Fayoum University

Faculty of Archaeology

EXPERIMENTAL STUDY TO ASSESS ALTERNATIVE SUPPORTS FOR EXTENSIVELY DETERIORATED WOODEN ICONS

Fatma Magdy ALI,[1] Nesrin M. N. ELHADIDI,[2] Abubakr M. MOUSSA [3] and Wadea Botros ABDEL-MALIK [4]

[1]Grand Egyptian Museum, Giza, Egypt (Correspond Author)
batot400@gmail.com
[2,3] Conservation Department, Faculty of Archaeology, Cairo University, Egypt
[2] nelhadidi@cu.edu.eg ; ,[3] dr_abubakr@cu.edu.eg
[4] Ministry of Tourism and Antiquities, Egypt
wadeea64@yahoo.com

ABSTRACT

Experimental and analytical studies were carried out on five different types of alternative supports from processed wood; plywood, pine block board, oak block board, medium density fibre (MDF) and chipboard. Color changes and emitted gases were measured by Kitagawa gas test tubes, Oddy test and Raman spectroscopy. Results proved that slight amounts of formaldehyde, ammonia and acetic acid were emitted from block board samples. Oak block board emitted higher amounts of formaldehyde compared to pine block board, but the emission of ammonia and acetic acid was relatively similar in both types of block board. A higher quantity of acetic acid and ammonia, and a small amount of formaldehyde were emitted from plywood. There was an increase in formaldehyde, ammonia and acetic acid gas emission in MDF and chipboard. FTIR analysis of wood components and color change measurements were conducted for further evaluation. In plywood a high decrease of lignin was noted, causing the wood to lighten in color. The rise of formaldehyde in oak block board, MDF and chipboard led to decrease in carbohydrates, causing darkening of wood color. Chemical composition and color change measurements were stable in the pine block board, proving it to be the most suitable alternative support.

KEYWORDS

Alternative support; VOC; Oddy test; Kitawaga tubes; FTIR, Raman spectroscopy.

الملخص

أجريت دراسات تجريبية على خمسة أنواع مختلفة من الحوامل البديلة من الأخشاب المصنعة المختارة؛ خشب الأبلكاج، خشب كونتر الصنوبر، خشب كونتر البلوط، الخشب الليفى والخشب الحبيبى. تم قياس التغير اللونى والغازات المنبعثة بواسطة إختبار أنابيب كاشف الغاز و إختبار "أودي" ومطياف رامان. أثبتت النتائج إنبعاث كميات طفيفة من الفورمالديهايد والأمونيا وحمض الخليك من خشب كونتر الصنوبر، كما أنبعث من خشب كونتر البلوط كميات أعلى من الفورمالديهايد مقارنة بخشب كونتر الصنوبر، لكن إنبعاث الأمونيا و حمض الخليك كان متشابهًا نسبيًا في كلا النوعين، و أنبعثت كمية أعلى من حمض الخليك والأمونيا و كمية قليلة من الفورمالديهايد من خشب الأبلكاج.

كانت هناك زيادة في إنبعاثات الفورمالديهايد والأمونيا و حمض الخليك في الخشب الليفي والحبيبى. تم إجراء تحليل FTIR لمكونات الخشب وقياسات التغير اللونى لمزيد من التقييم. لوحظ إنخفاض كبير في اللجنين في خشب الأبلكاج، مما تسبب في تفتيح لون الخشب. أدى إرتفاع الفورمالديهايد في خشب كونتر البلوط والخشب الليفي متوسطة الكثافة والخشب الحبيبي إلى إنخفاض في الكربوهيدرات، مما تسبب في دكانة لون الخشب. كانت قياسات التركيب الكيميائي وتغير اللون مستقرة في خشب كونتر الصنوبر، مما يثبت أنه البديل الأنسب كحامل جديد.

الكلمات الدالة

الحوامل البديلة ؛ المركبات العضوية المتطايرة؛ إختبار أودى؛ أنابيب كاشف الغاز؛ مطياف الرامان.

INTRODUCTION

Wooden panel paintings and icons are often exposed to different deterioration factors, which in some cases may lead to total loss of the artefact (El Sayed 2019, 238-256). For example in the past in cases where either the canvas or paint layer were still intact, but the wooden support had been attacked by insects, total transfer onto new alternative supports was practiced in Egyptian churches and monasteries. This transfer was rarely documented in conservation articles, contrary to artifacts of great importance at the time of their excavation, such as the complete documentation of the tomb of King Tut Ankh Amun a century ago. Even the analysis and most of the restoration procedures were recorded by Lucas *in situ*, and are currently available online. Such valuable information is beneficial when evaluating previous treatments and considering the removal of old treatments (Abdrabou 2021, 403-416) (A. E. Abdrabou 2018, 553-564).

In the case of icons, which are found in every church and are of high religious importance, artists and conservators focused on safeguarding the religious artifacts, but may not have considered the importance of documenting the restoration process. From recent field visits to Egyptian churches it is clear that in the 1980s, many icons had been physically transferred onto new processed wooden panels (Mohie,1-15) (Boutros 2010). Risk assessment of the transfer process, studies on the advantages or disadvantages of the transfer on new panels and/or the chemical interaction between the new panels and the remaining original components of the icon in the near or far future were not conducted or published.

It is a known fact that wood as a natural substance contains volatile organic compounds (VOC) such as formaldehyde that is found in small quantities; and is released when exposed to heat (Boruszewski 2011, 29-32). Formaldehyde content depends on the type of wood and adhesive used; solid hardwood (Costa 2014, 146-150) such as oak wood (Chaudhary 2014, A-H) emits more formaldehyde than soft wood (Abd Rashad 2019, 520-523). Formaldehyde can also be emitted from reproduced wood such as MDF and chipboard due to several factors such as thermal treatments (Hemmila 2019, 1-9), the use of adhesives such as urea formaldehyde resin (Dunky 2021, 189-268) and phenol formaldehyde resin (Bekhta 2020, 1-14) (Solt 2019, 99-131). In another previous publication, which confirmed the aforementioned information that formaldehyde emitted from manufactured wood panels depends on several factors related to wood species and the type of adhesive used, the possibility of reducing formaldehyde by using bark of wood species that have a high polyphenol content such as walnut, chestnut, fir and spruce was discussed (Antov 2020, 289-296).

Acetic acid, another VOC, is emitted after exposure to heat (Pohelven 2019, 1-24), and ammonia (Lyutyy 2017, 107-112) which is used in wood processing stages (Liu 2021, 557-565) for bleaching wood can be identified in processed wood (Stanic 2020, 1-17).

