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ASSESSMENT OF DETERIORATION AND CONSERVATION OF A POLYCHROME WOODEN COFFIN, FROM AL-ARISH MUSEUM, EGYPT

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Abstract

This paper describes the deterioration and preservation of an Ancient Egyptian polychrome wooden coffin, dating back to the 1st century. Common deterioration problems are the wood splitting and cracking, detachment of ground and paint layers, fungal damage, dirt adhesion and staining. The project entails securing the severely damaged wood, preparation of lime layer, the painting layer, and paint layer to a substrate, by consolidation, cleaning, dust removal and treatment of the degraded wood. Qualitative analysis of samples selected from the coffin, was reported. Studies that includes the identification of wood species, ground layer, paint layer, binding medium and microbiological identification were made. Several analytical methods were employed in the identification processes such as the Light optical microscopy (LOM), Scanning electron microscopy equipped with energy dispersive X-ray analyzer (SEM-EDS), X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). The obtained data were used to evaluate the deterioration status of the coffin and to establish suitable treatment methods.

Keywords: *polychrome wooden coffin; biodeterioration; wood identification; treatment.*

Introduction

At the beginning of 2010 a conservation treatment was applied on the polychrome wood coffin which was exhibited at El-Arish Museum. The coffin is composed of two halves; the lower half and the top half (Fig. 1). The coffin box (lower half) consists of several wooden boards linked by wooden dowels. The length of the coffin box is 206cm, the width approximately 70cm and the height approximately 47cm. The inside of the coffin box is prepared for a mummy to fit in (Fig. 2A). On the exterior it is covered with primer layers, vertical rows of hieroglyphs and drawings of some gods are inscribed. The second piece is the top (coffin lid), which is carved. The maximum length is 206cm, the thickest part has 70cm and the height is between 27cm and 45cm at the feet (Fig. 2B). The carving represents the deceased in Osiri posture. This posture was traditional and preferred for the deceased in the other world. It depicts the deceased lying on his back, legs stretched and the arms bended on the chest, holding in the right hand the column, (jade) emblem of Osiris and in the left hand the whisk, emblem of Isis. The body is presented as wrapped in linen and covered with primer layers on

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which hieroglyphs are painted symbolizing the guaranteed happiness of the deceased in the afterlife. The painter succeeded in presenting the main features of the deceased: inlaid eyes, straight nose, hooked beard and a long hair which rests on both sides of the chest. The painter protected the deceased by painting/carving the god Nut, "the sky goddess" on her knees spreading out her wings down to the deceased chest, as if in a warm embrace. The painted wooden coffin has writings and drawings of some gods as evidence of titles of the gods, where the represented son of a king or God, is shown as equal with the gods Amon, Amon-Ra, Hoor akhty, Petah, Thoth, Maat, and other popular gods or local goddess as Bastt, Taurt, Bess, who are included in the magic incantations. The coffin is severely deteriorated, due to microclimate inadequate the museum. The climate inside the museum was very wet; the moisture inside exhibition hall reached above 65% because of permanent technical problems in central conditioning in the museum, also the coexistence of the museum in a coastal environment close to the sea. In addition, the coffin was displayed in the hall without show case. As a result, the coffins were in a much deteriorated condition and easily collapsible from any movement. The aim of this study is to characterize the components of the pictorial surface which consists of pigments, binding media and ground layer, in addition to identify the wood support and uses some analytical technique to explain the deterioration mechanism caused by deterioration factors to introduce suitable treatment [1-3].

Fig. 1. Polychrome coffin consists of coffin box, coffin lid and third piece forms the projecting 'toe and foot' of the top.

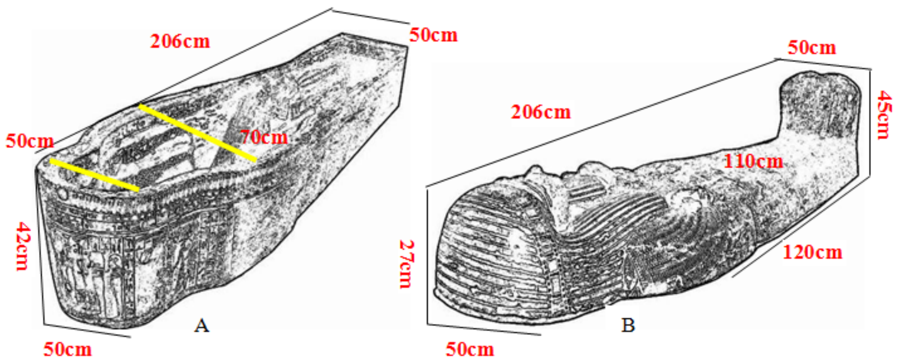

Fig. 2. The size of the coffin: A - the coffin box, B - coffin lid

The Conservation State of the Coffin

The *wood* has decomposed and darkened, small wood chips could be easily blown away and the brittle wooden outer layer would be easily scratched this confirmed the very fragile nature of the deteriorated wood and losses over time are probably from the severely degraded condition of the wood. The shrinkage of the wood was resulted in numerous transverse and longitude cracks, some which penetrate through the thickness of the wood and warping of some desiccated parts was observed (Figs. 3 and 4).

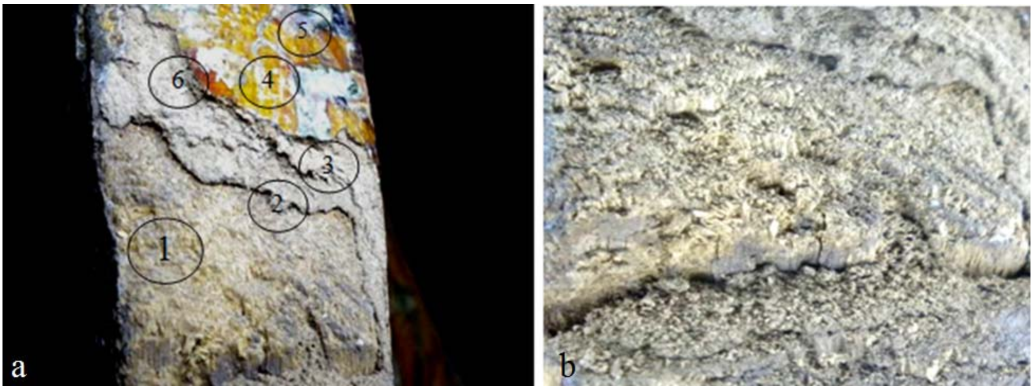

Fig. 3. Surface details: a - Structure layer of coffin (1- wooden support, 2 - rough layer, 3 - fine layer, 4 yellow pigment, 5 - blow pigment, 6 - red pigment); b - decomposition of wood**.**

