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"A Study on some Physical, Mechanical and Chemical Changes of Deteriorated Archaeological Wood and it's Consolidation, with the Application on some Selected Artifacts at the Islamic Museum of the Faculty of Archaeology"

Submitted by

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Summary

Wood is a natural solid product obtained from trees. It is a perfect example of a natural composition containing cellulose, lignin and extractives. Due to the different percentages of the 3 major components, not only in the different species, but also within one tree, wood is considered an anisotropic and complex material. The complexity of modern wood is related to the microstructure of a tree during its growth, while archaeological wood is more complex due to its exposure to various deteriorating factors throughout the years. Therefore, it becomes very difficult sometimes to identify archaeological wood or to study its properties.

In order to find a relationship between the physical and mechanical properties of archaeological wood and its chemical composition, 11 different archaeological samples were chosen. They had been either affected by microbiological or insect infestation, mechanical deterioration factors or by their burial in soil.

Chapter One: Identification of Wood Samples

It was essential to begin this study by identifying all the chosen wood samples after examining them under the light microscope (LM) and scanning electron microscope (SEM). The identified wood samples were divided into two main groups:

1) Softwoods: a- Lycee and Qualaun samples that were made of Pine wood.
   b- Miscellaneous sample that was made of Fir wood.
   c- Sample of coffin 852 (the Faculty Museum) that was made of Cypress wood.
2) Hardwoods: a- Two samples, one taken from an ornament in the Faculty Museum and the second taken from a Mashrabiah in Wikalat Bazarah, that were made of Oak wood.
   b- Two samples taken from Safia mosque, two wooden masks (119-a &119-b) and a part of coffin 122 (Cairo University Herbarium) which were made of Sycamore wood.

For comparative studies modern wood samples of the same or similar species were prepared.

Both archaeological and modern samples were used in the first three chapters for studying the physical, mechanical and chemical properties of archaeological wood.

Chapter Two: Physical and Mechanical Properties of Wood

a) Physical Properties

The following properties of archaeological and modern wood samples were studied:

- Density:

The density of wood was measured using a Helium Pycnometer. In the case of modern samples the density ranged between 1.43 – 1.47 g/cm^3, and this was more or less similar to that reported in references dealing with the density of wood cellular components. However, it was observed that the density of the wood cellular components of all archaeological samples increased. The archaeological softwood's density reached 1.64 g/cm^3, whereas the hardwood's density reached 1.71 g/ cm^3. It was only noticed in one case, namely the outer wood layer of the Bazarah Mashrabieh, that the density reached 1.84 g/ cm^3. Probably this was due to the fact that the sample was taken from the outer layer, which may have been covered with old varnish in the past (as seen in the SEM micrographs). The density of the inner wood layer of the same sample measured only 1.61 g/ cm^3.

- Contraction:

An increase was observed in the contraction rate of archaeological wood samples in both longitudinal and radial directions (in comparison with the modern samples). The only exception was the contraction rate in the longitudinal direction of the Qualaun sample (which was 0%). The range of contraction in the longitudinal direction of modern samples was between 0-1.2%, whereas in archaeological samples it reached 13.1%. Contraction in the radial direction ranged between 1.23-5.7% in modern samples, and ranged between 5-28.5% in archaeological samples.

- Cellulose Crystallinity:

With regard to the cellulose crystallinity degree, which was measured by using the X-ray diffraction method; it was noticed that the results obtained from archaeological samples were more or less close to those of the modern samples (± 4%). The cellulose crystallinity degree decreased by approximately 19% in the case of the big sample taken from Safia mosque, by 9% in the case of the Lycee sample and by 7% in the case of Mask 119-a (in comparison to the modern samples). The highest increase of crystallinity was observed in the Qualaun sample, where a rise of 6% was measured.

b) Mechanical Properties

Conservators need special equipment to study the mechanical properties of wood, without using large amounts. Due to the difficulty of obtaining such equipment, it was not possible to carry out more than one mechanical investigation using the resistograph, which records accurately the wood resistance during drilling.

The drilling resistance of eight archaeological samples was studied (Qualaun, Miscellaneous, Mashrabieh from Bazarah, Museum sample, two samples from Safia Mosque, Coffin 122 and Mask 119-a). The investigations gave a clear picture of the sample's condition, e.g. the arrangement of the annular wood rings, wood pits, wooden dowels (if present), the depth of the decayed wood and the size of the undecayed core. The results of the test are represented by graphs, the scale of which is 1:1.

The sample of the Mashrabieh of Bazarah represented a very good example of a combination of several problems. The outer layer showed a small resistance against the drill, but towards the centre resistance grew gradually stronger. In the first experiment, where the wooden dowel was missing, the core showed no resistance due to the lacuna in that part. A strong resistance was clearly measured in the core ares, while carrying out the second test since the dowel used was made of a different and stronger type of wood.

Chapter Three: Chemical Composition of Wood

This chapter dealt with the different methods used in the quantitative analysis of wood elements and wood components.

- Wood Elements

By using a CHN Elemental Analyzer, the percentages of carbon, hydrogen and nitrogen were measured in both modern and archaeological samples. Changes in the carbon and nitrogen percentages of the archeological samples were observed. Carbon decreased by 18% in the museum sample and by 7% in the Mashrabieh of Bazarah sample (in comparison to the carbon content of the modern samples). In the case of coffin 122 the carbon content increased by 8.5%.

There was also an increase of nitrogen content in the archaeological samples. In the museum sample it reached 1.78% and in the sample taken from coffin 852 the nitrogen content reached 2.82 %, whereas in the modern samples the nitrogen content recorded was 0 %.

As for the hydrogen content, there was only a minor difference between modern and archaeological samples.

