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# A Study on the Previous Restoration Materials that had been applied on two deteriorated wooden parts in the storage of the Cheops' First Boat.

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**Abstract**

The conservation of wooden objects is a complicated process, due to their response to changes in the surrounding environment. This paper discusses the investigation of two wooden pieces from the Cheops boat to identify two of the old restoration materials that had been used in pieces no. 362 and 390, which had been replaced with new wood, due to their extremely fragile condition. The study was conducted by characterizing the original materials and the materials added during the previous restoration using a number of scientific and analytical approaches to better understand the state of deterioration, in addition to the condition of the object and the previous restoration interventions, in order to facilitate the choice of the most appropriate cleaning and consolidating measures in the future, and to help conservators decide whether or not to remove the previous restorations, to establish suitable treatment methods, and to provide a deeper understanding of its materials and techniques of preservation as well as its' deterioration.

**Keywords**

Cheops' First Boat - wooden objects - previous restoration- scientific and analytical.

## 1. Introduction

The ancient wooden boat "first Boat of King Khufu" had been buried under desert sand in a limestone pit carved into the south side of the Great Pyramid of Giza {Nabil, E, M., 2017}. The boat, which was discovered in 1954 in a disassembled state {Mark, S 2009}, dates back to the Fourth Dynasty (2613-2498 BC), during the reign of Pharaoh Cheops (Khufu) and is one of the most important wooden objects in the world {Atiya, F., 2002}. The boat is a huge wooden structure with an overall length of 42.32 meters, an estimated 50 tons {Mark, S. 2009} and has a hull that is 1.78 deep with an overall height including the super structure of between 5 and 9 meters {Hana, H., 2007}. It had been completely dismantled in the form of a puzzle of 1224 wooden pieces, while the longest piece was 23 meters long, the shortest was just 10 cm long {Yousseo, A. 1960}.

The boat was reconstructed by the physical assembly of the pieces and was exhibited at the museum {Mark, S 2009} which opened to the public in May 1982 {Atiya, F., 2002}. In August 2021 the boat was transferred to the Grand Egyptian Museum, where it will be exhibited in the near future.

The discovery of Cheops Boat is one of the most important archaeological discoveries in Egypt and the world. Its importance is due to the fact that it is the oldest vessel in perfect condition ever found in the world. The dismantled parts of the boat made mostly of Lebanese cedar wood, had been placed in systematic order with the major parts laid out in 13 layers, consisting of 651 definable groups comprising a total of 1224 pieces {Youssof, A. 1960; Jenkins, N. 1980, El Hadidi, N.M.N. 2005}. All the very small pieces - about 5 percent of all - are made from local wood {Lipke, P 1984} (Fig 1 A and B).

It was immediately noticed that hieratic signs had been carved on each end of most of the larger wooden blocks. All the blocks were connected to each other in accordance with these signs indicating that the ancient Egyptians in the Old Kingdom believed that the instructions were necessary on the buried boat so that it could be reconstructed in the after-life, to make sure that reconstruction could take place. The various parts of the boat had also been carefully dismantled and laid out to prevent the collapse which would have taken place had it been buried completely). Every piece of wood found in the pit was moved to the laboratory for treatment by Ahmed Youssef, where they were photographed and given reference numbers.

Many polymers have been applied for the treatment of different parts of the boat, which include polyvinyl acetate, Paraloid B72 and a mixture of rosin and wax {Nakhla, S 1986}. It may not be clear which parts were treated with which polymer, but it is definite that a sample from the hull had been treated with Paraloid B72 {El Hadidi, N.M.N & Darwish, S, 2008}.

Currently there are many studies on the evaluation of previous restorations in Egypt and methods of removing old polymers that are causing a risk in wooden artifacts {El Hadidi, N.M.N et al. 2020}. The two chosen pieces are an example of the treatment that had been applied on the extremely fragile parts of the boat, but they do not represent all the treatments that were conducted in the years that followed the excavation of the boat prior to its exhibition in the boat museum.