The harmful volatile organic compounds (VOC) released by wood and adhesives may have a negative effect on paintings, similar to the effect of conservation materials like adhesives, consolidants or coatings in treated objects or materials used in display cases. Volatile wood gases affect a wide range of museum collections (Korenberg 2019, 249-260), where it causes the metal to corrode and damage artifacts made from lead and silver (Hunt 2020, 133-142). It also leads to chemical changes in wood as a change in the proportions of lignin, cellulose and hemicellulose (Wencek 2020, 5812-5828). Moreover, it causes color changes in artifacts (DeLaet 2013, 855-862). Therefore mass testing series utilizing the Oddy test, which is

known for its simplicity, is often conducted for mass screening of different materials for harmful emissions (Steger 2022, 1-12).
The rising risk of VOC release in heritage collections due to the application of alternative supports for wooden panel paintings may have been slightly neglected in the past, and published studies on the criteria of choosing processed wood are scarce. The methodological approach to assess the suitability of different materials in the field of conservation to find alternatives to the expensive materials imported into Egypt is currently being applied in some museums (Elkhial 2022, 1-11). This paper aims to assess the suitability of five types of processed wooden panels that are available in the Egyptian market, have been used as alternative supports in the past and may be used in the future in cases where there is an urgent need to replace the original support. It goes without saying that in any transfer process, the alternative support has to be adhered to the rear side of the artifact using polymers, but evaluating the VOCs released by adhesives is beyond the scope of this paper, and is currently being assessed.
To study the chemical stability of the panels, and assess the amount of emitted VOC, the samples were exposed to accelerated heat and light ageing. The decision on the type of accelerated ageing process that should be conducted can be extremely difficult, when it comes to the ageing of wood. A lot of research has been published in the past on the ageing of cellulosic paper. Researchers noted in the past that "with the aid of extensive accelerated aging data" it was possible to attempt to find reproducible degradation patterns with different papers (Bansa 1992, 114-137), yet the experiments can lead to conclusions that can be *deceitful* (Shahani 1995, 1-18). In another publication it was noted that ageing could be conducted in combination with the effect of light (280-380 nm) in the temperature range of 50 - 85°C and RH 10% and 70% (Dellaportas 2014, 1-11).
The color changes of the processed wooden panels under study and the hazardous gases emitted from them were measured as a preliminary step to define the risk of their use as alternative wooden supports in valuable icons that had deteriorated over the years due to their exposure to different decay factors, that lead to partial or even total loss of the original wooden support. This was followed by studying the chemical changes using FTIR spectroscopy to specify and explain the chemical changes within the five processed wood samples. The Oddy test and Kitagawa gas detector tube system results were used to verify the chemical changes in the experimental wood samples.

MATERIALS AND METHODS

Materials: With the increasing demand for natural wood and the shortages of wood supply worldwide, there was a need to find alternative raw materials, leading to the use of some types of manufactured wood as alternative supports (Akgul 2008, 438-443). Moreover, the disadvantages of joining wood panels are always a major concern for conservators. Therefore the idea of using alternative supports has been applied in many cases, yet it was rarely documented. Thus, five types of processed wooden panels available in the Egyptian market, were used in the experimental part of this paper (Fig.1). The chosen wooden panels were:
1- Pine plywood, made of a number of thin wood venners adhered to each other in a way that the direction of the fibres is opposite to the previous layer (Bohm 2012, 68-79).

 DOI: 10.21608/shedet.2023.291533

2- Two types of block board, pine block board wood and oak block board. This type of wood consists of a central layer (core) of solid or softwood strips. The facing on the block board is stiffened and bound together by glued, hot-pressed rotary-cut veneers (Singh 2020, 96-100).
3- Medium density fibre board wood (MDF), which is manufactured by converting wood into a (fibrous paste) that is mixed with an adhesive substance from one of the resins and pressed under the influence of heat, which turns into wooden boards (Campos 2004, 421-425).
4- Chipboard wood, which consists of small particles of wood attached to each other with adhesive from one of the synthetic resins under pressure (Melo 2014, 682-686) (Alam 2015, 203-211).

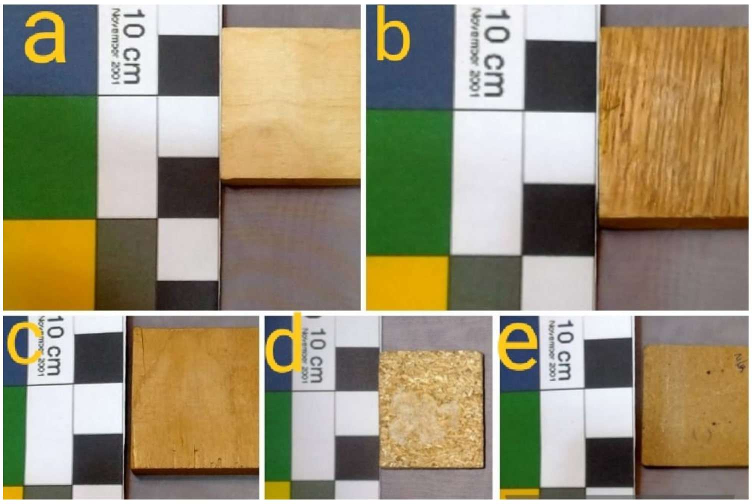


Figure 1. Five types of processed wood (a) pine block board, (b) oak block board, (c) pine plywood, (d) chipboard, (e) medium density fibre board wood (MDF).

Methods: The studied alternative wooden panels were exposed to heat and UV light accelerated ageing; which were conducted in two separate stages. Heat ageing was achieved using an oven (M120-VN/PID system by CTS) at 80°C for 240 hours is an equivalent of 50 years in normal conditions (El Hadidi 2020, 48-65), while UV light ageing was carried out using luminaire CTS art with 2 UV fluorescent tubes, 45 cm long, 5000 K, 40 Lux, 30 W, 220 V with a Plexiglas protection screen for 240 hours, an equivalent of 50 years in normal conditions (Arias 2013, 227-230).