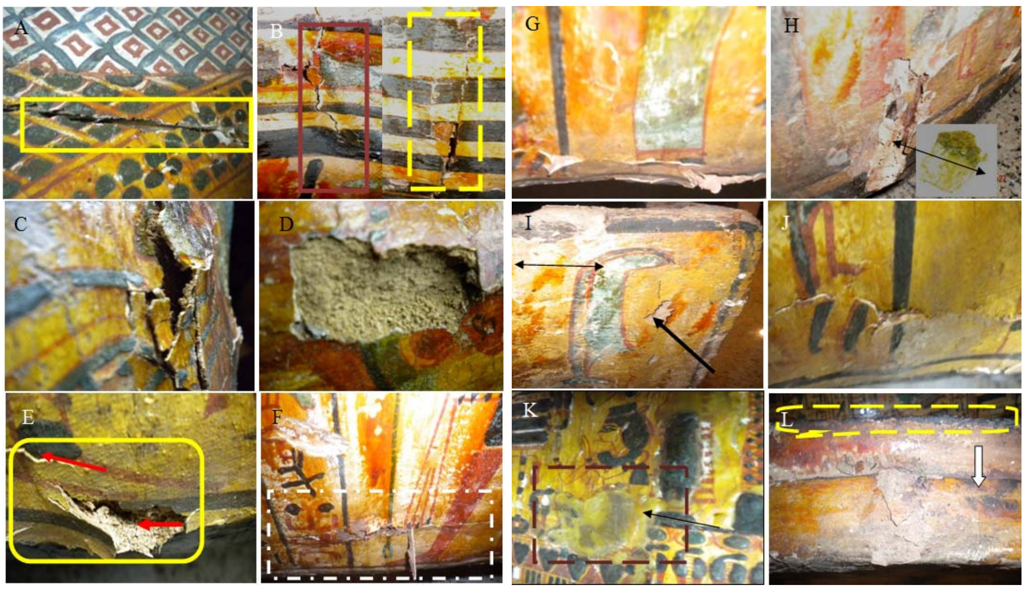

Fig. 4. Deterioration features of the coffin a shrinkage and warping of the wood: A – transverse, B – longitudinal, C - separation of the painted plaster from the wooden support of the coffin, D - painting layer lost, E, F - flaking and chipping of the ground and paint layer, G - flaking and crumbling of paint layer, H - the paint flakes with thick layers dropping off in small particles, I - the areas of yellow and green pigment detached, highly friable and chromatic alterations, J - cracking and accumulation of dust particles, K - particles of candles, L - biological damage, along the edges.

The *ground layer* of the coffin consists of two layers, the rough layer which covered the wood directly with thickness approximately 3mm and fine layer used under the pigments directly with thickness approximately 30μm (Fig. 3A). It was dirty white in color and of fairly grainy texture covers the wood on all surfaces. This ground material which presumably mixed with adhesive binder was applied as a very thin wash on all surfaces except the exterior of the top, where it is significantly thicker and contributes to the modeling of the shape. The ground material was also used to build up areas such as the nose and knees. Shrinkage of the wood beneath this ground layer was resulted in many cavities and detached areas of the painted plaster from the wooden support (Fig. 4C), in some area the painting layer was entirely lost (Fig. 4D). The fragile layer is extremely susceptible to further flaking and chipping whenever the coffin is exposed to fluctuations in humidity (Fig. 4E).

Although areas of the *paint layer* were still well attached to the ground layer, others were had lost their cohesion and separated into many pieces with exfoliated colored layer in flakes shapes in several areas and crumbing in some parts (Fig. 4F and G). The paint flakes from the under painting with thick layers dropping off in small particles (Fig. 4H). The areas of yellow and green pigments were often detached, highly friable and chromatic alterations (changes in appearance) (Fig. 4I). In addition to cracks, accumulation of dust and insects staining were noticed (Fig. 4J). The drawn shapes are indistinct because of the accumulation of wax which had been used from previous fault restoration to fixate the paint layer in coffin lid (Fig. 4K), Efflorescence salts, staining and fungal damages were observed (Fig. 4L).

Materials and Methods

The scientific examination was intended to elucidate the nature of the original and added materials as well as to establish the state of conservation of the coffin. Samples were carefully chosen during conservation work from areas that had no aesthetic value for restoration and from areas which suffer from deterioration. Ground layer, yellow, green, black pigments were taken from some fragments that had previously fallen and small wood sample taken from the open area of the left side of the coffin's box. Samples have been studied by deferent methods.

Stereo microscope

The samples were first observed using Olympus BX40 optical stereomicroscope, and recorded with digital camera under 40-60X magnification to study their surface. LOM can provide information of the damage layer such as the sequence of layer, particle size, color and texture of this layer.

Scanning electron microscope (SEM-EDX)

Wood sample analyzed using a Jeol JSM-6400 LV scanning electron microscope (SEM) equipped with an Oxford energy-dispersive X-ray (EDX) system, detector model 6587. To be analyzed, the sample was coated with gold.

X-ray diffraction (XRD)

Selected samples were analyzed by X-ray diffraction (XRD) using a Philips PW 1840 Diffractometer, the patterns were run with Ni-filtered Cu Kα radiation (λ= 1.54056Å) at 40kv and 10mA. Diffractograms were taken between 5.025 and 73.96°

Fourier transforms infrared spectroscopy (FTIR)

Binding medium was studied by Fourier transform infrared spectroscopy (FTIR).The samples were analyzed as KBr pellets by JASCO FT\IR–460 plus. 0.5 mg of powder sample was dispersed and further ground in about 70 mg of KBr and pressed into pellets under about 10 tons/cm^2. KBr pellets of powdered samples were examined between 4000 and 400 cm^{-1} at a resolution of 4 cm^{-1}. Spectra were acquired between1000-4000cm^{-1}.