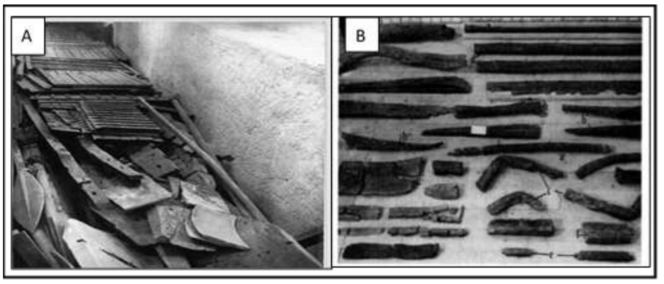


**Fig. 1 A The boat in the pit, B - before conservation {Jenkins, N. (1980)}**

## 2.Description and documentation of the wooden parts :

The royal wooden boat known as Cheops' first boat, was mostly made of imported wood, covered by a layer of varnish added in the previous restoration treatments that disturbed the authenticity of the object, also filling materials were used in the previous restoration.

The wooden pieces of the boat understudy were not used in the rebuilding the boat because of their badly deteriorated condition and had been stored inside the Khufu boat Museum storages {Osman, M. S., 1960}. The dimensions of the first piece with the register number 362, which is one of the boat's oar blades, were around 164 cm length, 28 cm width and 8 cm thickness, and the second piece, register no. 390, was 40 cm length, 10 cm width and 1.5 cm thickness.

## 3. Visual assessment

* Digital Microscopy

In order to detect the deterioration aspects and to document the condition of each part of the wooden piece of the boat oar, a digital microscope was used. It had a focus range of (10–500 mm), magnification ratio of (20–200x).

* Optical Microscopy:

For optical microscopy (OM) used a Zeiss Stereo DV 20 (stereomicroscope) equipped with an Axio Cam MRC5 to investigate the surface morphology of the wood layers of the wooden pieces no. 362 and 390 for this case study. Thin sections were obtained in the three principal anatomical directions, transverse (TS), tangential (TlS), and radial (RlS) {Waly, N., 1994}.

* Scanning electron microscope )SEM)

A Quanta 3D 200 scanning electron microscope made by FEI was used for examining the wood used in the studied boat and for studying and determination of the aspects of deterioration and in the identification of wood.

*Fourier transformed infrared spectroscopy (FTIR):

Fourier transformed infrared spectroscopy Fourier transform IR spectroscopy was conducted using FTIR spectrometer (IR Prestige – 21, Shimadzu) in the 400 – 4000 cm-1, range with resolution of 8 cm-1. Pellets were prepared by mixing the wood sample and KBr in an agate mortar, pouring the mixture into a press and then applying a pressure of 6 t/cm2 for 1 min. Paper-based databases, reference spectra from literature and web databases were used to identify the species in each FTIR spectrum, by comparing experimental peaks standards created in the FTIR laboratory. FTIR was also used to identify the previous gap filler.

*Raman Spectroscopy

An "In Via" Renishaw Raman spectrometer was used in the current work, consisting of a confocal Raman microscope (50x objective lens) with a spectral footprint of about 2 microns and up to 100 spectral accumulations, 2cm-1 spectral resolution, operating with a laser wavelength of 785 nm and with a CCD diode array. The time required for obtaining each spectrum was about 10 minutes. Each specimen was analyzed using 785 nm laser excitation line and Raman spectra were subjected to baseline correction and smoothed using a GRAMS/AI package prior to stack plotting for visual comparison and identification purposes. All compounds were identified by comparing their characteristic vibrational spectra with those in published databases.

## 4. Results

Using OM, SEM, FTIR and Raman microscopy, helped in characterizing the original materials, the materials added during the previous restorations and their effect on the anatomical structure of wood. The results obtained should help conservators in future choose the most appropriate cleaning and consolidation measures and to decide how to remove previous materials that disturbed the authenticity of the wood.

* Visual Assessment and Digital Microscopy

The condition of the wooden piece no. 362, which had been subjected to deep restoration indicated that it had been previously restored and kept in inappropriate condition, which led to advanced deterioration. The following deterioration aspects were noticed on it; the surface of the wooden piece was extensively embedded with dust, previous restoration using solid materials, a lot of cracks, missing parts, and separation of the wood layers. (Fig 2 A. piece no 362, B-D cracks, splitting, separation and the previous filling materials used on the wood).

The images for piece no. 390 showed different materials on the surface that had been used to join two parts of previous restoration. Moreover, two parts were wrongly assembled in the previous restoration interventions with a white hard material that could cause breakage of the object (Fig 3 A, piece no 390, B- D cracks, and the previous filling materials). Other forms of damage include layers of dust, old adhesives, wood fiber separation and missing layers (Fig. 4).