Color change measurements in wooden samples:
The color change of the wooden panels was measured using a spectrophotometer type CM-700d model IN Japan INC. After exposure to heat and light ageing for 240 hours, color alterations were measured according to the CIE Lab system (Barick 2019, 789-798), based on the L*, a*, b* color coordinate system, where L* represents black-and-white axis, a* the red-green axis and b* the yellow-blue axis (Muasher 2006, 1156-1165). The total color change (ΔE*) was calculated according to the following equation (Li 2018, 818-823):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Oddy test:
Emitted gases from the studied panels were detected using: copper, lead and silver coupons according to the Oddy test technique. This test is used to detect potentially hazardous gases (Keable 2018, 2-12) emitted in elevated humidity and temperature (Heine 2018, 362-365). In the Oddy test, the products are ranked as follows; safe for permanent use "P, no corrosion", only for temporary use "T, slight corrosion", and unsuitable for any use at all "F, heavy

corrosion" (Steger 2022). Silver is used to detect sulphur and ammonia compounds, lead to detect organic acids, aldehydes, and acidic gases, and copper to detect chlorides and oxides (Wang 2011, 138-153). Formic acid affects the appearance of copper and lead, where copper sulfate and copper monoxide appear as black spots in the copper coupons and a thin and dark layer of lead formate hydroxide is formed in the lead coupons. Acetic acid affects the appearance of lead by forming a white layer consisting of lead acetate and lead carbonate compounds (Tetreault 2003, 237-250).
The test was conducted for 28 days by placing each type of the processed wood samples separately inside a sealed glass container with three metal coupons (silver, copper and lead) and a small amount of water in an open vial at 60°C to maintain a high relative humidity of ~95 to 100% (Gerhard 2021, 127-129). After the elapse of 28 days, the metal coupons were carefully studied using a dino-lite digital microscope with a 1.3MP camera (magnification 20:200x) to document any changes that may indicate the coupons' exposure to VOC's.

Kitagawa gas tubes:
The Kitagawa gas detector tube system for determining hazardous gas emitted from the wood samples was used to further evaluate the chosen samples. This method is considered a complete sampling and analysis system for determining hazardous gas and vapour concentrations quickly and easily (Cecily 2006, 30-52). The Kitagawa gas detector tube system comprises an air sampling pump and precision gas detector tubes (www.komyokk.co.jp). Each detector tube is formulated with high purity reagents that absorb and react with the target gas or vapor being measured. The concentration is read directly from a scale color change on each tube that is proportional in length to the concentration. Wooden samples were placed in a sealed container in an oven at 30 °C to allow the gas emission. This was followed by taking in 100 ml of sample air through the ammonia tube no. 901NHL, formaldehyde tube no.171SB and acetic acid detector tube no. 910.

Raman analyses of corrosion products:
Raman measurements of corroded coupons (Oddy test) were conducted using Bruker (Senterra II) equipment Laser type: 785, Laser Power: 1%, Integration time: 1000 ms, Resolution: 4 cm^{-1}.

FTIR analyses of wood samples:
Aged and non-aged wood samples were analyzed using a FTIR spectrometer (IR Prestige-21, Shimadzu) in the 400-4000 cm^{-1} range, with a resolution of 8 cm^{-1} to identify chemical changes and further assess the changes that occurred in the wood samples.

RESULTS AND DISCUSSION

Color changes in wood samples:
The values of color alteration of the selected five wooden supports varied. The value of ΔE was lowest in the case of block board wood, ΔE values of chipboard wood were slightly higher than block board wood, and the highest ΔE values were recorded in the plywood, oak

 DOI: 10.21608/shedet.2023.291533

block board and MDF samples, as listed in table (1). According to the L* values, the plywood sample whitened in color, the a* values decreased, and the b* values increased. The MDF, oak block board and chipboard sample darkened, the L* and a* values increased, but the b* values did not significantly change.

Table 1. Color change of the examined alternative wooden supports

Wood Types	Before ageing			After ageing			Color change			
	L*	a*	b*	L*	a*	b*	ΔL	Δa	Δb	ΔE
Pine Block board	**56.54**	**10.19**	**22.46**	**57.22**	**9.45**	**22.28**	**0.683**	**-0.746**	**-0.18**	**1.028**
Ply Wood	**72.17**	**7.15**	**21.87**	**75.06**	**5.46**	**25.8**	**2.89**	**-1.69**	**3.93**	**5.166**
MDF Board	**69.26**	**8.64**	**23.21**	**66.52**	**11.68**	**22.89**	**-2.74**	**3.04**	**0.65**	**4.10**
Oak Block board	**64.89**	**8.47**	**20.76**	**61.53**	**10.30**	**20.83**	**-3.36**	**2.16**	**0.756**	**4.067**
Chip Board	**70.09**	**3.34**	**24.12**	**67.7**	**5.89**	**24.45**	**-2.39**	**2.55**	**0.33**	**3.51**

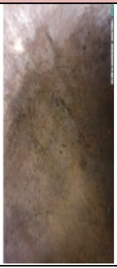
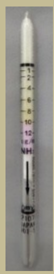
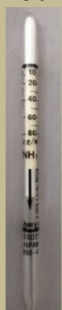
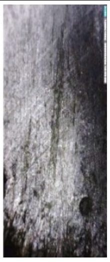
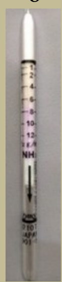
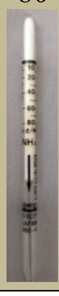
Oddy test:

All the obtained results were studied and documented using a digital microscope, and they revealed that there was no apparent difference in the three metal coupons that were placed with the block board. In the case of plywood, the copper coupon was affected by the growth of greenish-blue crystals, a white layer appeared on the lead coupon and the silver coupon showed yellowing and small number of black spots. Chipboard wood and MDF wood caused the formation of black spots on lead, copper and silver coupons in addition to a yellow tarnish in the silver coupon and the growth of greenish-blue crystals on the copper coupon. In the case of the oak block board the lead and copper coupons showed black spots, but the silver coupon did not change in appearance (table 2).

Kitagawa gas detector tube:

The ammonia detector tube indicated that the block board and oak block board emitted 6 g/m^3, plywood emitted $10g/m^3$, but chipboard and MDF wood emitted 80 g/m^3. Plywood emitted 100 g/m^3 of acetic acid, whereas all other samples emitted only 50 g/m^3. The concentration of formaldehyde gas emitted by processed wood was also measured by the detector tube. Block board emitted formaldehyde gas with a concentration of 1 ppm, plywood emitted 3 ppm, oak block board emitted 15 ppm formaldehyde gas, but chipboard and MDF wood emitted 20 ppm.

