WOOD RESEARCH
63 (1): 2018
1-14

THE CONSERVATION OF A WOODEN NABATAEAN COFFIN BOX FROM JORDAN - APPLICATION OF NON-DESTRUCTIVE ULTRASONIC TECHNIQUE

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(Received July 2017)

ABSTRACT

In this study, a wooden Nabataean coffin box from Jordan was examined and investigated for its conservation. The previously neglected coffin box was subject to various problems such as fragility, structural disintegration, and biological degradation. Microscopic examination using transmitted light microscope and scanning electron microscope showed the coffin box to be constructed of Lebanon cedar wood. Microbiological investigations allowed the isolation and identification of the fungal and bacterial species that have contributed to the biological degradation of the object. Non-destructive ultrasonic velocity measurements were carried out on the coffin wood to evaluate its deterioration level and to assess the effectiveness of consolidation treatments. Based on these analyses, several conservation processes were carried out on the object. These include cleaning, sterilization, consolidation, and reconstruction. For the consolidation of the coffin box, four different consolidation products were tested. Using ultrasonic technique, Paraloid B72 proved to be the most effective consolidation material for application on the coffin.

KEYWORDS: Coffin box, wood, conservation, ultrasonic velocity, Jordan.

INTRODUCTION

Wood is one of the earliest and most common materials that have been utilized by humans since antiquity. Being an organic material, wood can easily decompose under the action of biological and chemical deterioration. Nonetheless, archaeological wood may survive for thousands of years (Blanchette 2000, Blanchette et al. 1994). This depends on a number of factors that mainly include the nature of the burial environment and the type of wood (Florian 1990). In general, dry, cold, and near anaerobic conditions result, normally, in slower degradation of wood (Helms et al. 2004, Powell et al. 2001). Waterlogged wood is the most commonly found sort of archaeological wood, mainly due to the reduced concentration of oxygen in such environment (Blanchette 2003, Powell et al. 2001). Dry wood tends to survive biological degradation when the environmental conditions are not favorable for microbial growth such as in dry sealed conditions in arid regions (Blanchette 2000, Blanchette et al. 1994). Regarding the type of wood, trees are divided into two broad categories; angiosperm and gymnosperm. Angiosperms, often referred to as hardwoods, are characterized by the presence of an ovary that encloses the ovules or seeds. They are usually broadleaf deciduous trees. Gymnosperms, commonly referred to as softwoods, are trees that reproduce by means of exposed seeds or ovules. They include coniferous trees, which have needle-like leaves and are often evergreen. Hardwoods and softwoods, and the varied species within them, exhibit varying degrees of resistance to degradation. This depends, for example, on the content and types of cellulose, hemicelluloses, lignin, and extractives in the wood and on the properties of wood, such as density (Unger et al. 2001).

Wood can be degraded by variety of biological agents that include fungi, bacteria, and insects. For biological deterioration to take place, certain conditions must be available, above all moisture. However, archaeological wood excavated from dry terrestrial environments may still suffer from microbial attacks. Blanchette (2003) pointed out that some moisture is usually present even in buried tombs from arid regions that allows for selected microorganisms to grow and progressively degrade wood. Fungi are the primary degraders of wood in most terrestrial environments (Blanchette 2000, 2003). Wood-destroying fungi are grouped into three categories based on the colour and texture of the residual wood after decay. These are brown-rot, white-rot and soft-rot fungi (Blanchette 2003, Eriksson et al. 1990). According to Blanchette (2003), soft-rot fungi are the major cause of decay in archaeological wood from terrestrial sites. This form of decay has been identified in dry archaeological wood from various locations in arid and sealed conditions (Blanchette 2000).

Deterioration of wood may result in various chemical and morphological changes, which will be exhibited as loss of strength, increased permeability, loss of weight, hygroscopicity, and other physical alterations (Florian 1990). Identifying the factors and forms of deterioration in archaeological wood and assessing its condition is an important step to determine the appropriate conservation treatments and measures. Therefore, the primary objective for the examination of archaeological wood is to determine its condition before and after conservation treatments. For museum wooden objects, this mainly implies the investigation and diagnosis of biological deterioration by fungi, bacteria, and insects (Unger et al. 2001).