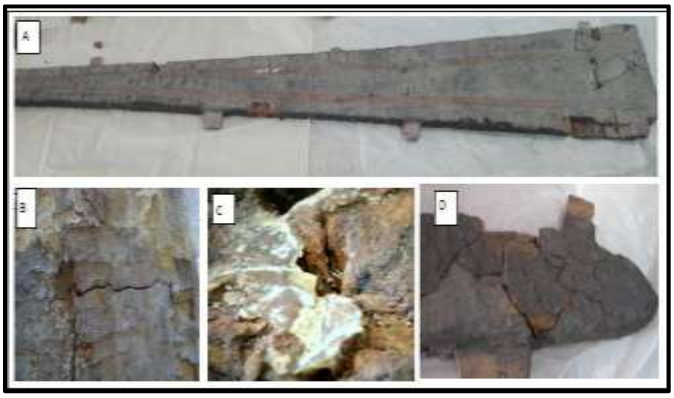

**Fig 2 A: One of the Cheops boat oar blades (piece no 362) show aspects of deterioration found in the oar, B-C-D show cracks, dust, and friable wood layers and separations between the wood layers and missing parts.**

**Fig 3 A: One of the Cheops pieces (piece no 390), B-C-D- Deterioration aspects and previous adhesive**

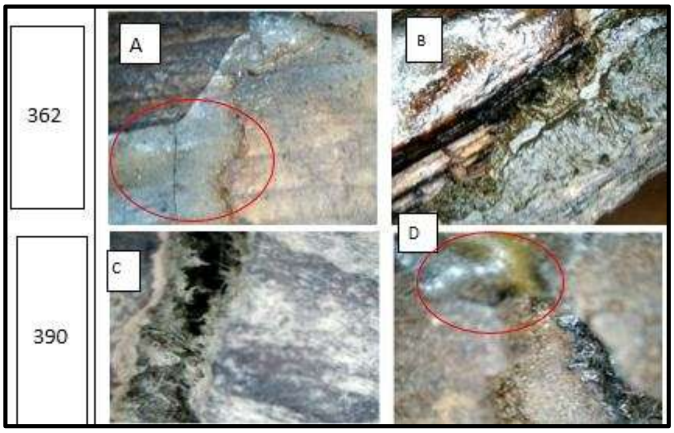


**Fig 4: Investigation under digital microscope A-D, Adhesives that were previously used and seeped into the wood cells B, C separation between wood fibers, sandy calcification and dust.**

* Optical Microscopy

Identification of wood species

OM micrographs showed that the wood used in the two samples was Lebanese cedar, (Cedrus libani). This timber was used in boat building and furniture as early as Predynastic periods until as late as Greco– Roman times in ancient Egypt {Gale, R. et al. 2000}. When the boat was discovered, the scent of cedar wood was prevailing. Landström indicates that most parts of Cheops boat were made of Lebanese cedar which was also mentioned by {Youssof, A. 1980; El Hadidi, N.M.N. 2005, and Lipke, P. 1984}.

The diagnostic characteristics of Cedrus libani were growth rings distinct and a gradual change from early wood to late wood tracheids as seen in TS (Fig. 5A) {Ismail, Y. et al., 2016}, {Cartwright, C. 2001}. Although not present in this specimen, it should be noted that cedar of Lebanon wood, can sometimes have a row of tangentially orientated traumatic resin canals which show up in TS. Rays are uniseriate and its average height is high to very high (more than 30 cells) as seen in TLS (Fig. 5B) {Crivellaro, A. & Schweingruber, F.H., 2013}, ray tracheid commonly present with smooth cell walls and end walls of ray parenchyma cells distinctly pitted (nodular) as seen in RLS (Fig. 5A) {Yaman, B 2007}.