Table 2. Oddy test and Kitagawa gas detector tube results

Sample	Oddy Test				Kitagawa gas detector tube		
	Digital microscope images of the coupons			Result	NH_3 gas g/m^3	CH_3COOH gas g/m^3	HCHO gas ppm
	Pb	Cu	Ag				
Pine Block board	 **No change**	 **No change**	 **No change**	Permanent	6 	50 	1 
Plywood	 **white crystal growth on edges**	 **greenish-blue crystals**	 **yellow / brown tarnish**	Fail, Unsuitable	10 	100 	3 
Medium Density Fiberboard (MDF)	 **black spot corrosion**	 **black spot, greenish-blue crystals**	 **yellow / brown tarnish**	Fail, Unsuitable	80 	50 	20 
Oak Block board	 **black spot corrosion**	 **black spot corrosion**	 **No change**	Fail, Unsuitable	6 	50 	15 
Chipboard	 **black spot corrosion**	 **black spot, greenish-blue crystals**	 **yellow / brown tarnish**	Fail, Unsuitable	80 	50 	20 

 DOI: 10.21608/shedet.2023.291533

Raman analyses:

By correlating results obtained from both the Oddy test and Kitagawa test tube with the Raman spectra of the corrosion products (Fig. 2-6) it was possible to confirm that the increase of emitted formaldehyde gas led to the formation of black spots of lead formate hydroxide, as confirmed in the Raman bands (Steger 2022, 1-12) that appear at 750, 1051, 1342, 1531 and 1595 cm^{-1} in the lead coupon exposed to VOC's released by MDF wood, oak block board and chipboard wood. The formation of the gas as mentioned above also led to the formation of black spots of copper oxide that appear in the Raman bands at 311, 358 cm^{-1} in the copper coupon in the cases of MDF wood, oak block board and chipboard wood. Yet, in the cases of block board, where the emission of formaldehyde gas decreased, no change was evident in the lead and copper coupons.

The increase in acetic acid gas emission, due to the presence of the carbonyl group acetate CH_3COO^- which are attributed to emissions of organic carboxylic acids from wood (Elmarazky 2021, 1-6), led to the appearance of white spots of lead acetate that appear in the Raman bands at 370, 642, 923, 1345 and 1429 cm^{-1} and lead carbonate compound that appears in the Raman bands at 1051 cm^{-1} (Steger 2022, 1-12) on the lead coupon in the case of plywood. As for block board wood, there was no change in the copper or lead coupon due to the slight emission of formaldehyde gas and acetic acid.

The increase in ammonia gas emission led to the formation of brown spots of silver oxide that appear in the Raman bands at 95, 147, 249, 437, 527, 914 and 1396 cm^{-1} (Martina 2012, 1-8) on the silver coupon in the case of plywood, MDF wood and chip board wood. It also led to the appearance of greenish-blue crystals of copper hydroxide bands that appear in the Raman spectra at 283, 452, 609, 983 and 1145cm^{-1} (Zimbovskiy 2018, 1-8) (Pramanik 2015, 14604-14612) on the copper coupon in the plywood, MDF and chipboard samples.

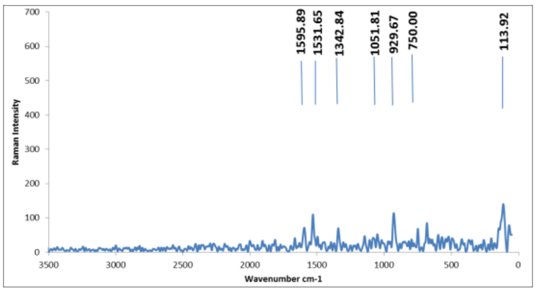


Figure 2. Raman spectra for lead formate

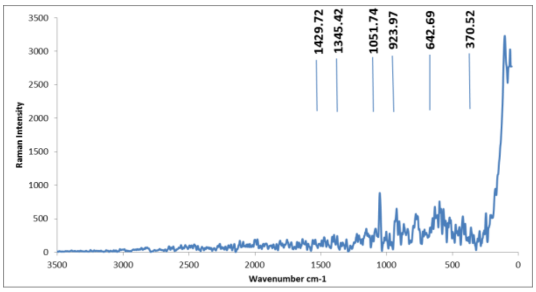


Figure 3. Raman spectra for lead acetate

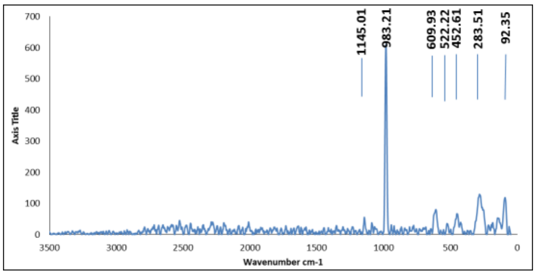


Figure 4. Raman spectra for copper hydroxide

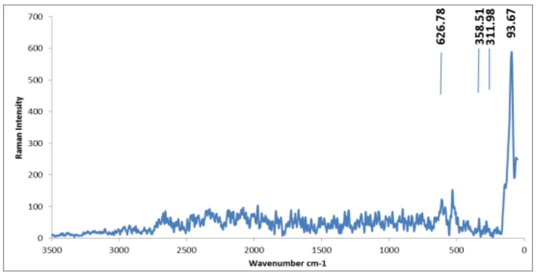


Figure 5. Raman spectra for copper oxide

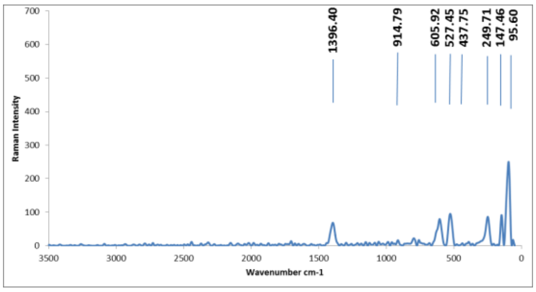


Figure 6. Raman spectra for silver oxide

FTIR analyses:

The release of VOCs from wood is a result of breakdown of the main wood components. Therefore wood samples were analyzed using FTIR spectroscopy to study the effect of artificial ageing on the main wood components: cellulose, hemicellulose and lignin (Varadhan 2020, 958-963). Slight shifts in wavenumber were noticed in the FTIR spectra of the samples, as recorded in the shaded cells in table 3, figures 7-11:

- OH stretching band at 3405 cm-^{1} in the MDF, chipboard and oak block board samples.
- C-H stretching band at ~ 2918 cm^{-1} in the pine block board, oak block board, plywood and MDF samples.
- Aromatic C=C stretching lignin band at 1505 cm^{-1} in the oak block board sample.
- CH_2 bending cellulose (crystallized I and amorphous) at 1425 cm^{-1} in the plywood and
- CH bending cellulose band at ~ 1375 cm^{-1} in the plywood, MDF and chipboard samples.
- C- O stretching in cellulose, hemicellulose and lignin band at ~ 1049 cm^{-1} in the pine block board, oak block board and chipboard wood samples.
- Out-of-phase ring stretching cellulose band at 896 cm^{-1} in MDF sample.

