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Investigation and Analysis Study of an Old Kingdom Cheops First Boat Oar Blade

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Abstract

This paper describes the conservation process of one of the oars of the Cheops' First Solar Boat. It was subjected to several scientific and analytical methods in this study in order to provide a deeper understanding of its materials and techniques of preservation as well as deterioration.

Introduction

The royal wooden funerary vessel known as Cheops' First Solar Boat was discovered in May 1954 buried under desert sand and covered with limestone blocks in Giza Plateau near the Great Pyramid.[1] It dated back to the 4th Dynasty during the reign of Pharaoh Cheops (Khufu).[2] Unfortunately, it was completely dismantled, taking the form of a puzzle of wood pieces, up to 1224 pieces. While the longest piece was 23 meters long, the shortest one was just 10 cm long.[3] It is one of the most important wooden objects in the world and one of the largest ancient boats found to date. Just for the purpose of comparison, the longest Viking boats found in Europe were no more than 30 meters, while the Cheops boat was, after being rebuilt, 43.40 meters long, about 5.90 meters wide and 1.75 meters deep. The prow, which was formed in the shape of a papyrus bundle, was about 6 meters tall, and the stern was 7 meters high (Fig. 1).[4] It was equipped with twelve oars. The rudders consisted of two massive oars, and the other ten were found arranged in five pairs on each side of the main cabin and the captain's cabin.[5] The current study aimed to characterize the materials and techniques used in manufacturing the oar blade. The results obtained provide us with the essential information needed to choose the suitable materials and methods to be used in conservation and restoration works.

The oar blade under investigation was discovered on the upper deck of the Cheops boat.[6] It was made of wood, without any decorations. After the discovery, every piece of wood found in the vicinity was moved to the laboratory for treatment by Ahmed Youssef (Fig 2A), where they were photographed and given reference numbers (Fig. 3B).[7] This oar blade was previously restored and kept in Cheops Museum stores. It was not used in rebuilding of the boat because of its bad condition,[8] and it was stored under reference No. 105 by Ahmed Youssef. Then, it was transferred to the lab for restoration and study. It was 162 cm long and 27.5 – 14.5 cm wide.

Materials and Methods

Visual microscopy and SEM were used for preliminary morphological observations of the oar

Note: All figures are located at the end of the article.

blade, and determination of the aspects of deterioration. In addition, OM and SEM were utilized in the identification of wood. XRD and FTIR were used to analyze the small fragments from its external surface.

Materials

The royal wooden funerary pieces known as Cheops's First Solar Boat consisted of foreign wood and covered with a layer of varnish added during an older modern restoration.

Methods

These methods were as the following.

Visual Assessment

Visual assessment was performed to determine the oar's blade aspects of deterioration. It is very effective, as the causes and mechanisms of deterioration are easily identifiable by an expert. It can also determine the most effective techniques of analysis to be applied to identify its conditions.

Digital Microscopy

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

Optical Microscopy

An optical microscope, Zeiss Stereo DV 20 apparatus, was used with transmitted light. It was equipped with optical B 9 digital camera to identify the wood, fungi, and bacteria species. Thin sections were obtained in the three principal anatomical directions, transverse (TS), tangential (TLS), and radial (RLS).

Isolation media

Media used for isolation of fungi:

- Potato dextrose agar medium, PDA (Nissui).
- Lignin cellulose medium, LCM.[9]
- Modified Czapeck's medium by adding lignin cellulose as a carbon source instead of sucrose. This medium composed of (g/L): Lignin cellulose, 10; KH2PO4.3H2O, 1.0; NaNO3, 2.0; KCl, 0.5; MgSO4.7H2O, 0.5; FeSO4.7H2O, 0.01; Agar, 20.
- All of the above media amended with antibacterial agent (chloramphenicol).

Media used for isolation of bacteria:

- Nutrient agar medium (Nissui).[10]

Environmental Scanning Electron Microscopy

A Quanta 3D 200i scanning electron microscope made by FEI was used to identify wood and determine the stratigraphic structure of its layers. Its accelerating voltage was between 10-15 KV in the field of magnification orders of (150- 1200x). The investigation was carried out in the large filtered detector mode (LFD) and the back scattered electrons mode (BSE). ESEM was performed in the Egyptian General Authority for Mineral Resources.

X-ray Diffraction Analysis

X-ray diffraction analysis was conducted using X-ray Diffract meter System PW3040–Analytical Equipment–Analytical pro model, Cu-target tube and Ni filter at 40 kV and 30MA. (X' Pert High score) software was used to detect the changes in the crystallization of cellulose at the National Research Center.

Fourier-Transform Infrared Spectroscopy

IR Prestige-21 (FTIR spectrometer) and the IR solution software in the 400– 4000cm^{-1} range with resolution of 8cm^{-1}, was used to identify the changes in selected wood building material and changes in specific FTIR absorbance peaks designated to different wood deterioration processes and the identification of varnish. It was performed at the National Research Center.