Identification of the wood

The wood sample was taken from the coffin box was desiccated and brittle. It was embedded in poly ethylene glycol (PEG) and cut with rotative microtome. Thin section (15-20μm was obtained in the three principal anatomical directions, transverse (TS), tangential (LS) and Radial (RLS). The histological sections were observed by optical microscope in transmitted light (Olympus BX40) with digital camera under 40-60X magnification.

Biodeterioration study

The changes in wood resulting from fungal decay were investigated. Samples of the predominant alterations were taken from the original paint layer and wood. For the isolation of fungi, Czapek's agar medium [4] was used and was melted and kept at 45°C. Czapek's medium comprised (gL^{-1}): sodium nitrate, 3.0; potassium dihydrogen phosphate, 1.0; magnesium sulfate, 0.5; potassium chloride, 0.5; ferrous sulfate, 0.01; glucose, 10; agar, 15. Chloramphenicol (0.05 mg/ml) was used as bacteriostatic agent [5]. The plates were incubated at 28ºC for 5-7 days during which the developing fungi colonies were counted and identified [6].

Results and discussions

The Ground layers

The EDX analysis of rough layer (table1) showed the presence of $CaCO_3$ (calcite) and SiO_2 (quartz) as the main elements and small amounts of S, Cl, Na, Mg, Al, K, Ti, Fe and Sr. These results showed that the preparation layer is a mixture of lime (CaO) and sand (SiO_2). The presences of S essentially owed to the pollution of sulphure dioxide. The occurrence of Na and Cl are indicative of the existence of halite (NaCl), whose presence is due to materials used in the ground layer or moisture. The presence of aluminum oxide and potassium oxide are from dust. The presence of MgO owed to limestone which had been used in makes lime. The presence of Fe is essentially owed to painted layer. Finally presence of Ti and Sr are sign of the organic rest. The EDX analysis of many places in the underneath colored layer showed the fine layer contains high percentage of CaO, SiO_2 as the main elements. In addition to ZnO (zincite), indicating that the preparation layer is a mixture of lime, sand and zincite. The XRD analysis confirmed that, the inner coarse ground layer contain mainly calcite ($CaCO_3$) mixed with quartz (SiO_2). Spectrum of XRD shows that the materials composition of the fine ground layer underneath the paint layers contain mainly calcite mixed with quartz, in addition to zincite (ZnO) (table 2).

The paint layer

Red pigment: LOM showed that coarse morphology of the surface, homogeneous distribution of the pigment, some places shows fading of the color with some microcracks distributed on the entire pigment surface (Fig. 5A). The results of SEM-EDX microanalysis (Table 1 and Fig. 6A) showed that silicon, calcium and iron are the main elements. Small amounts of S, K, Al, Zn, Pb, Na and Cl were detected in the sample. Calcium and Silicon is related mainly to calcite and quartz (ground layer), Na, and Cl are probably related to the presence of some salts, Al and Si to some clay minerals. Zn is related to zincite, Pb is related to red lead Pb_3O_4. XRD analysis in figure 7b and table 2 proved that red lead Pb_3O_4 and Iron oxide (Hematite) is responsible for the red color. Lead tetroxide, also called minium, red lead or triplumbic tetroxide is a bright red amorphous pigment. Chemically, red lead is lead tetroxide, Pb_3O_4 or $2PbO{\cdot}PbO_2$. Lead tetroxide was used as a red pigment in ancient Rome, where it was prepared by calcinations of white lead. In the ancient and medieval periods it was used as a pigment in the production of illuminated manuscripts and coffins, and gave its name to the minium or miniature, a style of picture painted with the color [7].

Yellow pigment: LOM examination showed the rough morphology of the yellow surface. The pigment surface is inhomogeneous in thickness, most probably due to inadequate preparation of the paint layers. There were also black spots in the coarse grains due to the additives that were mixed with it (Fig. 5B). EDX analysis (Table 1 and Fig. 6B) of the yellow paint indicates that Ca, and Si are the main elements, Al, Fe, K, Mg, Ti and Sr in small amount were detected. Ca and Si related to ground layer. Al, Fe, K, Mg, Ti and Sr are related to the accompanied impurities. Traces of S and As were also detected representing Orpiment As_2S_3. XRD results in (Fig. 7C and Table 2) improved that yellow pigment attributed Orpiment As_2S_3 and iranite $Pb_{10}Cu(CrO_4)_6(SiO_4)_2(F)_2$ and showed the presence of Calcite $CaCO_3$ and zincite ZnO which owed to ground layer. Orpiment is a yellow to greenish yellow sulfide of arsenic (As_2S_3), containing 60% arsenic [8]. Early known uses of orpiment as a pigment occur in Middle and New Kingdom Egypt (sixteenth to eleventh centuries BC) as painted decoration on wooden coffins and stelae and as a cosmetic [9]. Because of its bright color, the pigment was popular for use on mediaeval manuscripts and it has been identified from the Book of Kills. It was undoubtedly the most prized yellow for artists, even when mixed with blues to obtain greens [10]. Orpiment has been verified that painters applied the pigment in pure form or ground with white to obtain intense hues and imitate the glitter of gold in jewels and brocaded cloths, or superimposed it onto earths to obtain duller or darker hues [11].

Green pigment: The paint granules of green color were defined by LOM (Fig. 5C) and showed inhomogeneous composition of the sample. The EDX analysis (Tablel 1 and Fig. 5C) shows that SiO_2, CaO, and Cu are the dominant oxide in the sample. Significant amount of S was recorded small amounts of Al, K, Fe, As and Pb are observed. XRD analysis of the green pigment (Fig. 7D) showed the presence of calcite ($CaCO_3$), quartz (SiO_2), malachite ($CuCO_3Cu(OH)_2$) and zincite (ZnO). Malachite was used for green color.

Black pigment: The examination of the black color by LOM (Fig. 5D) showed the compact surface of the sample, the color layer is very thin and tends to be brown confirming the presence of carbon with red particles residue. EDX analysis, (table 1 and figure6d) indicates that Ca and Si are the dominant elements. The sample contains small amount of Na, Cl, K, Ti, Sr and Fe. No other elements related to carbon black (graphite) or other element typically used to obtain a black color are present. But XRD analysis (Fig. 7E) proved that, the sample contains crystalline phase related to Graphite. Calcite, quartz and zincite were recorded which related to ground layer.