By comparing the ratio of peak heights between lignin and wood carbohydrates (hemicellulose at 1735 cm^{-1}, crystalline cellulose at 1425 cm^{-1}, amorphous cellulose at 1375 and 897 cm^{-1}) as previously mentioned in literature (El Hadidi 2017, 83-95) (El Hadidi 2020, 48-65), it is clear that the chemical composition of pine block board is the most stable (table 4). The change in ratio of intensity between lignin and carbohydrates in plywood clearly indicates a decrease in lignin, whereas a decrease of wood carbohydrates was noted in oak block wood, MDF and chipboard.

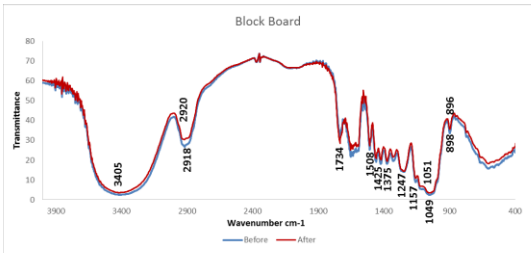


Figure 7. FTIR spectra of the block board wood before and after ageing

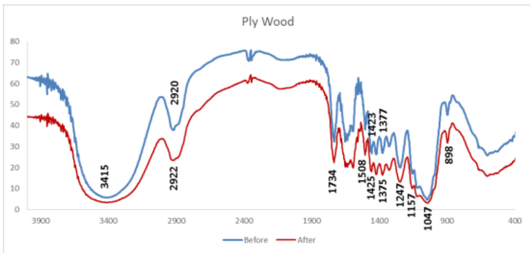


Figure 8. FTIR spectra of the plywood before and after ageing

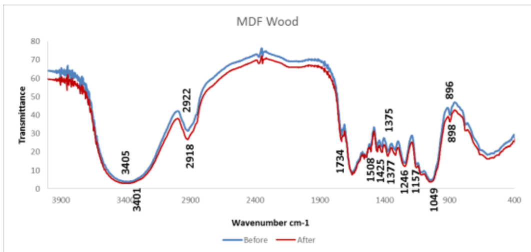


Figure 9. FTIR spectra of the MDF wood before and after ageing

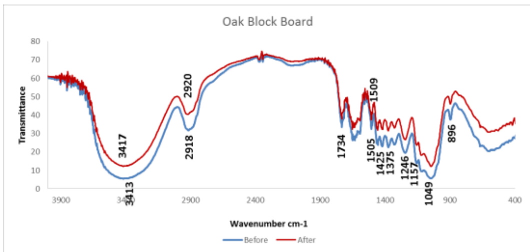


Figure 10. FTIR spectra of the oak block board wood before and after ageing

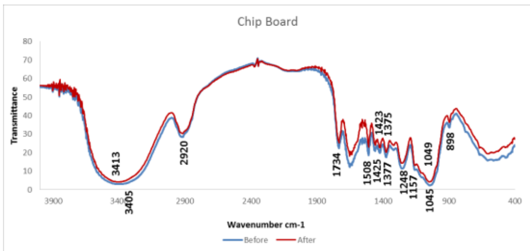


Figure 11. FTIR spectra of the chipboard wood before and after ageing

The results obtained from the Raman and FTIR analyses, the Kitagawa test tubes, and the observations recorded after conducting the Oddy test are in agreeance with the results discussed in previous research, which noted that wood, as a natural substance, contains volatile organic compounds.

In the five tested samples the content of formaldehyde, which rises when exposed to heat (Boruszewski 2011, 29-32) depending on the type of wood and adhesive used, ranged from 1 to 20 ppm. The oak blockboard emitted a higher amount than the pine blockboard, which is in agreeance with the fact that solid hardwood such as oak wood emits more formaldehyde than softwood (Costa 2014, 146-150), (Chaudhary 2014, A-H), (Abd Rashad 2019, 520-523). MDF and chipboard emitted the highest content of formaldehyde, as noted in previous research (Hemmila 2019, 1-9) (Bekhta 2020, 1-14) (Solt 2019, 99-131) (Dunky 2021, 189-268).

Four of the five tested samples emitted 50 g/m^3 acetic acid, and only the plywood sample emitted double that amount, which agrees with the fact that wood emits acetic acid when exposed to heat (Pohelven 2019, 1-24). As for ammonia, which is used in wood processing stages such as bleaching wood (Lyutyy 2017, 107-112), (Stanic 2020, 1-17), (Liu 2021, 557-565) recorded the highest amounts in the chipboard and MDF samples, the two types of processed wood that undergo a more sophisticated manufacturing procedure.

The changes noted in the FTIR spectra agree with the results obtained from both the Oddy test and the Kitagawa test tubes, which indicated that the emission of the three gases in different percentages from the wood samples affected the three main wood components in the form of a slight shift in the bands or decrease/increase of lignin and/or carbohydrates as recorded in tables 3 and 4.

Table.3 FTIR bands and functional groups of the studied alternative supports before and after ageing

absorption bands (cm^{-1})	Block board wood		Plywood		MDF wood		Oak Block board wood		Chipboard wood	
	Before ageing	After ageing	Before ageing	After ageing	Before ageing	After ageing	Before ageing	After ageing	Before ageing	After ageing
OH stretching	3405	3405	3415	3415	3405	3401	3413	3417	3405	3413
C-H stretching	2918	2920	2920	2922	2918	2922	2918	2920	2920	2920
C=O stretching hemicellulose	1734	1734	1734	1734	1734	1734	1734	1734	1734	1734
Aromatic C=C stretching lignin	1508	1508	1508	1508	1508	1508	1505	1509	1508	1508
CH_2 bending Cellulose (crystallized I and amorphous)	1425	1425	1425	1423	1425	1425	1425	1425	1425	1423
CH bending Cellulose	1375	1375	1375	1377	1375	1377	1375	1375	1377	1375
C-O Guaiacyl stretching	1247	1247	1247	1247	1246	1246	1246	1246	1248	1248
COC asym. bridge oxygen stretching Cellulose	1157	1157	1157	1157	1157	1157	1157	1157	1157	1157
C-O stretching in cellulose, hemicellulose and lignin	1051	1049	1047	1047	1049	1049	1049	1047	1045	1049
Out-of-phase ring stretching Cellulose	896	898	898	898	896	898	896	896	898	898