Results and Discussion

Visual assessment and digital microscopy

The oar blade was previously restored and stored in bad conditions, which led to advanced deterioration. In addition to the exposure to unstable environmental conditions, the surface of the oar blade was extensively embedded with dust. There was friable and powdered wood layer separation (Fig. 4A, B, C), cracking in the longitudinal and transverse direction of wood fibers (Fig. 4D, E, F). There were also some missing parts of the surface (Fig. 5 A, B, C). Many areas were insecurely attached that tended to shatter when touched. Furthermore, there were other forms of damage and sandy calcification in many areas of the surface (Fig. 5 D, E, F). Varnish layers were also cracked and brittle.

Optical microscopy

Wood identification

Studying the boat itself, it was found that most of the hull was made of Lebanese cedar.[11] When it was discovered, the scent of cedar wood was prevailing.[12] Landström indicates that most parts of Cheops boat were made of Lebanese cedar, but a few pieces were of sycomore.[13] In agreement with the examination of the boat in the British Museum,[14] the microscopic investigation indicated that it was made of Lebanese cedar (Fig. 6). The diagnostic characteristics through transverse, longitudinal and radial cross sections, used to identify wood. (TS) showed the gradual transition between early and late wood formation. In addition, the resin canals that characterized cedar wood[15] appeared (Fig. 6A). (TIS) were rays single-cell sequencing, cell walls have spiral thickening (Fig. 6B). (RLS),ray tracheid were distinguished by their bordered pit ray parenchyma cell that had simple pits (Fig. 6C) as well as mentioned previously by Youssef, El Hadidi, and Lipke.[16]

Interpretation of Fungi and Bacteria

The results revealed that there is strong fungal infection in all examined objects, four fungal genera were isolated and identified from both type of media. The ability of fungi to grow on LCM medium revealed their lignocellulatic activity and hence their ability to grow on wood. Bacterial infection was also found and grown in gram negative bacilli (Figs. 8, 9), showing the types of fungi *(Aspergillus flavus*, *Aspergillus nidulans*, *Penicillium*sp and *Aspergillus terreus*), as El Hadidi[17] refers that there is fungi infection in some sample of wood.

Environmental Scanning Electron Microscopy

It was evident that the wood suffered from different problems. Most of the samples were too weak for light microscopy preparations and would crumble if touched. Thus, ESEM was a suitable option.[18] The anatomical structure of wood was also investigated using SEM. It enabled us to identify the form of pits, rays, and some anatomical structure of cedar wood (Fig. 7).

SEM examination showed that wood appeared to be in a bad condition. The micrographs obtained were sufficient for the assessment of decay. It showed a collapse of cell walls, presumably due to mechanical pressure (Fig. 10A) and cell wall degradation in the middle lamella, primary wall and secondary wall (Fig. 10B). There were also many ruptured cell walls and remnants of previous conservation material (Fig. 10C).

X-ray Diffraction Analysis

XRD was utilized to detect the changes of cellulose crystallization[19] (Fig. 11) that were decreasing. Cellulose crystallization degree and the crystal size were estimated by the deviation curve of the oar blade wood where they were found to be 42% and cellulose crystal size (0.5 ångström)

Fourier-Transform Infrared Spectroscopy

The Varnish Layer and Other Previous Restoration Materials

The findings indicated that the varnish type was shellac. After a comparison with the control sample[20] (Table 1, Fig. 12), it was found that the previous restorations material was animal glue (Table 2, Fig. 13) characterized with the presence of N-H 1500-1565 cm-1. It was confirmed by the N-H stretching band at 3200-3500 cm-1 and bands corresponding to the stretching frequencies of carbonate (1490-1370cm-1, 910-870Cm-1).

Measurement of Changes in the Collection of Wood Building Materials

This method was also used to measure the changes in the collection of wood building materials,[21] and those in specific FTIR absorbance peaks that were designated to different wood deterioration processes (Figs. 14, 15).[22] A comparison between standard and archaeological samples showed a change in the general structure of cellulose. There was an increase in some absorption areas of the distinct groups of cellulose and a shortage in other areas. It appeared that there was a significant decrease in the hydroxyl absorption group CH2-OH stretching group in the area (3300-3340). The C-O Stretching group appeared in Area 1000-1300. At the area (1550-1650), C = O stretched and there was a strong carbon absorption zone that appeared as a result of the loss of cellulose in the surrounding atmosphere.

Conclusion

The oar studied dated back to the 4th Dynasty during the reign of Pharaoh Cheops (Khufu) (GEM No. 305). It 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

Table 1: The wave numbers and functional groups of shellac.