Ultrasonic technique is a simple and non-destructive method that can be used to evaluate the condition of archaeological objects and evaluate the effectiveness of their conservation treatments (Ahmad et al. 2009). Several authors have studied the use of ultrasound for locating defects in wood and investigating its condition (Hasenstab 2006, Unger et al. 2001). The velocity of ultrasonic wave inside a material depends mainly on its properties (such as density, porosity, moisture content and internal structure) and its state and level of deterioration (Ahmad et al. 2009, Hasenstab 2006). Therefore, measuring ultrasonic velocity in weathered and fresh materials of the same type may give an indication of the degree of deterioration. Furthermore, measuring ultrasonic velocity before and after conservation of an archaeological material may help to assess the effectiveness of conservation treatments (Ahmad et al. 2009). Because wood is an anisotropic material, the velocity of ultrasonic waves depends on the direction of measurement inside the wood, being the highest in the longitudinal (axial) direction (along the axis of the trunk), about half as much in the radial direction (perpendicular to the tree-rings), and the lowest in the tangential direction (parallel to the tree-rings) (Hasenstab 2006).

In this study, a wooden Nabataean coffin box from Khirbet edh-Dharih in southern Jordan was examined and investigated for its conservation and reconstruction. The previously neglected coffin box was subject to various problems and was in need for urgent conservation. Non-destructive ultrasonic technique was applied for evaluating the extent of damage and assessing the effectiveness of consolidation materials and treatment.

MATERIAL AND METHODS

Archaeological site

Khirbet edh-Dharih is located near the King's Highway in south-western Jordan, around 100 km to the North of Petra (Fig.1). The excavation works at the sites started in 1983 by Yarmouk University, the Institut Français du Proche-Orient (IFPO), and Sorbonne University. The uncovered archaeological remains in the site indicate different periods of occupation that include Bronze, Iron, Nabataean, Byzantine, and Islamic periods (Al-Muheisen and Villeneuve 1994, Villeneuve and Al-Muheisen 1988).

The Nabataean settlement in the site, dating between the 1st and 4th centuries A.D., includes a sanctuary and a small village with dwellings, agricultural structure, water systems, and two cemeteries (Fig. 2). The cemeteries extend over the slopes to the east of the village. They consist of many individual graves that were sometimes used for multiple burials. The graves were topped by steles of the nefesh type, sometimes reused and inscribed in the Byzantine and Umayyad periods (Villeneuve and Al-Muheisen 1988).

The studied wooden coffin box was discovered in grave number 2 (Fig. 3) in the northern necropolis in 1991 (Al-Muheisen and Villeneuve 1994). It was largely disintegrated and fragmented (Fig. 4).

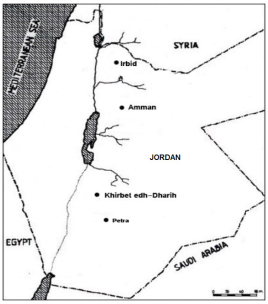

Fig. 1: Map of Jordan showing the location of Khirbet edh-Dharih archaeological site.

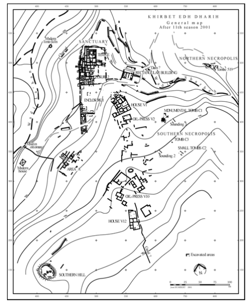

Fig. 2: Site plan of Khirbet edh-Dharih (Lenoble et al. 2001).

Fig. 3: Aerial photo shows the grave in which the wooden coffin was found.

Fig. 4: The coffin box inside the grave (upon excavation).

Methods

Several investigation methods and tests were carried out to characterize the wooden coffin box and investigate the agents, forms, and state of its deterioration. These include visual and microscopic examination, microbiological investigations, and ultrasonic wave velocity measurements.

Microscopic examinations

Microscopic examinations were carried out using transmitted light microscope on thin sections to determine the type of wood used for the construction of the coffin. To prepare thin sections for examination with transmitted light microscope, the wood specimens were first dehydrated with acetonitrile in stepwise increasing concentration of 70%, 90%, and three changes of 100%. The specimens were gradually infiltrated with upgraded mixture of Spurr's resin and acetonitrile, imbedded in Spurr's resin and allowed to polymerize at 65°C for at least 8 hours. Thin sections were cut using a Reichert-Jung Ultracut E Ultramicrotome and mounted on microscope slides.

Scanning electron microscope (SEM)

Furthermore, wood cross sections coated with a gold layer were also examined using scanning electron microscope (SEM) to investigate the morphology of wood surface and its characteristic elements for identification of the type of wood and its microbial decay. SEM investigation was carried out using a Quanta 200 SEM (FEI company, Netherlands). The SEM micrographs were taken using the ordinary secondary electron (SE) mode.