 DOI: 10.21608/shedet.2023.291533

Table 4, The calculated ratio of "lignin: carbohydrate intensities" of processed wood samples before and after exposure to ageing, and the gases emitted from the samples according to the aforementioned Kitagawa test

<table>
<tr><th>Wood type</th><th>Sample</th><th>L/ 1735</th><th>L/ 1425</th><th>L/ 1375</th><th>L/ 895</th><th>Remarks</th><th>Emitted gases</th></tr>
<tr><td rowspan="3">Block board</td><td>Standard</td><td>1.27</td><td>3.48</td><td>3.51</td><td>4.32</td><td rowspan="3">Minimal alteration in main wood components after ageing</td><td>6 g/m^3 NH_3</td></tr>
<tr><td rowspan="2">after ageing</td><td rowspan="2">1.34</td><td rowspan="2">3.38</td><td rowspan="2">3.61</td><td rowspan="2">4.37</td><td>50 g/m^3 CH_3COOH</td></tr>
<tr><td>1 ppm HCHO</td></tr>
<tr><td rowspan="3">Plywood</td><td>Standard</td><td>0.67</td><td>4.98</td><td>3.83</td><td>4.59</td><td rowspan="3">Relatively high decrease of lignin in comparison to wood carbohydrates.</td><td>10 g/m^3 NH_3</td></tr>
<tr><td rowspan="2">after ageing</td><td rowspan="2">0.21</td><td rowspan="2">1.63</td><td rowspan="2">2.65</td><td rowspan="2">1.91</td><td>100 g/m^3 CH_3COOH</td></tr>
<tr><td>3 ppm HCHO</td></tr>
<tr><td rowspan="3">MDF board</td><td>Standard</td><td>0.058</td><td>1.87</td><td>0.023</td><td>0.340</td><td rowspan="3">Decrease of wood carbohydrates in comparison to lignin</td><td>80 g/m^3 NH_3</td></tr>
<tr><td rowspan="2">after ageing</td><td rowspan="2">0.669</td><td rowspan="2">2.65</td><td rowspan="2">0.625</td><td rowspan="2">0.883</td><td>50 g/m^3 CH_3COOH</td></tr>
<tr><td>20 ppm HCHO</td></tr>
<tr><td rowspan="3">Oak Block board</td><td>Standard</td><td>0.427</td><td>1.50</td><td>1.01</td><td>0.983</td><td rowspan="3">Decrease of wood carbohydrates in comparison to lignin</td><td>6 g/m^3 NH_3</td></tr>
<tr><td rowspan="2">after ageing</td><td rowspan="2">0.557</td><td rowspan="2">4.42</td><td rowspan="2">1.20</td><td rowspan="2">3.31</td><td>50 g/m^3 CH_3COOH</td></tr>
<tr><td>15 ppm HCHO</td></tr>
<tr><td rowspan="3">Chip Board</td><td>Standard</td><td>0.428</td><td>1.65</td><td>2.066</td><td>3.59</td><td rowspan="3">Decrease of wood carbohydrates in comparison to lignin, except for cellulose at 1375</td><td>80 g/m^3 NH_3</td></tr>
<tr><td rowspan="2">after ageing</td><td rowspan="2">0.912</td><td rowspan="2">2.21</td><td rowspan="2">2.070</td><td rowspan="2">5.97</td><td>50 g/m^3 CH_3COOH</td></tr>
<tr><td>20 ppm HCHO</td></tr>
</table>

CONCLUSION

Based on the results obtained from the present study, it can be concluded that the block board is the most appropriate processed wood type that can be recommended as an alternative support for the following reasons:

- Color change measurements proved that block board wood barely altered in color; while all other types significantly changed.
- Oddy test results of block board wood showed that lead, silver and copper coupons were not affected. In the case of plywood, a white layer appeared on the lead coupon which indicates the escalation of acetic acid and black spots were also formed on the silver coupon as a result of the presence of ammonia. MDF and chipboard wood indicate the emission of formic acid, which formed black spots on lead and copper coupons, and black spots were also formed on the silver coupon as a result of the presence of ammonia. Oak block board affected the lead and copper coupons by forming black spots.
- The gas test tube showed a rise of emitted ammonia and formaldehyde gas from the MDF and chip board wood samples. Oak block board emitted a relatively high amount of

formaldehyde too, but plywood and block board emitted a relatively low amount of the gas. The plywood sample emitted a low amount of ammonia gas, and the lowest amount of emitted ammonia gas was in both types of block board. The highest amount of emitted acetic acid was from plywood, while both types of block board wood, MDF and chipboard wood emitted the same amount.

- The chemical composition of block board wood did not change after ageing; cellulose, lignin and hemicellulose percentages remained constant. Chipboard wood showed a slight change in its chemical composition, yet plywood, MDF, and oak block board wood samples were significantly affected after ageing; the proportion of cellulose, lignin and hemicellulose changed.

By correlating the results and summarizing the previous points, it is clear that pine block board is the processed wood that emits the least amount of hazardous gases that may affect artefacts. This fact is in agreeance with the Oddy test result, in which the block board was classified as “permanent”. Furthermore, there were no significant changes in color and chemical composition of the block board sample.

RECOMMENDATION

The main challenges that most conservators currently face are getting the opportunity to see the reverse side of a painting, checking the originality of the support and finding old reports in which previous restoration was documented, because the use of alternative panels has always been a solution for safeguarding paintings and different types of cultural heritage objects suffering from irreversible disintegration in their original support. In the past museums, private collectors, institutions or churches used various types of supports for transferring the polychrome artifact, without studying the disadvantages of the restoration/ conservation treatment applied to the painting. Now, with the expanding knowledge and criteria that have been set in conservation laboratories, to which conservators are expected to adhere, most of the conservation materials must undergo some kind of testing before their application.

It is recommended that any type of material, whether it is natural/ processed wood or any other material, should be tested prior to its use as an alternative panel in the case of icons or panel paintings so as not to cause any alterations in the original pigments or colors of the painting. Similar testing techniques can be applied to other materials used during the transfer of a wooden panel painting, such as adhesives and facing materials. As long as the material does not emit gases, it can be considered safe during and after the transfer process from the original deteriorated support to a permanent one, yet, after transferring the polychrome layer to the alternative panel, it is necessary to monitor the artefact on a regular basis, to assure that the polychrome layer remains stable. The testing methodology applied in this paper is efficient and simple to apply on a large scale in museums and private collections, when there is an urgent need to assess conservation and restoration materials available in local markets and when the financial resources are limited.