Wave number (cm-1)		
Shellac	Sample	Functional Group
3600–3200 cm^{-1}	3420.14	O-H Stretching
3100–2800 cm^{-1}	2937.08	C-H Stretching
1740–1640 cm^{-1}	1725.01	C=O Stretching
1650–1600 cm^{-1}	1597.73–1509.03	C-C Stretching
1480–1300 cm^{-1}	1395.25	C-H Bending
1300–900 cm^{-1}	1275.68–1129.12	C-O Stretching

Table 2: The wave numbers and functional groups of animal glue.

Wave number (cm-1)		
Animal Glue	Sample	Functional Group
3400–3200 cm^{-1}	3752	N-H Stretching Band
3100–2800 cm^{-1}	2925	C-H Stretching Bands
1660–1600 cm^{-1}	1610	C=O Stretching Band
1575–1500 cm^{-1}	1509	N-H Bending Bands
1480–1300 cm^{-1}	1294	C-H Bending Band

wood layers. The wood species identification indicated that the ancient Egyptian carpenter made the oar of Lebanese cedar, indicating that he was aware of the wood properties. The analysis with different methods using ESEM, XRD and FTIR to detect changes in the degree of crystallization of cellulose, changes in selected wood building material, and changes in specific FTIR absorbance peaks were designated to different wood deterioration processes.

Acknowledgments

The authors would like to thank all Conservation Center's staff in Cheops Boat. Special thanks are due to Dr. Amany Hussien Zaky, director-general of restoration at Cheops Museum.

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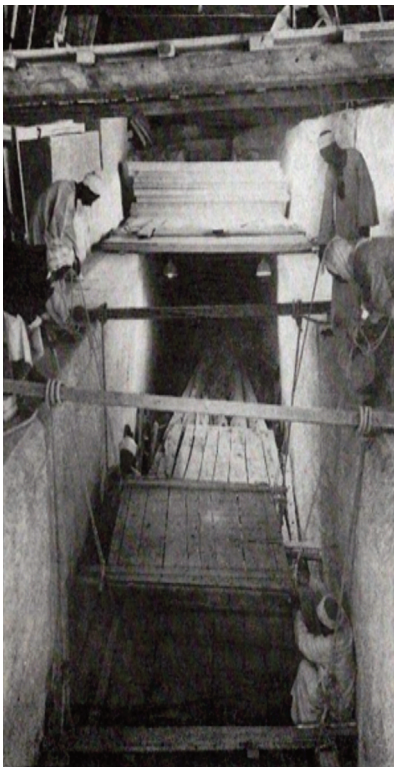
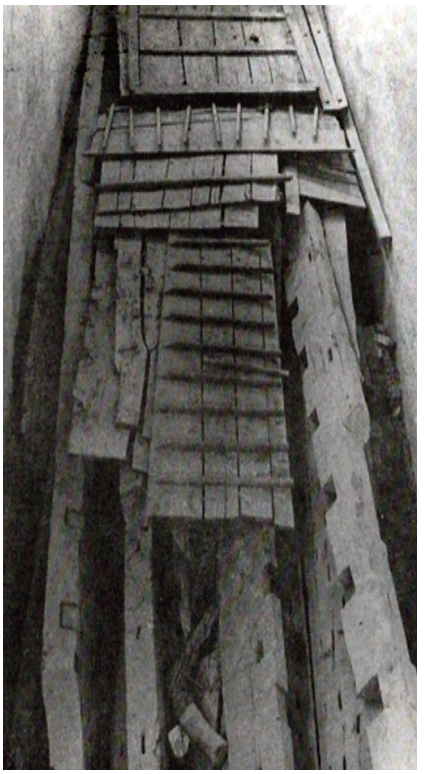


A



B

Figure 1: Cheops First Boat, upon discovery

A

B

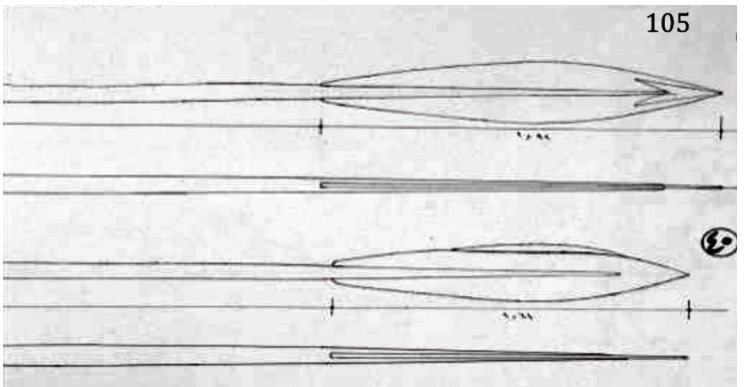


Figure 2: A: During treatment by Ahmed Youssef; **B:** Exhibition No. (39–40), by Ahmed Youssef, Cheops Museum stores.

FIGURE 3: One of the Cheops boat oar blades and its dimensions.