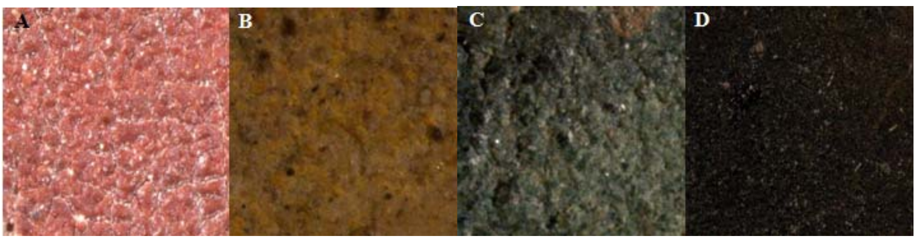

Fig. 5. Photomicrographs of the paint layer of the coffin:
a - red, pigment b - yellow pigment, c - green pigment, d - the black pigment.

Table 1. EDX results of samples taken from ground layers, paint layers and wood

Preparation layer		Yellow pigment		Red pigment		Green pigment		Black pigment	
Element	(%)	**Element**	(%)	**Element**	(%)	**Element**	(%)	**Element**	(%)
Na	0.5509	Na	2.5485	Na	1.04	Al	1.5018	Na	1.0798
Mg	2.9456	Mg	1.8974	Al	2.1281	Si	13.3567	Al	1.3775
Al	3.4694	Al	2.1638	Si	16.6078	S	5.2266	Si	9.9343
Si	26.6133	Si	18.5037	S	6.3529	K	2.1322	S	2.1669

S	4.3237	S	2.7336	Cl	2.1198	Ca	52.9571	Cl	5.1374
Cl	3.1077	Cl	5.6115	K	1.4312	Fe	1.7286	K	0.7170
K	2.0204	K	1.7938	Ca	52.0656	Cu	21.5131	Ca	76.0253
Ca	47.5209	Ca	57.9117	Fe	7.9680	As	0.8106	Ti	0.9489
Ti	2.2728	Ti	1.6138	Zn	6.0249	Pb	0.7554	Fe	2.3530
Fe_2	6.7312	Fe	4.7443	Sr	0.4802	---------	---------	Sr	0.2599
As_2	0.1269	As	0.1748	Ba	4.4560	---------	---------	---------	---------
Sr	0.2700	Sr	0.3031	Pb	0.3655	---------	---------	---------	---------

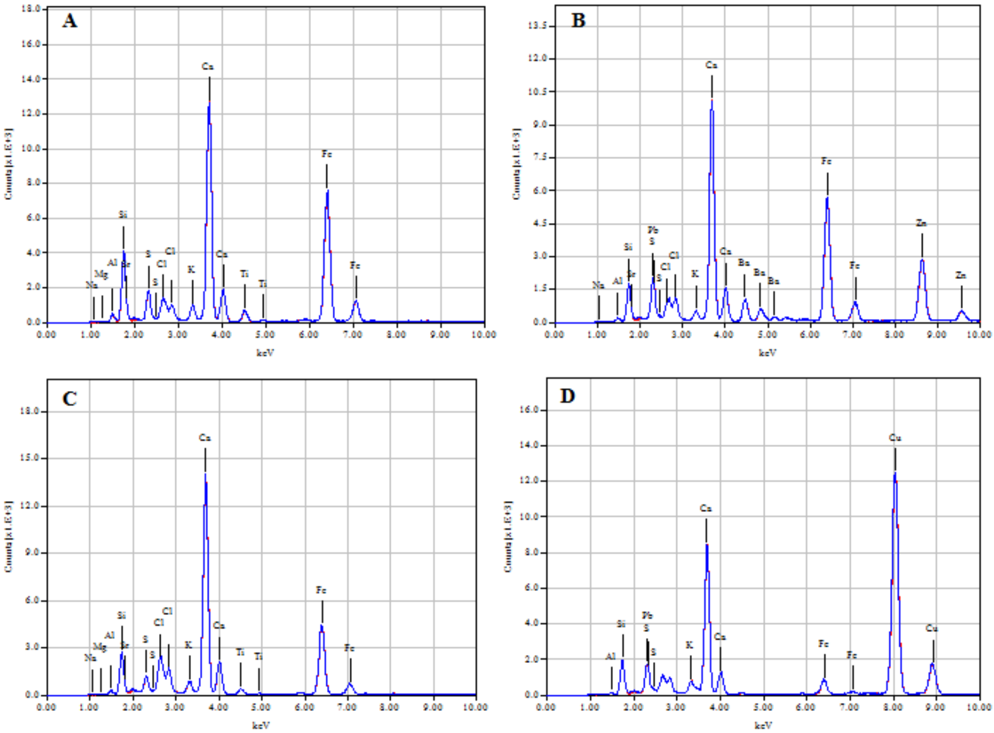

Fig. 6. EDX patterns of the polychrome coffin components:
A - red pigment, B - yellow pigment, C - green pigment, D - black pigment.

Table 2. X-Ray Diffraction results of samples taken from ground layers, paint layers and wood

Kind of samples	**Compounds**
Wood sample.	Cellulose, $(C_6H_{10}O_5)_n$; Gypsum, $CaSO_4 \cdot 2H_2O$ and Calcite, $CaCO_3$
Rough Plaster layer	Calcite, $CaCO_3$ and Quartz, SiO_2
Fine Plaster layer	Calcite, $CaCO_3$; Quartz SiO_2 and Zincite, ZnO
white pigment	Calcite, $CaCO_3$ and Zincite ZnO
Red pigment	Calcite, $CaCO_3$; Red lead Pb_3O_4; Hematite, Fe_2O_3; Microcline, $KAlSi_3O_8$; Quartz, SiO_2 and Kaolinite, $Al_2Si_2O_5(OH)_4$
Yellow pigment	Calcite, $CaCO_3$; Orpiment, As_2S_3; Iranite, $Pb_{10}Cu(CrO_4)_6(SiO_4)_2(F)_2$ and Zincite ZnO
Green pigment	Calcite, $CaCO_3$; Quartz, SiO_2; Malachite, $CuCO_3Cu(OH)_2$ and Zincite ZnO
Black pigment	Calcite, $CaCO_3$; Quartz, SiO_2; Zincite, ZnO and Graphite, C