Microbiological investigation

For the identification of the microbial contaminations on the coffin box, samples of predominant alterations on the object were taken using sterile cotton swabs. The swabs were placed in sterile tube containing transport general purpose media and transferred to the laboratory. The samples were inoculated on suitable media (nutrient agar (NA) and potato dextrose agar (PDA)) and incubated at 30°C for 24h and 3-8 days for bacterial and fungal tests respectively. Bacterial and fungal colonies with different morphologies were picked and re-streaked on fresh plates. Isolated fungi and bacteria were identified based on their morphological characteristics according to Barnett and Hunter (1998), Gilman (1957), Holt et al. (1994).

Ultrasonic wave velocity measurements

Non-destructive ultrasonic velocity measurements were carried out using a Consonic 2-GS ultrasonic measuring device from Geotron-Elektronik with ultrasonic transmitter (UPG) vibrating at 250 kHz and ultrasonic receiver (UPE). The velocity of longitudinal ultrasonic waves in the wood samples was determined using the transmission method, in which the ultrasonic transmitter and receiver are placed opposite to each other on either side of the sample and the time needed for the wave to travel along the distance between them is measured. The coupling between the ultrasonic transducers and the wood was achieved using an acoustic coupling material made of silicone rubber.

In this study, the velocity of ultrasonic waves was only measured along the radial direction because of the dimensions of the coffin parts and the used ultrasonic transducers, which made it not possible to accurately measure the ultrasonic velocity in the longitudinal and tangential directions.

RESULTS AND DISCUSSION

Examination

The studied coffin box had been stored in uncontrolled conditions in the storerooms of the Faculty of Archaeology and Anthropology at Yarmouk University for over 20 years. It was disintegrated, covered with dirt, and suffered from various problems due to ancient decay during burial and inappropriate storage and lack of maintenance after excavation (Fig. 5).

Fig. 5: The coffin box in the storerooms before conservation.

The wooden coffin box was therefore in need for urgent conservation. To do this properly, it was first documented and visually examined to determine its physical properties and general condition. Further examination using the afore mentioned investigation methods was carried out to identify the construction materials of the coffin and to assess its condition and determine the major factors and forms of its deterioration.

Description of the coffin box

The coffin box was rectangular cuboid in shape with a rounded head-area, being approximately 193 cm long, 54 cm wide, and 32 cm deep. It was broken into many pieces of different dimensions that mainly constitute its two sides, the head-piece and the foot-piece. The available pieces included three large boards with the following dimensions 178x32.5x2cm, 176x25.5x2cm, and 148.5x10.5x2cm, six middle-sized pieces with dimensions between 17x7.5cm and 50x23cm, and many small pieces with dimensions between 5 and 10 cm. Some of these pieces were broken and some were only separated. In addition, there were many tiny fragments with size smaller than 2 cm. Wooden pegs were used to join parts of the coffin together.

Types of the construction materials of the coffin

Microscopic examination showed the coffin box to be constructed of coniferous wood (softwood), particularly Lebanon cedar (*Cedrus libani*). Fig. 6 shows the microstructure of the wood in transverse, tangential and radial sections. Vessel pores are absent, and the structure is mainly made up of longitudinal tracheids. These are typical characteristics for coniferous wood. Lebanon cedar is microscopically distinguished by sparse axial parenchyma, gradual transition from earlywood to latewood, inter-tracheid bordered pits with fringed torus margins, taxodioid cross-field pits, mainly uniseriate rays that are usually (1)3-20(40) cells high and composed of ray parenchyma cells with nodular end walls and marginal ray tracheids, and lack of resin canals or the occasional presence of resin ducts of the traumatic types (Cartwright 2001, Fahn et al.1986). However, the wooden pegs used to hold the coffin parts together, were made of hardwood. Although no microscopic investigation could be carried out on the wooden pegs because the found fragments were tiny and fragile, it seems that they were most probably made of local pistachio trees (*Pistacia atlantica*).

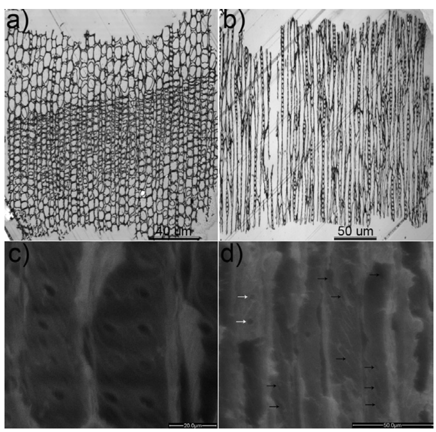

Fig. 6: The microstructure of the wood. a) transverse section showing the gradual transition from earlywood to latewood; b) Tangential section showing uniseriate rays (3 – ca. 28 cells high); c) SEM micrograph of radial section showing taxodioid cross-field pits; d) SEM micrograph of radial section showing inter-tracheid bordered with fringed torus margins (white arrows) and cavities in the secondary cell wall (black arrows) due to soft-rot attack of wood.