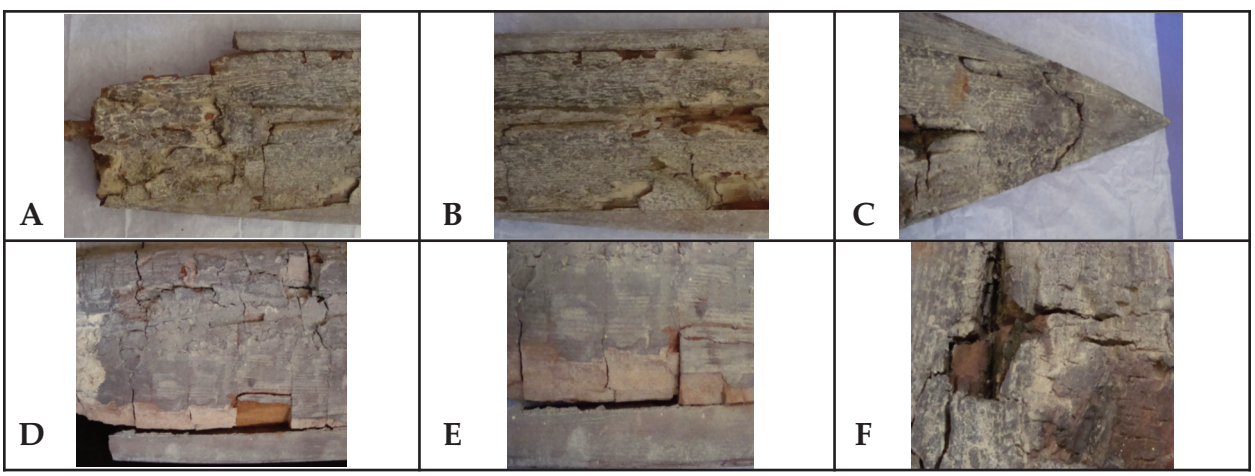


FIGURE 3: Aspects of deterioration found on the oar, **A,B,C:** exhibitions showing cracks, dust, and friable wood layers, **D,E,F:** exhibitions showing the separations between the wood layers and missing parts.

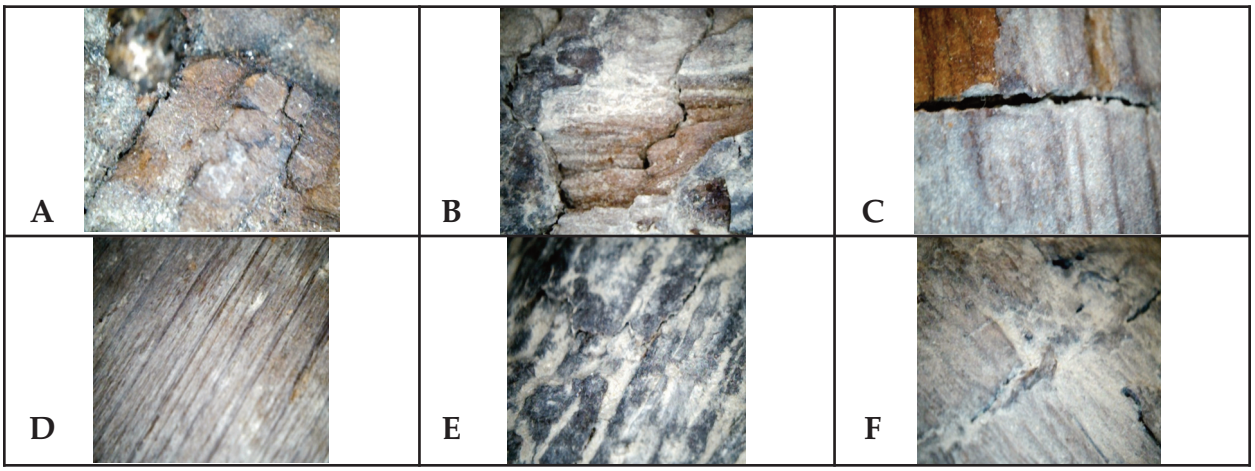


Figure 5: Investigation under digital microscope. **A, B, C:** exhibitions showing friable wood layers, cracks in the longitudinal and transverse direction of the wood fibers and missing parts, exhibition. **D, E, F:** separation between wood fibers and sandy calcification, and dust.

Figure 6: 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 tracheid's are distinguished by their bordered pit ray parenchyma cell have simple pits.