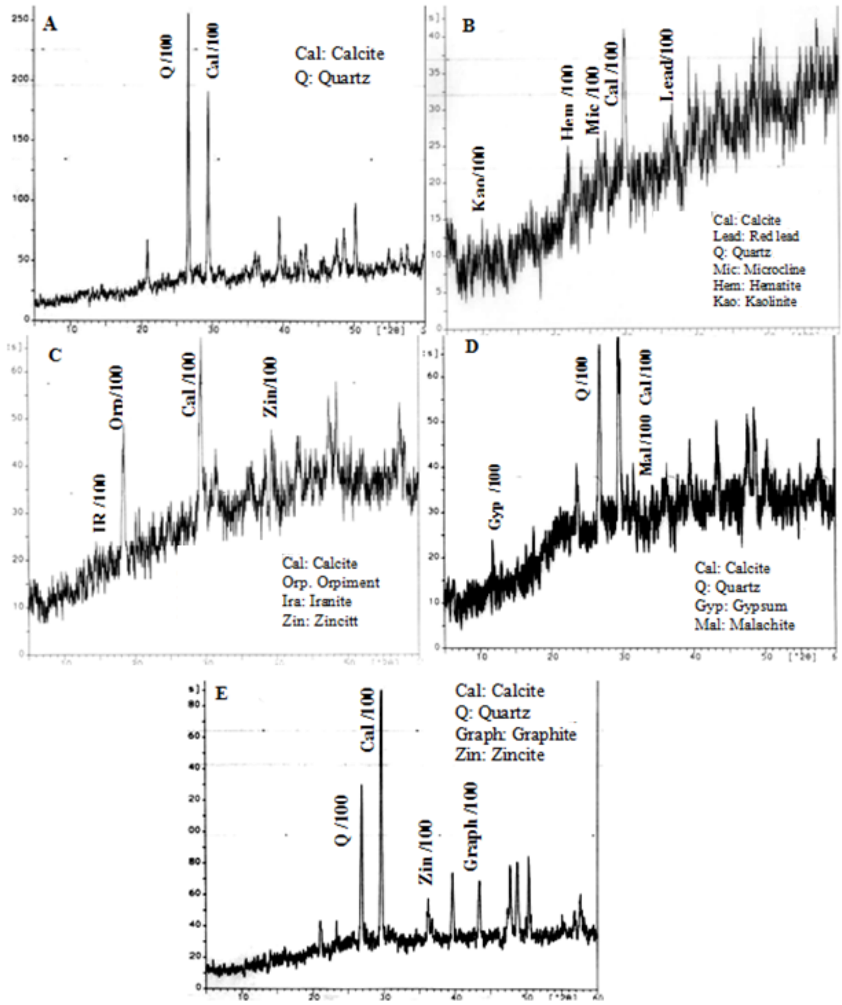

Fig. 7. XRD patterns of the polychrome coffin components:
A - ground layer, B - red pigment, C - yellow pigment, D - green pigment, E - black pigment

Identification of organic binding media

Fourier-transform infrared spectrometry (FTIR) analysis was performed to detect the organic binding media. Yellow samples were taken from the coffin. The results of FTIR showed that Arabic Gum was used to bind paint grains and fix it at ground layer (Fig. 8 and Table 3).

Table 3. The wave numbers and Functional groups of coffin sample and Arabic Gum

Wave number (cm^{-1})		Functional group
Arabic gum [12]	Sample	
3600-3200	3402	OH- stretching bands
3000-2800	2980	C-H stretching bands”
1650-1850	1789	O-H bending band
1480-1300	1411	C-H bending band
1300-900	1051	C-O stretching band

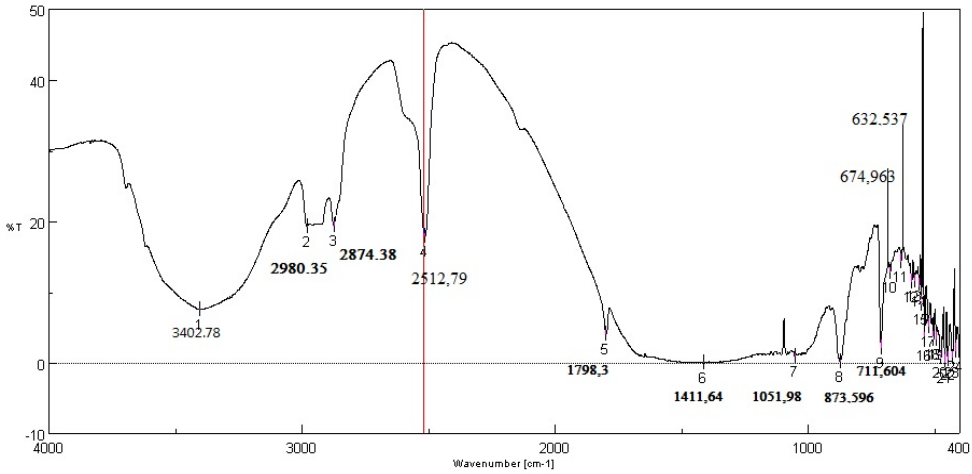

Fig. 8. FTIR spectra of the samples taken from the coffin showing the bonding of paint layer and plaster.

The support. Wood identification

The wood was identified as cypress wood (*Cupressus sempervirens*). It is important to note that, this type of wood has been rarely documented in ancient coffins and even today this species is not used commonly as a timber product, but it may have been of some local importance in some countries and has been identified in some ancient Egyptian objects [13]. In addition to microscopic photos - TS (Fig. 9), and microscopic photos - RLS (Fig. 10) confirms the weakness of wood.

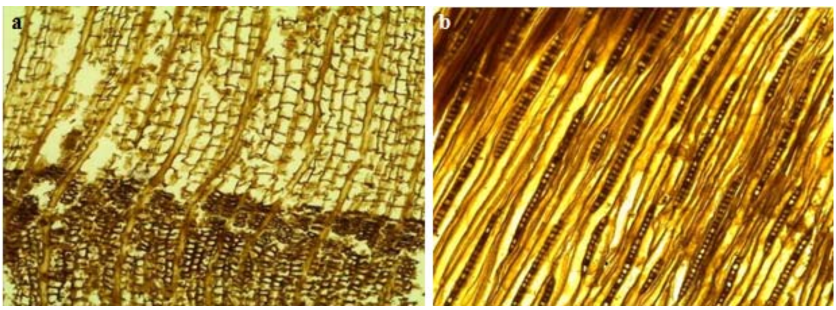

Fig. 9. Transverse (TS) of coffin wood sample, shows growth rings are clear, composed of equilateral bronchioli, and have links in a regular sequence, confirming that, the type of the wood is *cupressiod (a),* Tangential section of archaeological wood of the coffin (43X) (b)