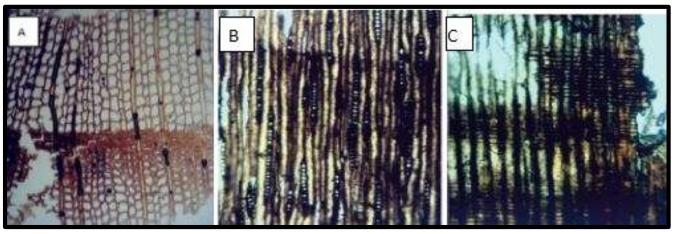


**Fig 5: Lebanese cedar wood. a: Transverse section showing gradual transition between early and late wood formations, and appearance of the resin canals. b: longitudinal section showing sequencing single-cell rays. c: Details of radial section ray tracheids for both piece no 362 and 390**

*Scanning electron microscope (SEM):

Examination using SEM showed that the wood appeared to be in good condition, no fungal decay was evident and the cells were intact showing no signs of deterioration (Fig. 6A and B). There were also many ruptured cell walls and remnants of previous adhesive material (Fig. 6 C and F) in the parts that had been previously treated.

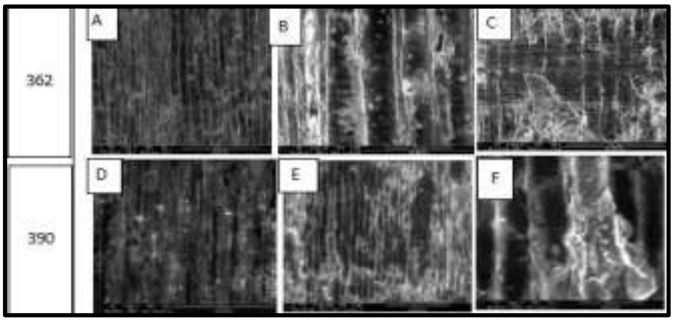


**Fig 6 SEM microphotographs of Lebanese cedar wood A-B & D-E the anatomical characteristics of cedar wood. Resin canals, sequencing single-cell rays and simple pits, C&F ruptured cell walls and remnants of previous adhesive material.**

**Identification of the previous filling materials:**

FTIR spectra of sample taken from piece no 362 showed characteristic peaks of C-H stretching bands at 2916 cm-1, bending bands at 1472 cm-1 and C-H torsion bands at 729 cm-1, which are ascribed to animal glue {Derrik, M. R. et al. 1999} as well as some peaks at 2917 cm-1, 1473 cm-1 and 728 cm-1, also ascribed to the animal glue that had been applied according to Ahmed Youssof's notes, in which he mentioned its use in the restoration process of the boat (Fig. 7).

| Wave number ($cm^{-1}$) | | |
|---|---|---|
| Animal glue | Sample | Functional Group |
| 3400-3200 $cm^{-1}$ | 3352 | N-H Stretching Band |
| 3100–2800 $cm^{-1}$ | 2925 | C-H Stretching Bands |
| 1660–1600 $cm^{-1}$ | 1613 | C=O Stretching Band |
| 1575-1500cm1 | 1504 | N=Bending Bands |
| 1480–1300 $cm^{-1}$ | 1394 | C-H Bending Bands |

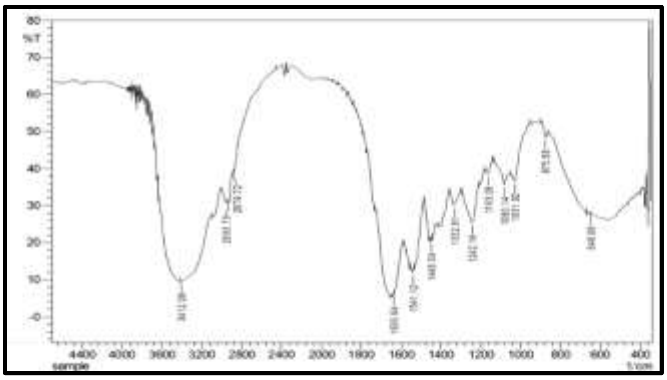

**Fig 7 FTIR analysis of the previous filling materials**

*Raman spectrum

The Raman spectrum of the sample taken from piece no 390 (Fig.8) helps in the determination of the chemical groups of the restoration material. Evidence for a phoenix resin C18H2003 is exhibited in strong Raman bands at 3017, 2936, 1609, 1412 and 1112 cm-1. Raman bands corresponding to epoxide vibration are in the range of 1230 cm-1 and 1280 cm-1 according to the epoxide vibration band at 1252 cm-1 (breathing of the epoxide ring) {Vaskova, H, & Křesálek, V., 2011}. The intensity of this peak is linearly dependent on the concentration of epoxide groups in the resin mixture. The peak at 819 cm-1 assigned to the epoxide ring deformation is much weaker.

