*. London: Thames and Hudson.

Rifai, M. M. and N. M. N. El Hadidi. 2010. "Investigation and Analysis of Three Gilded Wood Samples from the Tomb of Tutankhamun." In Dawson, C. Rozeik, and M. M. Wright (eds.), *Decorated Surfaces on Ancient Egyptian Objects: Technology, Deterioration and Conservation*, 16–24. London: Archetype Publications.

Serpico, M., and R. White. 2001. "The Use and Identification of Varnish on New Kingdom Funerary Equipment." In W. V. Davies (ed.), *Colour and Painting in Ancient Egypt*, 33–42. London: British Museum Press.

Stein, R. A., and P. Lacounra. 2010. "Observations on the Preparation Layers Found on Ancient Egyptian Decorated Coffins in the Michael C. Carlos Museum." In Dawson, C. Rozeik, and M. M. Wright (eds.), *Decorated Surfaces on Ancient Egyptian Objects: Technology, Deterioration and Conservation*, 3–8. London: Archetype Publications.

Waly, N. M. 1996. "Identified Wood Specimens from Tutankhamun Funerary Furniture." *Taeckholmia* 16:61–74.

Notes

1 Hepper 1990.

2 Reeves 1990.

3 Carter 1963.

4 Gänsicke 2010.

5 Gale et al. 2000.

6 Gilbert 1997.

7 Griffith Institute 2018.

8 Gilberg 1997.

9 Ismail and Abdallah 2016.

10 Korkut and Guller 2008.

11 Colom et al. 2003; Waly 1996.

[12] Abdrabou et al. 2019.

[13] Lucas and Harris 1962.

[14] Cartwright et al. 2009.

[15] Hatchfield and Newman 1991.

[16] Hatchfield and Newman 1991.

[17] Newman and Halpine 2001.

[18] Ismail and Abdallah 2016.

[19] Serpico and White 2001; Stein and Lacounra 2010; Darque-Ceretti et al. 2011.

[20] Derrik et al 1999.

[21] Ismail and Abdalah 2016.