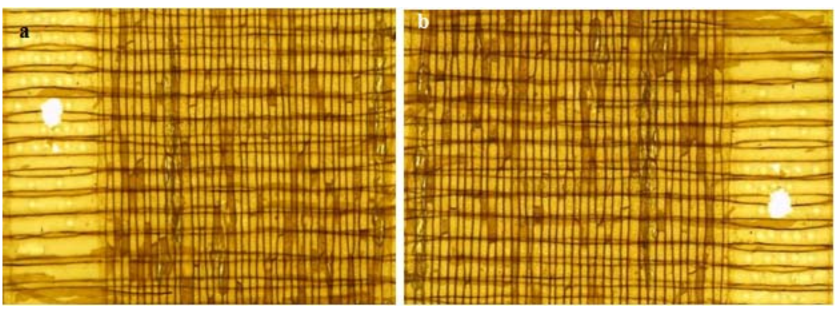

Fig. 10. Radial (RLS) of coffin wood sample shows rays parenchyma with pitted horizontal walls and smooth vertical walls and *cupressiod* cross-field pits is noted (43X)

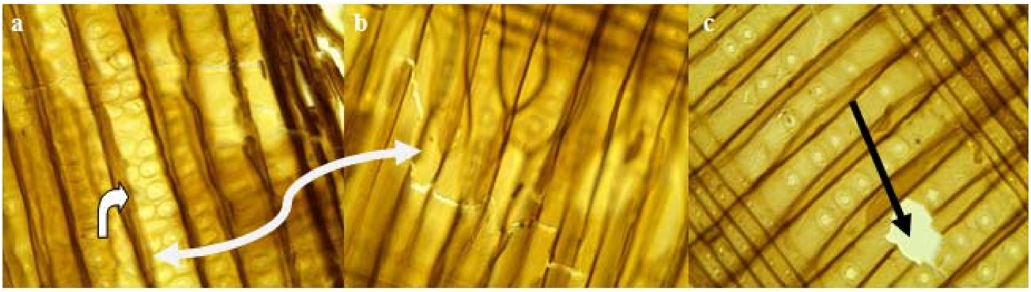

Fig. 11. Radial longitudinal section of coffin wood sample:
a, b - arrow indicates the characteristic spiral thickenings in tracheids, c - cavities and cupressiod cross-field pits (43X).

SEM-EDX Examination

Results from the samples studied using SEM are presented in (Fig. 12) show that, there is deterioration forms affected the wood, weakness in the bonding materials between the fibers, and fungi infection. Cellulose fibrils originating from mechanical disruption of the wood cells surface by the fungal attack were observed in the inner part of a timber that was apparently barely damaged (Fig. 12A). Due to the fungal attack, degraded of pits were observed in the inner part (Fig. 12B). In addition, crystallized sodium chloride was found inside (Fig. 12C). Moreover, bored vessels and fibers surrounded by crystals were also found (Fig. 12D).

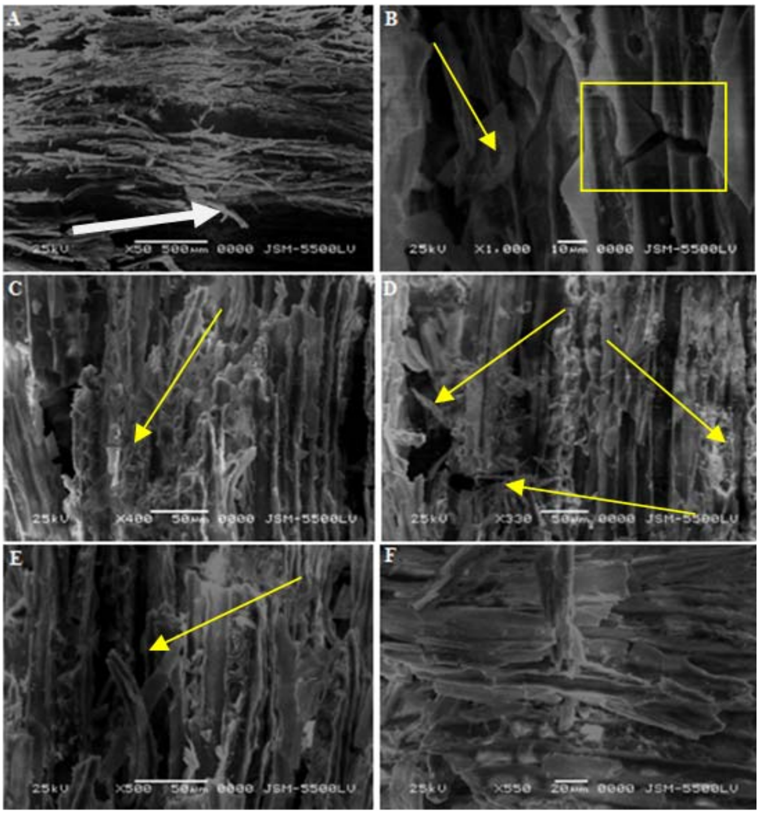

Fig. 12. SEM photographs show deterioration aspects of wood coffin: a - detachment of anatomical elements (fibres) tracheids for softwoods, possibly due to lignin degradation, b - degraded pit membranes, c - decayed wood fiber surrounded by crystals of salts, d, e, f - bored tracheirds

SEM–EDS microanalysis of the wood sample (Fig. 13a and Table 4) revealed the presences of Si, Ca, Cl, S, Fe and Na are the dominant elements. The sample contains small amount of, K, Al, Mg, Ti, Mn and Br. The presence of Ca essentially owed to calcium carbonate as a plaster, the occurrence of Na and Cl indicative of the existence of Halite was found, the presence of Si, Al and K owed to the presence of aluminum silicates from dust, large signals from sulfur (S) and calcium (Ca) confirm that calcium sulfate dehydrate was found, which is produced upon sulfur dioxide emission. Finally presence of Ti and Br is sign of the organic rest. The results obtained by XRD (Fig. 13b) show the presence of sodium chloride, Cellulose $(C_6O_{10}H_5)_n$, Hematite Fe_2O_3, Gypsum $CaSO_4 \cdot 2H_2O$ and clay minerals such as Montmorillonite (calcium and aluminum silicate hydrated) have low crystallinity and their signal-to-noise ratios are worse. It should be pointed out that X-ray powder diffraction analysis identified low percent of Cellulose $(C_6O_{10}H_5)_n$ and greater compositions of salts, these owed to the decay proceeds, cellulose and lignin disappear and inorganic salts form. Thus, the secretion of several acids (such as sulphuric acid) by fungal hyphae leads to the precipitation of authigenic salts [14].