| Structure and composition (Starting from the lower layer) | Raman shifts ($cm^{-1}$) | Spectra in Figure 8 |
|---|---|---|
| Phoenix resin $C_{18}H_{20}0_3$ | 1112 $cm^{-1}$ and 1412,1609,2936,3017 $cm^{-1}$ | (A) sample |
| Epoxy resin | 1230 $cm^{-1}$ and 1280 $cm^{-1}$ | (B) Vaskova, H, 2011 |

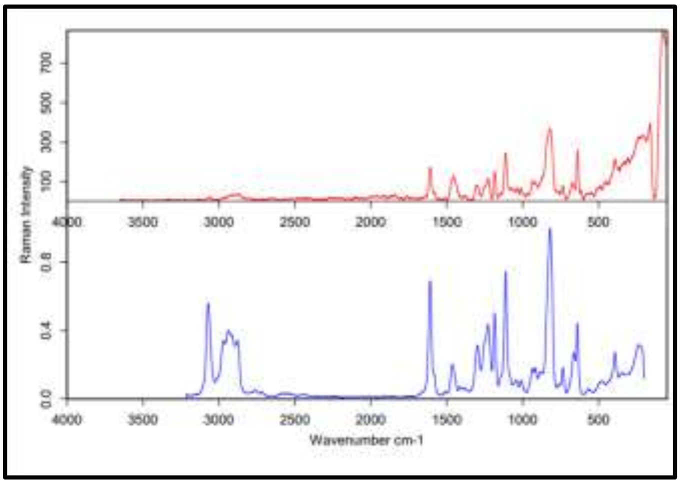


**Fig. 8 Raman spectra analysis of the previous adhesive materials**

## 5- Discussion:

Many factors played a major role in the deterioration of the boats' wood during its burial, additionally the application of epoxy or animal glue as a structural adhesive exhibited poor structural compatibility with wood. Other factors such as the change in the wood's hygroscopic nature, and the resultant hygroscopic dimensional change in wood at the interface can cause stress at the rigid epoxy bonding which eventually exceeds the strength of the wood. The structural incompatibility negatively affected by the rigid cross-linked structure of the epoxy bond line was a result of an irregular distribution of stress throughout the adhesive and wood bond area. Moreover, in humidity and wet environment the application of epoxy as a structural adhesive can exhibit poor structural compatibility with wood Nakhla, S.M., (1986).

Wooden antiquities are exposed to many different deteriorating factors due to the nature of wood; which is an organic material that easily disintegrates and can be damaged by several deteriorating factors present in ambient environment. Therefore it is necessary for a conservator to understand the mechanism of wood damage through studying its chemical, physical and mechanical characteristics, as well as the micro structure of wood after being exposed to the deteriorating factors using modern scientific methods during investigation and analysis. It is also necessary to study both the negative and positive effects of a consolidant and gap filler that was used in the past, whenever there is a possibility to do so (El Hadidi et al., 2020), because it may help in taking decisions for future conservation applications.

A conservator should study and use the scientific methods for the investigation and conservation of wooden artifacts (Ismail et al., 2016) in order to identify the best methods to keep “Our antiquities well preserved.

## 6-Conclusion :

The wooden pieces that were studied (No. 362 and 390) date back to the 4th Dynasty during the reign of Pharaoh Cheops (Khufu). Wood species identification results confirmed, what had been previously published in literature, that the type of wood used was Cedrus libani. Analysis using FTIR and Raman spectroscopy helped characterize the materials added during the previous restorations, which had been previously mentioned by Ahmed Yousef, the chief restorer of the boat.

The wood suffered from deterioration caused by exposure to unstable environmental conditions. Visual assessment and investigation of the surface’s morphology showed many aspects of deterioration such as cracks, missing parts, and separation of the wood layers. Previous restoration materials led to a weakness for the wood layers as adhesives that were previously used and had seeped into the wood cells and caused small cracks. The wood’s hygroscopic nature, is different than that of epoxy or animal glue, and the hygroscopic dimensional change in wood at the interface may cause stress at the rigid epoxy bonding line. The structural incompatibility may be one of the reasons why mechanical properties of previously treated wood should be considered in future research.

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