Cedrus libani occurs naturally in the mountains of Lebanon, Syria and southern Turkey (Kurt et al. 2008). The Nabataeans imported cedar timber and used it in their constructions (Rababeh 2005). The use of Lebanon Cedar wood for construction of coffins and other objects in antiquity has widely been reported (Ismail et al. 2016. Cartwright 2001, Fahn et al.1986).

Agents and forms of deterioration

Upon excavation, the coffin box was already suffering from several forms of deterioration mainly fragmentation and structural disintegration (Fig. 4). Nonetheless, it has rather survived the long-term burial. This might be attributed to the dry and sealed tomb environment in the arid region of Khirbet edh-Dharih and to the relatively good resistance of Cedar wood to biological degradation (Kurt et al. 2008, Blanchette, 2000). However, the inappropriate storage has further contributed to the damage of the coffin box and exacerbated its problems. Because of the cumulative damage during burial and inappropriate storage, the coffin box exhibited several forms of deterioration that include embrittlement, fragmentation and loss of physical integrity, buckling and warping, and biological degradation.

For a rough estimation of the deterioration level of the wood of the coffin box, non-destructive ultrasonic velocity measurements were carried out on the wooden coffin and on freshly sawn recent wood of similar species. The longitudinal ultrasonic velocity in different parts of the coffin measured in the radial direction was averaging around 1266±230 $m \cdot s^{-1}$, whereas the measured ultrasonic velocity in the radial direction in recent Lebanon cedar wood was 2097±33 $m \cdot s^{-1}$. This means that the ultrasonic velocity in the wooden coffin was dropped by about 40%, which might roughly indicate a strength loss of more than one third in the archaeological wood due to deterioration.

The biological degradation of the wood was mainly caused by fungal attack. Some insects such as cockroaches and silverfishes were found and identified by naked eye. However, these insects cannot generally attack and digest wood.

Microbiological investigations indicated that the coffin wood was infested with the following fungi: *Aspergillus niger, Aspergillus flavus, Aspergillus fumigatus, Aspergillus terreus, Penicillium chrysogenum*, and *Penicillium notatum*. Most of these fungi produce cellulose degrading enzymes and other chemicals that decompose the cellulose content of wood (Coughlan 1985, Osman et al. 2014, Salem et al. 2016). The fungal genera *Aspergillus* and *Penicillium* are commonly found on archaeological objects and they have been reported to be destructive (Florian 2002). The fungal decay has resulted in a considerable reduction in the strength of the wood of the studied coffin box, and it seemed to exhibit the morphological characteristics of an advanced state of soft-rot decay as can be inferred from the brown and crumbly appearance of the wood, which looks similar to brown-rotted wood (Blanchette 2003). Fig. 6(d) shows chains of cavities in the secondary cell wall that might be attributed to soft-rot fungi. Fungal spices of the *Aspergillus* and *Penicillium* groups have already been reported to cause soft-rot decay (Hamed 2013). Nonetheless, it might also be possible that past brown-rot fungi had contributed to the damage of the coffin box during burial. In terms of sterilization and restoration, it is, however, sufficient to identify the actual damaging organisms.

In addition, two bacterial species were found, namely *Bacillus stearothermophilus* or *Geobacillus stearothermophilus*) and *Bacillus acidocaldarius* (or *Alicyclobacillus acidocaldarius*). The Bacillus bacteria have been reported to show ligninolytic or cellulolytic activity (de Gonzalo et al. 2016, Meddeb-Mouelh et al. 2016, Tian et al. 2014). In general, bacteria can degrade wood by causing minute tunnels, cavities or eroded zone within the cell walls and they may favour wood degradation by fungi (Blanchette 2003, Blanchette et al. 1994, Eriksson et al. 1990, Prewitt et al.

2014, Unger et al. 2001). However, the wood degradation process by bacteria is very slow and it is not common in relatively dry terrestrial sites (Blanchette 2003, Crestini et al. 2009).

Conservation of the coffin box

Based on the diagnostic examination, the following conservation processes were carried out on the coffin box.

Cleaning and sterilization

The coffin box was covered with dust and extraneous materials due to prolonged inappropriate storage and lack of maintenance. Dust, soil and loose surface deposits were mechanically removed using soft brushes. Chemical cleaning was also carried out to remove the remaining dirt and stains. This was performed locally using cotton-swab damped with a solution of ethanol and distilled water in a ratio of 1:1.