- Carbohydrates:

Apparent differences were observed while measuring the sugar content in all wood samples using a UV/visible spectrophotometer. The sugar content ranged between 0 %, in the case of the sample taken from coffin 852 which was made of Cypress wood, and 68.5 % in the case of the sample taken from coffin 122 which was made of Sycamore wood.

The sugar content did not exceed 69 % in any of the samples, although references reported sugar contents, which usually ranged between 65-85 %.

To verify the presence or absence of some of the sugars, all archaeological samples were examined by FTIR. Absorption of cellulose bands was evident in all samples, except for coffin 852 sample, in which the carbonyl group was absent.

- Lignin:

Lignin was prepared and measured in all samples according to TAPPI methods. Lignin percentages ranged between 18-35 % in most of the samples, but a high increase of lignin was observed in the sample taken from coffin 852, where it reached 43.23 %, and the miscellaneous sample, where it reached 49.12%. In the case of the sample taken from Mask 119-a, lignin content decreased to 15.85 %. An apparent decrease of lignin content was observed in only two cases: the small sample taken from Safia mosque (9.99 %) and the Mashrabieh sample taken from Bazarah (5.11 %).

The two main absorption bands of the chemical bonds in lignin were also examined by FTIR in all archaeological samples. Although absorption percentages varied between samples, the chemical bonds of lignin were present in all cases.

For the study the pure lignin, lignin was carefully extracted from all samples according to chemical techniques. It was then studied by using ^{31}P NMR. The sample taken from coffin 852 showed the best lignin spectra.

- Extractives:

Literature citations report a percentage of about 4-10 % wood extractives in common wood samples. This amount was only recorded in five samples; viz. Lycee sample and modern pine, the small sample from the Safia mosque and the two wooden Masks 119 – a & b. The percentage of extractives rose slightly in the case of coffin 122, where it reached 11.65 %.

The extractives percentage ranged between 1 – 3.5% in three archaeological samples; viz. Qualaun, Miscellaneous and the small sample from Safia mosque, and four modern samples; viz. Fir, Cypress, Beech and Sycamore. In the case of the Mashrabieh of Bazarah the amount of extractives was less than 0.1 %.

Relatively high extractives content was measured in the two remaining samples; where it reached 15.6 % in the museum sample and 21.01% in the sample taken from coffin 852.

Chapter Four: **Wood Consolidation**

This chapter dealt with the study of the effect of UV rays on six consolidated archaeological wood samples that were chosen according to wood species and type of deterioration. Three softwood samples were taken from: the Qualaun sample, coffin 852 and the miscellaneous sample. The three hardwood samples were taken from the Mashrabieh of Bazarah, museum sample and coffin 122. The only common factor between the six samples was that they were all fragile and completely deteriorated.

Three commonly used polymers were chosen for consolidation; Paraloid B-72 (3% concentration), Methyl Cellulose (1.5% concentration) and Tylose (1.5% concentration). Each of the three polymers was used to consolidate the six wood samples. Consolidated wood was exposed to UV rays (280-300nm) for 72 hours at 55% relative humidity and 27°C temperature. All samples were then left for 18 months in normal environmental conditions.

The chemical changes were studied in the artificially aged samples and the absorption bands of the three polymers before and after aging were carefully compared using FTIR. The results obtained confirmed the earlier results mentioned from previous studies, which dealt mainly with the physical features of wood consolidants; e.g. change of colours, and the mechanical properties of polymer films; e.g. compression and tensile strength.

In the case of Paraloid B-72, a strong loss of absorption was clearly observed in the chemical bonds of the polymer, especially those in the 2250-2600 cm^{-1} region and at 1720 cm^{-1}.

Methyl cellulose was considerably stable in the case of the samples taken from the museum and coffin 122. Partial loss of absorption was observed in the Qualaun and miscellaneous samples. Total loss of absorption of all polymer bands was recorded in the samples of the Mashrabieh of Bazarah and coffin 852.

Tylose showed the highest stability, compared with the previous two polymers, and the change in the polymer's absorption bands before and after aging was minimal.

Chapter Five: **Carved and Inlaid Wood**

This chapter dealt with some of the traditional woodworking techniques characteristic to wood dating back to the Islamic period. Application was carried out on six small wooden ornaments dating back to different eras (Tulunid, Fatimid and Mameluk) as well as a part of a Minbar dating back to the Osman period.

All six pieces and part of a Minbar, which are kept in the Museum of the Faculty of Archaeology, were carefully studied. Wood and wood inlay materials were identified according to their anatomical patterns when examined under the light microscope. The deterioration factors were carefully identified from SEM micrographs. Moreover incrusted salts and dust that were found in two of the six objects were identified using XRD. For analyzing ancient glue used in the Minbar, FTIR technique was used.

After identification and analyses; the following conservation procedures were carried out:

1- Cleaning of all six wooden objects and the side of the Minbar.
2- Consolidation of the six wooden objects.
3- Straightening of the warped wood.
4- Filling of insect holes.
5- Gluing together broken pieces.
6- Replacement of missing ivory inlays with modern bone.
7- A new mahogany showcase was made for the display of six wooden objects.
8- Plexi glass holders were made according to size of the wooden objects, and were used to fix the wooden objects in the new showcase.
9- A new wooden base was made for the Minbar, and specially made plexi glass holders were used to hold the Minbar in an upright position.

Concluding remarks followed the discussion of the results obtained in the first four chapters. In addition to that the following topics were discussed in relation to each other:

- Wood density and chemical composition.
- Wood expansion and contraction and the chemical components of wood.
- Sugar content and cellulose crystallinity
- Consolidation of wood.
- Proposals for future research.