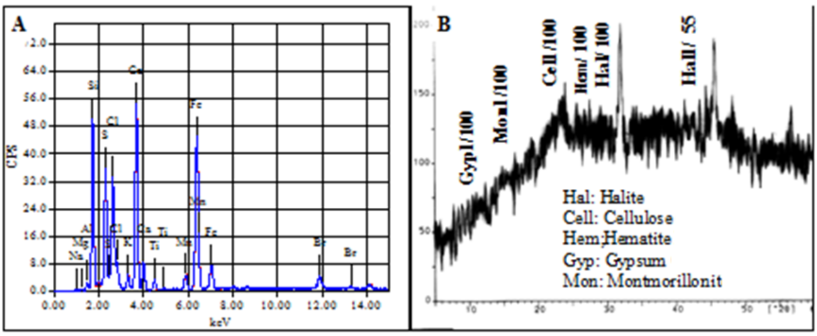

Fig. 13. EDX pattern (a) and XRD pattern (b) of wood sample

Table 4. EDX microanalysis results of coffin wood sample

Elements	**Si**	**Ca**	**Cl**	**S**	**Fe**	**K**	**Al**	**Mg**	**Ti**	**Mn**	**Br**
Weight (%)	29.63	26.18	11.11	9.65	8.83	2.27	2.80	1.84	1.09	1.01	0.34

Microbiology results

Scanning electron microscope (SEM) showed there was clear evidence of microbiological attack. These fungi were found in various parts of the coffin and there growth rate varied from one part to other. Microbiological investigation indicated that, the coffin was infested with the following fungi, *Aspergillus niger*, *Aspergilus flavus, Mucor humilas, E.moniliforme, St. Verruclosum, Actinomistate, Epicocum sp.* (Fig. 14)**.** A wide range of organisms can live in and degrade wood. In temperate climates, fungi cause the most damage to wood products [15]. Different chemical changes occur in wood depending on the action of the fungi, the phenomena of wood alteration are called white rot, brown rot, and soft rot. The diffuse decay appears to have been caused in the coffin by a brown rot fungus while the coffin was in the tomb. Brown rot fungi are preferential degraders of the polysaccharide components of wood and are responsible for extensive depolymerization of cellulose early in the decay process [16]. *Aspergillus flavus* which found in the coffin are major cellulolytic fungi and produce organic acids which decompose cellulose [17].

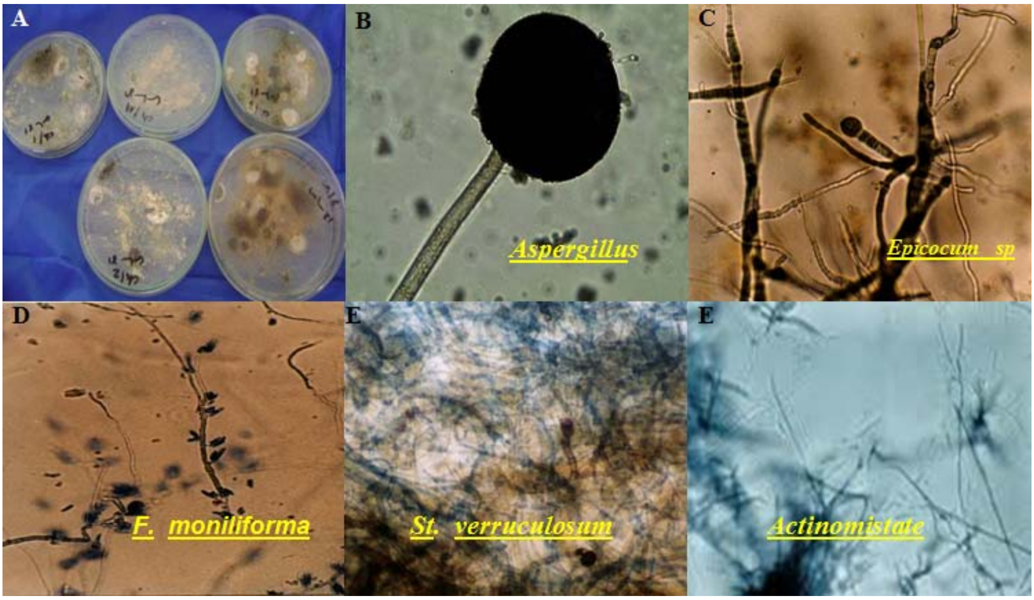

Fig. 14. Light microscope photos of isolated fungi from polychrome coffin, a - different colonies of isolated fungi, b – *Aspergillus,* c - *Epicocum sp.,* d – *moniliforma,* e - *St. verruculosum*, f - *Actinomistate.*

Treatments

The condition of the coffins required a careful working plan to ensure its safety during movement without causing any more damage. The process began with consolidation (pre-consolidant), as it was impossible to touch the coffin without applying at first an efficient and deep penetration of consolidate to strengthen and hold the pieces of the ground layer, fragile wood and paint layer together. Using Paraloid B72 dissolved in trichloroethylene, starting with 3% concentration and increasing to 5%. The consolidate was applied with Sprayer without damaging the very fragile pigments and wood; as well, the condition of the wood was such that it needed to absorb a large amount of consolidant.

Cleaning

Cleaning involves the removal of surface dust, grime, stains, biological growths, pollution layers, salts and other alterations which might otherwise have a detrimental effect on the condition of the coffin. It was important to begin with mechanical cleaning. Mechanical cleaning was used to remove any solid particles. Dust, sand and salts were found, to remove these particles, fine brushes was used. In some areas, heavier mechanical cleaning with dental tools was required to detach the solid particles. All of them were successfully removed. Mechanical cleaning was proceeded by chemical cleaning, in order to remove the remaining fungal mycelium, insect's remains and wax particles. Solubility tests indicated that mixed of ethyl alcohol or acetone with trichloroethanol would be the best solvent to remove the particles of dirties and insects remain, while leaving the original materials unaffected. Dirties was easily removed with cotton swabs and acetone. The swabs were checked throughout the cleaning to see if any of the pigment had come off the coffin.