 DOI: 10.21608/shedet.2023.291533

ACKNOWLEDGEMENT

The authors are grateful to Dr. M. El Khial Head of Fumigation and Environmental Management Laboratory, at the Conservation Center of the Grand Egyptian Museum, for her support.

 DOI: 10.21608/shedet.2023.291533

REFERENCES

Abd Rashad, S., Tahir, M.P., Rusli, R. and Hua, L.S. 2019. “Relationship between wood colour of seven tropical hardwood species and formaldehyde emission of plywood.” *International Journal of Recent Technology and Engineering* volume 8 (2 S4): 520-523.

Abdrabou, A., El Hadidi, N.M.N, Hamed, S., Betiha, M.A. 2021. “Experimental study on the efficacy of cleaning systems for the removal of previous conservation treatments from Tutankhamuns' gilded wooden bed.” *International Journal of Conservation Science* volume 12 (2): 403-416.

Abdrabou, A., El Hadidi, N.M.N, Hamed, S.A.M., Abdallah, M. 2018. “Multidisciplinary approach for the investigation and analysis of a gilded wooden bed of King Tutankhamun.” *Journal of Archaeological Science* volume 21: 553-564.

Akgul, M. and Camlibel, A. 2008. “ Manufacture of medium density fiberboard (MDF) panels from rhododendron (R. ponticum L.) biomass.” *Building and Environment* volume 43 (4): 438-443.

Alam, D.M.N., Rahman, K.S., Ratul,S.B., Sharmin,A., Islam,T., Hasan,A., and Islam,N. 2015. “Properties of Particleboard Manufactured from Commonly Used Bamboo (*Bambusa vulgaris*) Wastes in Bangladesh.” *Advances in Research* volume (3): 203-211.

Antov, P., Savov, V., Neykov , N. 2020. “Reduction of formaldehyde emission from engineered wood panels by formaldehyde scavengers.” *13th International Scientific Conference Wood EMA 2020 and 31st International Scientific Conference ICWST 2020.* Vinkovci, Croatia: Sustainability of forest-based industries in the global economy. 289-296.

Arias, T. E., Blanc, M.R., Montes, A.L., Montero, F.J., Valdivia, M.E., and García, D.C. 2013. “Conservation of Historic Book Bindings by Means of Facsimile Reproduction: The Torres Notarial Register (1382–1400) in the Archive of the Royal Chancellery of Granada, Spain.” Chap. 52 in *Science and Technology for the Conservation of Cultural Heritage*, by M.A .R., Lazzari,M., and Cano,E., Candelera, 227-230. London.

Bansa, H. 1992. “Accelerated Aging Tests in Conservation Research: Some Ideas for a Future Method.” *Restaurator* volume 13 (3): 114-137.

Barick, S., Gasparik, M. and Razumov, E. 2019. “Effect of Temperature on the Color Changes Wood During Thermal Modification.” *Cellulose Chemistry and Technology* volume 49 (9-10): 789-798.

Bekhta, P., Sedliacik, J. and Bekhta, N. 2020. “Effect of Veneer-Drying Temperature on Selected Properties and Formaldehyde Emission of Birch Plywood.” *Polymers* volume 12 (3): 1-14.

Bohm, M., Salem, M.Z.M. and Srba, J. 2012. “Formaldehyde emission monitoring from a variety of solid wood, plywood, blackboard and flooring products manufactured.” *Journal of hazardous materials* volumes 221–222: 68-79.

Boruszewski, P., Borysiuk, P., Mamiński, M., Szlak, L. and Danecki, L. 2011. “Formaldehyde emission from raw materials for particleboard production at the beginning of processing chain.” *2nd International Conference on Environmental Engineering and Applications.* Singapore: IACSIT Press. 29-32.

Botros, W. 2010. “Comparative study of the different International Schools for the treatment and conservation of Tempra Icons present in Egypt with experimental applications.” MA, Conservation Department, Faculty of Archaeology, Cairo University.

 DOI: 10.21608/shedet.2023.291533

Campos, C.I., Lahr, F.A.R. 2004. "Production and Characterization of MDF Using Eucalyptus Fibers and Castor Oil-based Polyurethane Resin." *Materials Research* volume 7 (3): 421-425.

Cecily, M.G. 2006. *Monitoring for Gaseous Pollutants in Museum Environments.* chapter 4. Los Angeles: The Getty Conservation Institute.

Chaudhary, A. and Hellweg, S. 2014. "Including Indoor Offgassed Emissions in the Life Cycle Inventories of Wood Products." *Environmental Science and Technology* volume 48 (12): A-H.

Costa, N.A., João, F., Pereira, J., and Cruz, P. 2014. "Formaldehyde emission in wood based panels: effect of curing reactions." *International Wood Products Journal* volume 5 (3): 146-150.

DeLaet, N., Lycke, S., Van Pevenage, S., Moens, L., and Vandenabeele. 2013. "Investigation of pigment degradation due to acetic acid vapours :Raman spectroscopic analysis." *European Journal of Mineralogy* volume 25 (5): 855-862.

Dellaportas, P., Papageorgiou, E.and Panagiaris,G. 2014. "Museum factors affecting the ageing process of organic materials: Review on experimental designs and the INVENVORG project as a pilot study." *Heritage Science* volume 2 (2): 1-11.

Dunky, M. 2021. "Wood adhesives based on natural resources: A critical review Part IV. Special Topics." *Reviews of Adhesion and Adhesives* volume 8: 189-268.

El Hadidi, N. M. N. 2017. "Decay of softwood in archaeological wooden artifacts." *Studies in Conservation* volume 62 (2): 83-95.

El Hadidi, N.M.N., Abdel-Monem, H., Fawzy M.,Hashem, G. G. 2020. "Retreatment and conservation of a wooden panel previously treated with bees wax." *Advanced Research in Conservation Science,* volume 1, No. 2,(2020), volume 1 (2): 48-65.

El Sayed, Y. 2019. "Conservation of a historic panel oil-painting coated with an ancient varnish layer." *Shedet* volume 6 (6): 238-256.

Elkhial, M. M. and El Hadidi, N.M.N. 2022. "Assessing the Suitability of New Film Laminates for Sustainable Insect Eradication by Modified Atmosphere in Museums, Heritage Science." *Heritage Science* volume 10 (28): 1-11.