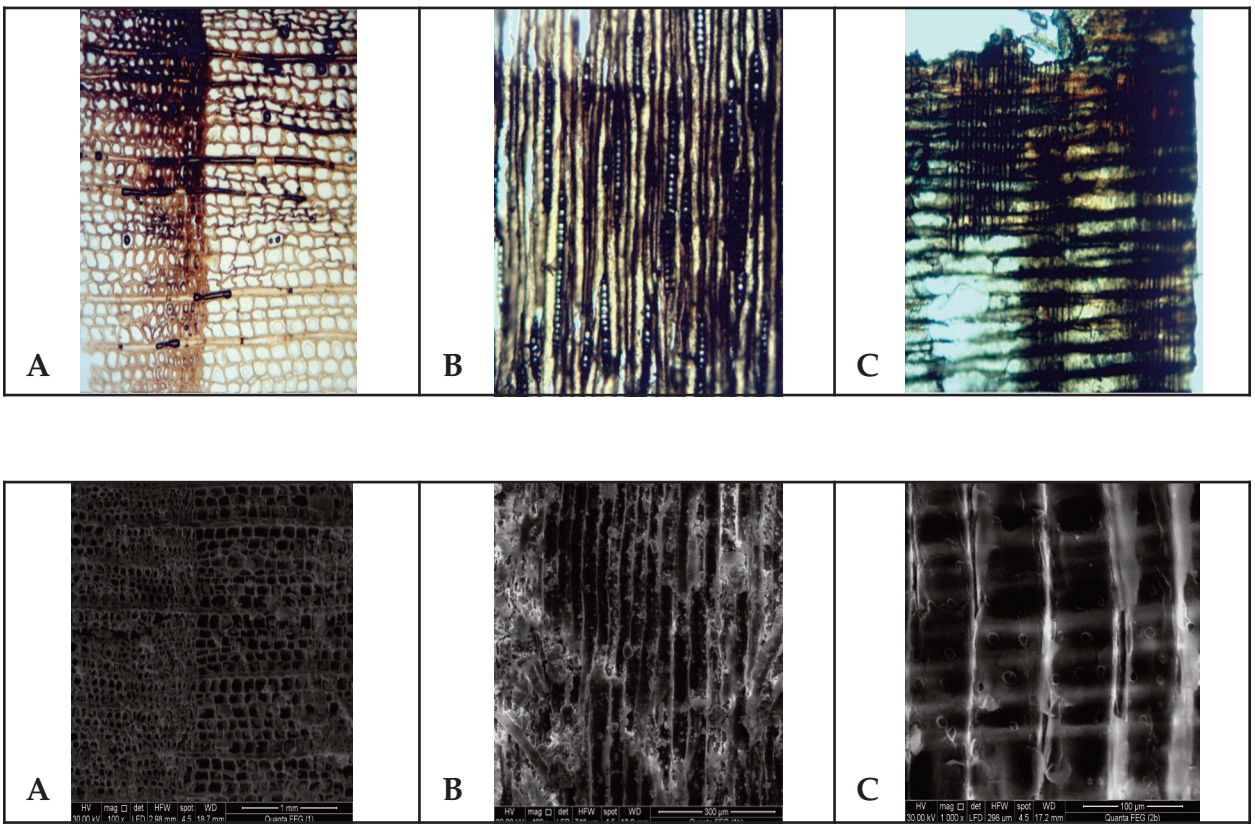


Figure 7: Lebanese cedar wood. SEM microphotographs of Lebanese cedar wood: **A, B, C:** the anatomical characteristics of cedar wood. Resin canals, sequencing single-cell rays and simple pits.

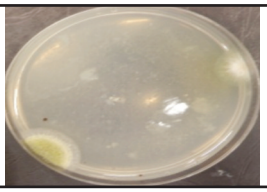
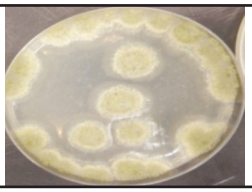
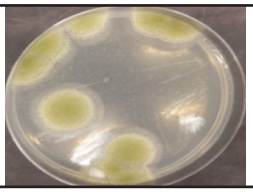
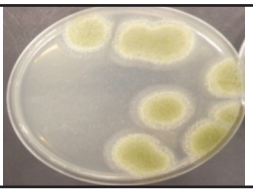
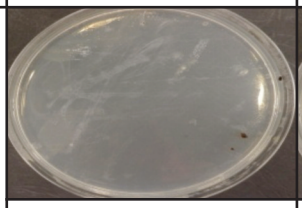
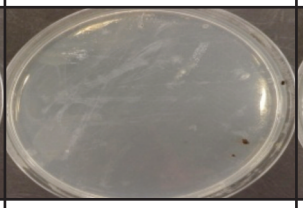
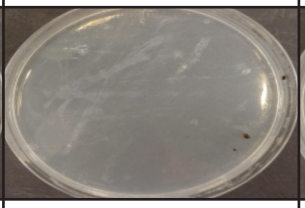
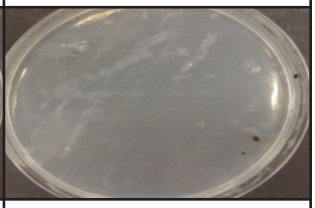
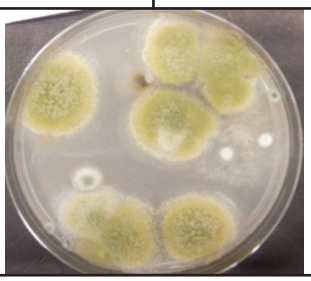
No	Swab 1	Swab 2	Swab 3	Swab 4
Medium				
	(1) *Aspergillus flavus* (1) *Aspergillus terreus* Total colony count = 2	(23) *Aspergillus flavus* Total colony count = 23	(10) *Aspergillus flavus* Total colony count = 10	(9) *Aspergillus flavus* Total colony count = 9
LCM Medium				
	-ve	-ve	-ve	(1) *Aspergillus terreus* Total colony count = 1
Nutrient agar medium				
	(5)G –ve bacilli a Total colony count=5	(1)G –vebacilli a Total colony count=1	(6)G –vebacilli a (6)G –vebacilli b (4)G –vebacilli c	(3)G –vebacilli a Total colony count=3
Air sample examination				
	(12) *Aspergillus flavus* (9) *Penicillium* sp. Total colony count= 21			