After cleaning, the coffin box was chemically sterilized by brushing with a 3% solution of thymol in acetone. It was then covered with a thin sheet of polyethylene for two weeks and aerated afterwards for other two weeks.

Straightening of the warped wood

Some parts of the coffin, particularly the larger ones, were suffering from buckling and warping. Therefore, it was necessary to flatten them and restore their original shape for the later reconstruction of the coffin box. To do this, the warped parts were first moistened by spraying them with a water-alcohol solution in ratio of 1:1. They were covered with polyethylene sheet to slow evaporation and left over for one week. Afterwards, they were separately placed between two wooden plates and gradually pressed using iron clamps to restore their original shapes. The adjusted pieces were left over under clamps for at least two weeks to ensure the completeness of the straightening process.

Consolidation

The wood of the coffin box was badly weakened and consolidation was, therefore, necessary to strengthen the fragile and degraded parts. Four different consolidants, namely Primal (acrylic emulsion), Paraloid B72 (ethyl methacrylate/methyl methacrylate copolymer), Carboxymethyl cellulose (CMC), and Shellac with Colophony resin, were selected and tested to choose the best consolidant out of them for application on the coffin.

Non-destructive ultrasonic velocity measurements were performed on small wooden fragments from the coffin before and after consolidation with each of these consolidants to determine the most effective consolidation material. Fig. 7 shows the results of ultrasonic velocity measurements performed on the wooden samples before and after consolidation with each product.

The consolidation product Paraloid B72 achieved the best results. The velocity of ultrasonic waves in the wood fragments increased by 20% in average after consolidation with Paraloid B72.

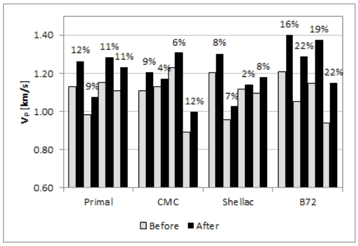

Fig. 7: The ultrasonic velocity in the wooden specimens before and after treatment with each of the tested consolidation products. The numbers above the bars represent the percent increase in ultrasonic velocity after consolidation.

Based on these results, the wood of the coffin box was consolidated with Paraloid B-72 at a concentration of 5% w/v in acetone. The consolidant was applied by brushing for the large pieces and by impregnation for the small fragments.

After consolidation with Paraloid B72, the ultrasonic velocity was re-measured in the radial direction at the same points of the coffin where it was measured before consolidation. It was found that the average ultrasonic velocity after consolidation increased by 28% from 1266±230 $m \cdot s^{-1}$ to 1627±220 $m \cdot s^{-1}$. The consolidant seems to have sufficiently penetrated into the wood and satisfactorily improved its strength.

Reconstruction of the coffin box

After consolidation, the broken pieces of the coffin box were re-joined using Paraloid B72 (20% w/v in acetone) as an adhesive. Clamps were used to support the joined pieces while the adhesive was setting. To stabilize the coffin box and improve its appearance for display purposes, it was necessary to reconstruct it by filling in some gaps and missing parts with suitable gap-fillers. Following a short empirical testing, a mixture of beeswax, 5% colophony resin, and linen fibres was chosen to fill in the gaps in the coffin box. Suitable colorants were added to the wax mixture to match the colour of the wood.

Finally, the coffin box was insulated by brushing with Paraloid B72 (5% in acetone). This treatment aimed to protect the wooden coffin box against fluctuations in relative moisture content by making it less hydrophilic.

CONCLUSIONS

Archaeological wood excavated from terrestrial sites suffers usually from severe deterioration mainly by biological agents of decay such as fungi and insects. Dry and near anaerobic burial conditions may, however, help to reduce the rate of microbial decay of archaeological wood. In such environments, wood may survive for thousands of years. In this study, a nearly 2000 years old Nabatean wooden coffin box from southern Jordan was investigated. The coffin box was subject to structural disintegration and biological decay mainly by soft-rot fungi, which brought about a considerable reduction in strength and rendered the object fragile. Non-destructive ultrasonic technique allowed the assessment of the condition of the object and the determination of the suitable conservation materials and treatments.

Fig. 8: The coffin after conservation and during the exhibition.

The results of this study indicate the ultrasonic technique might be useful for investigation of archaeological wood and evaluation of the effectiveness of its conservation. However, further and more detailed studies are required to establish correlations between ultrasonic velocity and changes in relevant wood properties before and after deterioration or conservation to allow for a more accurate assessment of wood condition. The conservation treatments and reconstruction work carried out on the coffin box proved to be successful, and the object was presented within the temporary exhibition "Burial habits in Jordan through ages" at the Museum of Jordanian Heritage in Irbid-Jordan (Fig. 8).

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