Elmarazky, A. and Kamal, H. 2021. "Impact of previous chemical treatments and environmental storage conditions on miniature agricultural implements from Tutankhamun's tomb." *Integrated Approaches to Conservation. ICOM-CC 19th Triennial Conference Preprints, Beijing, 17–21 May 2021, Paris.* Beijing: International Council of Museums. 1-6.

Gerhard, E. 2021. "Korrosion durch Konservierung, Restaurierungsmaterialien im Oddy test." *Deutsches Bergbau-Museum Bochum, Metalla Sonderheft* volume 11: 127-129.

Heine, H., and Jeberien, A. 2018. "Oddy test reloaded standardized test equipment and evaluation methods for accelerated corrosion testing." *Studies in Conservation* volume 63 (51): 362-365.

Hemmila, V., Meyer, E., Larsen, A., Schwab, H., and Adamopoulos, S. 2019. "Influencing factors, repeatability and correlation of chamber methods in measuring formaldehyde emissions from fiber- and particleboards." *International Journal of Adhesion and Adhesives* volume 95: 1-9.

Hunt, S.J. 2020. *Characterisation and monitoring of acidic emissions from marine archaeological wood.* Conference: UCL (University College London).

Keable, M.,Korenberg, C., Phippard, J. and Doyle, D. 2018. "Refinements introduced in the Oddy test methodology." *Studies in Conservation* volume 63 (1): 2-12.

Korenberg, C. and Bertolotti, G. 2019. "Emissions from MDF: Governing Factors and Mitigation Strategies." *Studies in Conservation* volume 64 (5): 249-260.

Li, R., Xu. W., Wang, X. and Wang, C. 2018. "Modeling and predicting of the color changes of wood surface during CO_2 laser modification." *Journal of Cleaner Production* volume 183: 818-823.

Liu, R., Qiu, H., Xu, J., Long,L., and Xiaoyan, L. 2021. "Surface color changes of oak (*Quercus alba* L.) treated with dopamine and iron ion compounds by acceleration of temperature–humidity condition." *European Journal of Wood and Wood Products* volume 79 (3): 557-565.

Lyutyy, P., Bekhta,P., Ortynska,G. and Sedliacik, J. 2017. "Formaldehyde, Phenol and Ammonia Emissions from wood/recycled Polyethylene Composites." *Acta Facultatis Xylologiae* volume 59 (1): 107-112.

Martina, I., Wiesinger, R., Simbürger, D.J. and Schreiner, M. 2012. "Micro-Raman Characterisation of Silver Corrosion Products: Instrumental Set up and Reference Database." *Preservation Science* volume 9: 1-8.

Melo, R.R. Stangerlin,D.M., Santana,R.R.C.,and Pedrosa,T.D. 2014. " Physical and Mechanical Properties of Particleboard Manufactured from Wood, Bamboo and Rice Husk." *Materials Research* volume 17 (3): 682-686.

Mohie, M.A. and Brania, A.A. n.d. "Alternative supports: an experimental and applied study." *Cairo University Scholars* 1-15.

Muasher, M. and Sain, M. 2006. "The efficacy of photo stabilizers on the color change of wood filled plastic composites." *Polymer Degradation and Stability* volume 91 (5): 1156-1165.

Pohelven, J., Burnard, M. D. and Kutnar, A. 2019. "Volatile organic compounds emitted from untreated and thermally modified Wood: A review." *Wood and Fiber Science* volume 51 (3): 1-24.

Pramanik, A., Maiti, S., and Mahanty, S. 2015. "Reduced graphene oxide anchored $Cu(OH)_2$ as a high performance electrochemical supercapacitor." *The Royal Society of Chemistry* volume 44 (33): 14604-14612.

Shahani, C. 1995. "Accelerated Aging of Paper: Can It Really Foretell the Permanence of Paper." *Preservation Research and Testing Series No. 9503* (Proceedings from the ASTM/ISR Workshop on the Effects of Aging on Printing and Writing Papers. Philadelphia, PA July 1994, Preservation Directorate, Library of Congress, Washington, D.C.) 1-18.

Singh, M.P., Prakash, V., Uday, D., Sujatha, D., Kiran, M. and Murthy, M. 2020. " Block Board from Melia dubia IJFWS Block Board from Melia dubia." *International Journal of Forestry and Wood Science* volume 7 (2): 96-100.

Solt, P., Konnerth, J., Gindl-Altmutter, W., Kantner, W., Moser, J., Mitter, R. and Van Herwijnen, H. W. G. 2019. "Technological performance of formaldehyde-free adhesive alternatives for particleboard industry." *International Journal of Adhesion and Adhesives* volume 94: 99-131.

Stanic, M. D., Sova, D., Savin, A., Ilias, N. and Gorbacheva, A. G. 2020. "Physical and Mechanical Properties of Ammonia-Treated Black Locust Wood." *Polymers* volume 12 (2): 1-17.

Steger, S., Eggert, G., Horn, W. and Krekel, C. 2022. "Are cellulose ethers safe for the conservation of artwork? New insights in their VOC activity by means of Oddy testing." *Heritage Science* volume 10 (53): 1-12.

Tetreault, J., Cano, E., Van Bommel, M., Scott, D., Dennis, M., Labrousse, M.G.B., Minel, L. and Robbiola, L. 2003. "Corrosion of Copper and Lead by Formaldehyde, Formic and Acetic Acid Vapours." *Studies in Conservation* volume 48 (4): 237-250.

Varadhan, S. R. 2020. "Identification of physical clues by FTIR spectroscopy." *Oriental Journal of Chemistry* volume 36 (5): 958-963.

Wang, S., Kong, L., An, Z., Chen, J., Wu, L. and Zhou, X. 2011. "An improved Oddy test using metal films." *Studies in Conservation* volume 56 (2): 138-153.

Wencek, A.S., Bartkowiak, M., Zborowska, M., and Bocianowski, J. 2020. "Effects of aqueous ammonia vapor on the color and chemical structure of *Robinia pseudo* acacia and oak woods." *BioResources* volume 15 (3): 5812-5828.

Zimbovskiy, D.S., Gavrilov, A.I. and Churagulov, B.R. 2018. "Synthesis of copper oxides films via anodic oxidation of copper foil followed by thermal reduction." *IOP Conference Series Materials Science and Engineering* volume 347 (1): 1-8.

Website:

https://www.komyokk.co.jp/en/index.html