Removing of the efflorescence salts

An efflorescence salt was highly visible on the bottom of the right coffin box. The efflorescence was visually distracting and also indicated that the coffin needed to be stabilized. The salt efflorescence was removed with cotton swabs dampened with distilled water with attempts to mechanically remove the salts with brushes or dental tools. Hopefully, the cotton swabs acted as poultices and pulled salts out from below the surface of the coffin.

Fixation of the crust of paint layer

The paint layer lost its adhesion to the support in many places of the coffin. Primary fixation of separated paint layer flakes was done by using emulsion of 10% Primal AC33, a drop of Primal AC33 was placed at the center on the fragment and then the surface was laid down on the support with small piece of cotton as shown in (Fig.15). For the powdering areas the Paraloid B72 was sprayed on the surface

Fig. 15. The fixation and consolidation of the paint layer of the right bottom of the coffins:
a - the separated crust of paint layer, b - the pumping of the adhesive by syringe, c - pressing phase.

Stabilization of ground layer and filling voids and cracks

After cleaning, the stabilization process began. Some of the fragments needed to be joined together, we adhered the fragments with a stable and reversible adhesive (15% Primal AC33). After localized humidification by acetone to relax the lifting plaster on the coffin, 5% Klucel G (hydroxypopylcellulose aqueous solution, viscosity of 75-400cp) was applied behind the layer and the pieces eased back into position with the help of a little gentle pressure (figure 16a). The voids between the painted plaster and the wood underneath required filling to reestablish both structure and adhesion. Initial consideration was given to using 5% Klucel G (hydroxypopylcellulose aqueous solution, viscosity of 75-400cp), but the size of the cavities ruled out this procedure; the voids were simply too large to reasonably expect resin solution to fill and strengthen without a filler or bulking agent. Therefore, an adhesive fill treatment was considered. Mixture of sawdust and carboxymethylcellulose (CMC) was used for this fill, it would flow easily enough to be pumped into the cavities with hypodermic syringe and needle and fill the entire cavity from a single entry point.

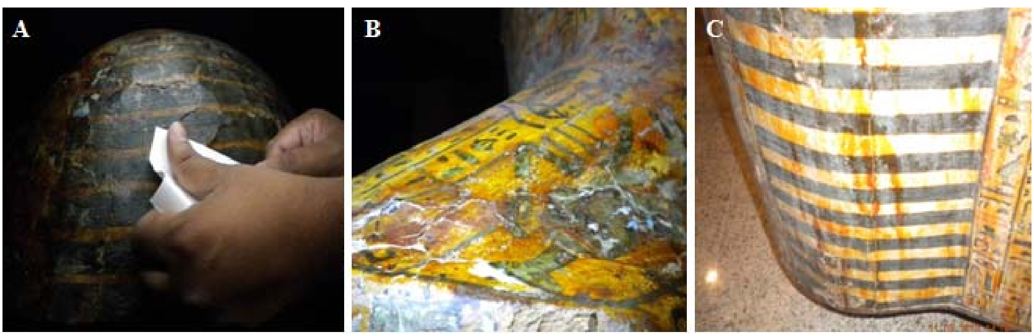

Fig. 16. Shows the stabilization of the ground layer of the head of coffin lid:
a - plaster during stabilization, b - plaster after stabilization, c - vertical cracks after filling

Consolidation

In the field of conservation and restoration of works of art, degraded polychrome wood is generally consolidated by means of synthetic products which can penetrate into the wood and restore sufficient mechanical strength [18]. The efficiency of the treatment depends on the depth achieved, the nature of the product employed and its permanence on the cells and cell walls of wood [19]. For the installation and the strengthening of the pigment, which turned into a powder as a result of deterioration factors, Paraloid B72 concentration of 5% in trichloroethylene was used with aerosol spray-style plastic. This process was repeated several times until the paint surface was consolidated. Also 5% Paraloid B72 was used to consolidate flaking gesso layers. In addition to the 5% Klucel G (hydroxypopylcellulose aqueous solution, viscosity of 75-400cp) was used to consolidate the wood. The coffin wood was consolidated daily with Klucel G for 5 days.

Fig. 17. The coffin box and the coffin laid after restoration.

Conclusions

The paper describes the material analysis and conservation intervention of the polychrome wood which was exhibited at El- Arish museum. The coffin was in a very poor conservation condition and required urgent conservation. The deterioration aspects appear as cracks, broken parts, fungi colonies, separated and loss of ground layer and pigments in many parts. Pigment materials in the grain store model are affected by salts and air pollution.

The materials were studied by optical and electronic microscopy while their composition was determined by EDX, XRD and FTIR. Based on the results of the analyses, the ground layer of coffin consists of two layers, the rough layer which covered the wood directly with thickness approximately 30µm and consists of mixture of calcite, sand and traces of gypsum and fine layer with thickness approximately 30µm consists of mixture of lime, sand and zincite.

As for the paint layer, mixture of Red lead Pb_3O_4 and Iron oxide (hematite) is responsible for the red color, the yellow color consist of mixture of orpiment As_2S_3 and iranite $Pb_{10}Cu(CrO_4)_2(SiO_4)_2(F)_2$, the green color is consist of malachite $CuCO_3Cu(OH)_2$ and Graphite is responsible for the black color. The binder used to bind the paint grains is Arabic Gum.

Analyses results confirmed that, the type of wood is (*cupressus sempervirens*). This type of wood has been rarely documented in ancient coffins and considered to be a soft type of wood, and has more predisposition to biodegradation.

The fungus (*Aspergillus niger, Aspergilus flavus, Mucor humilas, E.moniliforme, St. Verruclosum, sp*. as a biodeterioration, due to severe moisture and weakness of the painted wood.

Suitable materials and methods were used in preservation and restoration of the polychrome coffin as cleaning (mechanical and chemical), Fixation of the crust of paint layer with Primal AC33, Filling cracks and gaps were done with mixture of solution of sawdust and carboxymethylcellulose (CMC), Paraloid B72 was used in consolidation of the paint layer and Klucel G (hydroxypopylcellulose aqueous solution viscosity of 75-400cp) was used in consolidation of wood.

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