Figure 8: Isolation of fungi and bacteria from the oar blade.

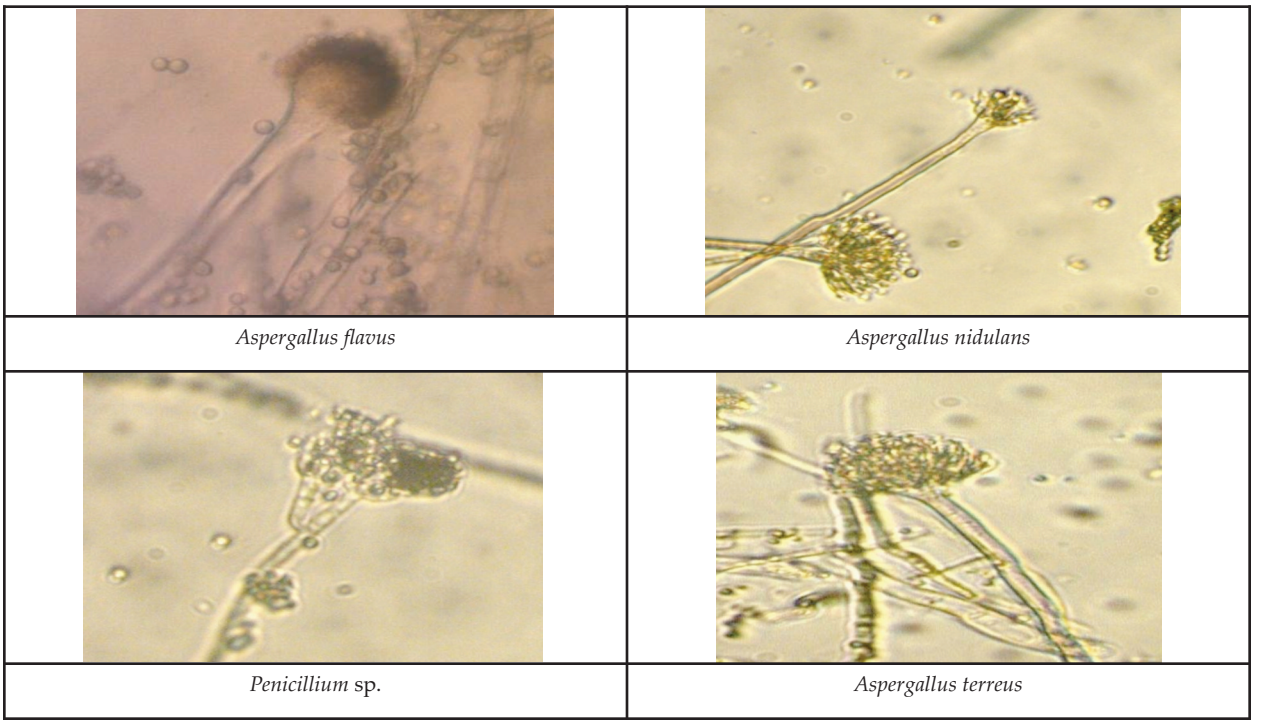


Figure 9: Examination under light microscope.

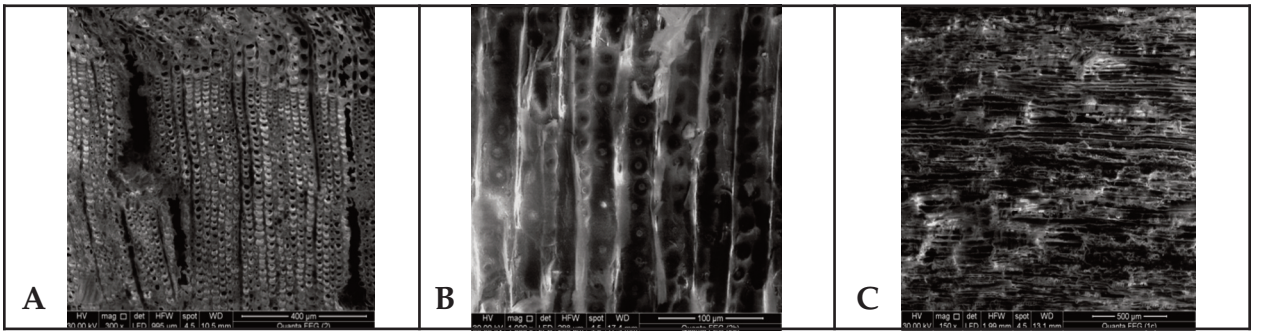


Figure 10: Scanning electron micrograph. **A:** collapse of cell walls, presumably due to mechanical pressure; **B:** showing cell wall degradation in the middle lamella, primary wall and secondary wall; **C:** rupturing of different cell walls with the remnants of the previous preservation material used .

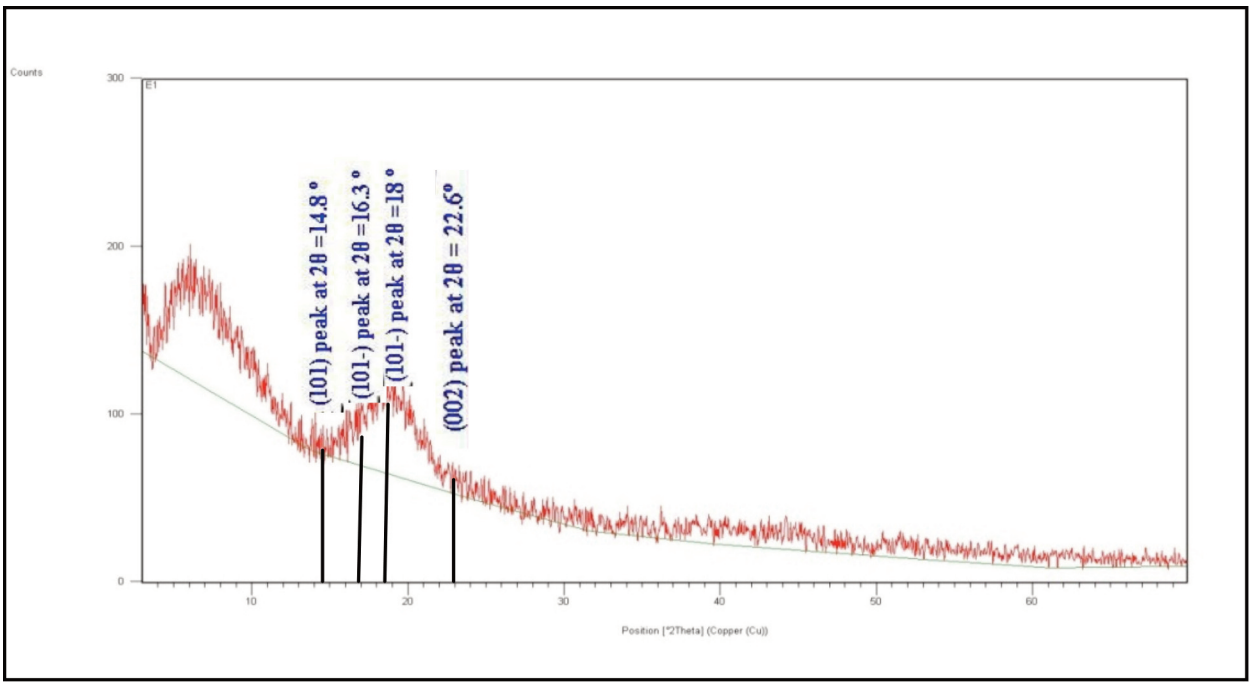


Figure 11: Cellulose analysis by X-ray deviation of the oar blade wood

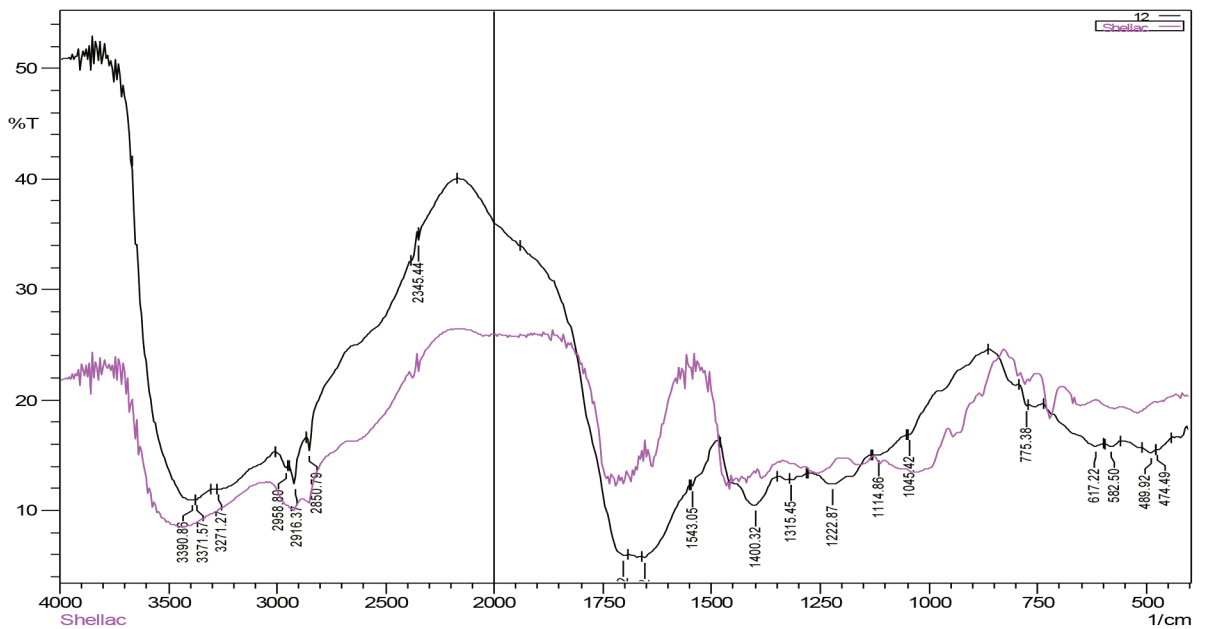


Figure 12: Findings of FTIR analysis for a varnish sample of shellac.

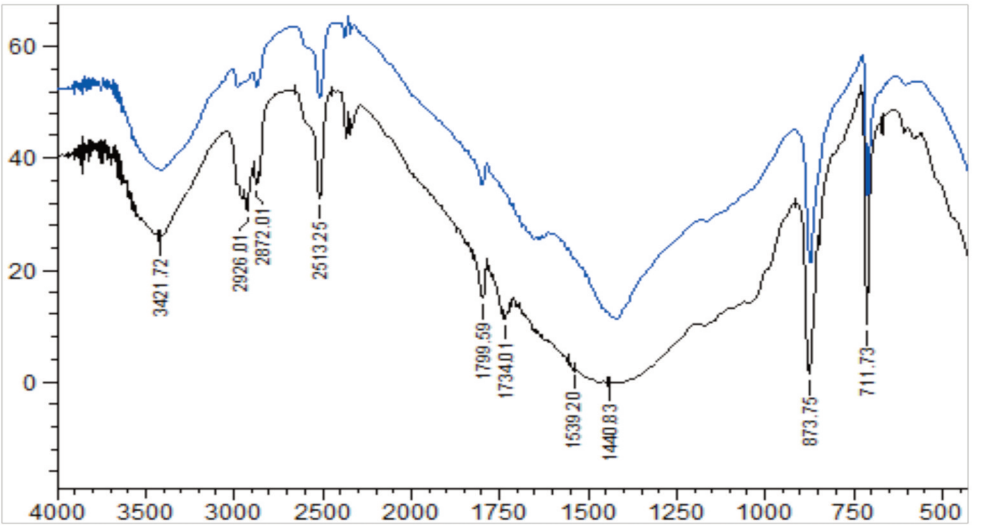


FIGURE 13: FTIR analysis of the previous consolidation material.

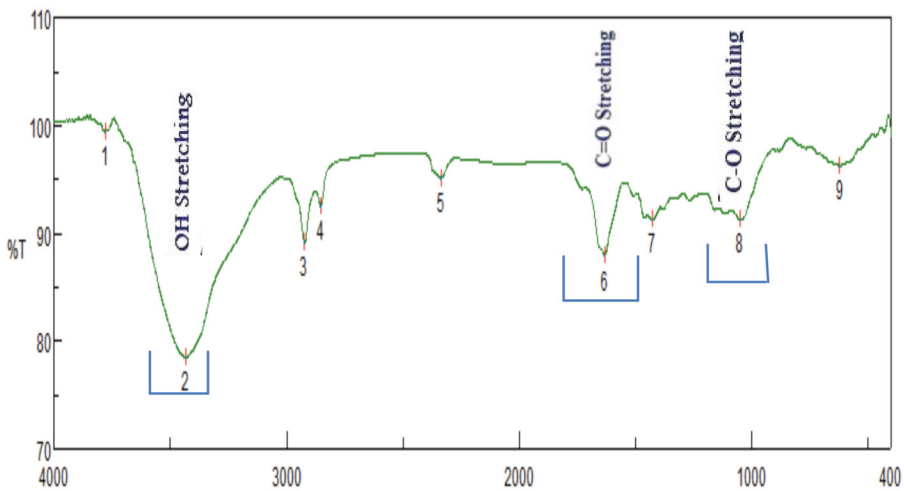


FIGURE 14: Findings of IR rays analysis of the standard sample of cedar wood.

FIGURE 15: Findings of IR rays analysis of the sample of ore blade wood.