

TUNG OIL AND LINSEED OIL AS TRADITIONAL FINISHING MATERIALS IMPORTANT FOR FURNITURE CONSERVATION

Xin You LIU

PhD student – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: liu.xinyou@unitbv.ro

Maria Cristina TIMAR

Prof.dr.chim. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: cristinatimar@unitbv.ro

Anca Maria VARODI

Dr.eng – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: anca.varodi@unitbv.ro

Song Lin Yi

Prof.dr.eng - Beijing Forestry University - College of Material Science and Technology
Adresa/Address: Qinghua donglu nr. 35, 100083 Beijing, China
E-mail: ysonglin@126.com

Abstract

*Tung oil and linseed oil are two representative traditional drying oils which were commonly employed, for centuries, for wood finishing. Therefore, their study in terms of properties, chemical structure features and alterations by ageing is important for furniture conservation. This paper focusses on some comparative properties of Tung oil and linseed oil as wood finishing materials. For this purpose, test wooden samples of Chinese walnut (*Juglans mandshurica Maxim.*) were coated with these materials by manual traditional techniques. Solids content of the oils was determined in order to approximate the thickness of the resulting film. The colour change brought about by coating of wood surfaces with these oils was measured in the CIELab system. Furthermore, an accelerated artificial ageing test under the action of temperature (100 °C) was performed in order to evaluate and compare the ageing resistance of the two types of oils. Ageing phenomena were investigated by colour measurements and FTIR - ATR spectrometry. Both uncoated and oils coated wood surfaces suffered colour changes observed as darkening and colour shade shifting to red and yellow, but these were obviously more evident for the oil coated samples. The overall colour changes were maximum for the samples finished with linseed oil, while tung oil seemed to be more resistant. FTIR investigations for two types of oils highlighted similarities and differences in their chemical composition, curing and aspects of the thermally induced ageing mechanism. The later proved to be mainly an oxidative degradation process leading to formation of free fatty acids and other carbonyl containing compounds, as suggested by the broader carbonyl (1740 cm⁻¹) and hydroxyl bands (3400 cm⁻¹).*

Key words: *Tung oil; linseed oil; ageing; colour measurement; FTIR analysis.*

INTRODUCTION

Drying oils are some of the oldest wood finishing materials. Tung oil and linseed oil are the most representative drying oils for traditional furniture finishing. Therefore, their study in terms of properties, chemical structure features and alterations by ageing is important for furniture conservation.

Tung oil originates from the seeds of several species of *Aleurites* spp., primarily *Aleurites fordii*, a deciduous shade tree native from China (Sharma et al. 2013). Tung oil dries quickly when exposed to air and polymerizes into a tough, glossy, waterproof coating that makes it especially valuable in furniture finishing. In China from Han Dynasty (206 BC -220 AD), people have known and used Tung oil mixed with colourful minerals as a special material for wood finishing (Guan 1999).

Linseed oil is obtained from the dried ripe seeds of the flax plant (*Linum usitatissimum*, *Linaceae*). Since the 15th century, linseed oil has been extensively used in varnishes and oil-based house paints in Europe (Lazzari 1999).

These drying oils contain in high percentage (90-95%) triglycerides of unsaturated fatty acids with two or three unconjugated carbon to carbon double bonds (C=C), which are responsible for their "drying", actually a complex chemical process known as oxidative polymerization, involving the C=C double bonds and oxygen from the atmosphere. Oxidation can result also in isomerisation of *cis* double bonds to *trans* isomers, cleavage of the carbon-carbon chain along with formation of volatile by products (Samadzadeh et al. 2011). A comparison of the composition of these two drying oils in terms of content of different types of unsaturated fatty acids is presented in Table 1.

In order to speed up this process, a heat treatment process (known as boiling or blown) can be used to increase the molecular weight (oligomerization) of the Tung oil and linseed oil for coating applications (Narin et al. 2012). These oils are materials with outstanding properties in terms of resistance of finishing surfaces. This is related of their chemical composition and film formation mechanism.

Table 1

Major unsaturated fatty acid components of Tung oil and linseed oil (compiled from Samadzadeh et al. 2011)

Fatty acid	Percent (weight)		Structural formula	Number C atoms	Double bonds No.
	Tung oil	Linseed oil			
Eleostearic	80	-	HOOC(CH ₂) ₇ CH=CH-CH=CH-CH=CH-(CH ₂) ₃ CH ₃	18	3 Conjugated
Linolenic	3	52	HOOC(CH ₂) ₇ CH=CH-CH ₂ -CH=CH-CH ₂ -CH=CH-CH ₂ CH ₃	18	3 Isolated
Linoleic	4	16	HOOC(CH ₂) ₇ -CH=CH-CH ₂ -CH=CH-(CH ₂) ₄ CH ₃	18	2 Isolated
Oleic	8	22	HOOC(CH ₂) ₇ -CH=CH-(CH ₂) ₇ -CH ₃	18	1

OBJECTIVE

This paper focuses on some comparative properties of Tung oil and linseed oil as finishing materials for wood surfaces. The investigated aspects were solids content of the liquid products, drying times and aspect of Chinese walnut (*Juglans mandshurica* Maxim.) finished surfaces. Moreover, the ageing resistance has been investigated by color measurements and FTIR analysis.

MATERIAL, METHOD, EQUIPMENT

Boiled Tung oil, produced by Jin Xing Chemical Ltd, Beijing, was purchased from Beijing Forestry University, China. Boiled linseed oil, produced by FABRYO SRL Romania, was purchased from CONREP shop, Brasov. White spirit, produced by SC TURNIR- Tirgoviste, was employed for diluting the oils.

Chinese walnut (*Juglans mandshurica* Maxim.) was purchased from North-east of China, as timber pieces with dimensions of (500×80×80) mm, moisture content of about 60-70%. These timber pieces were supposed to a combined multi-step sterilisation and artificial drying procedure, reaching a final moisture content of 9-11%. After drying, sawing, planing and sanding, 15 test samples with dimensions of (120×70×7) mm (Longitudinal×Radial×Tangential), without defects were selected for these experiments.

Solids content: In order to evaluate the quality of the two types of drying oils and calculate thickness of each layer, solids content was determined by the usual gravimetric procedure. Samples of oils were put in weighing flasks, weighed and placed in an oven at temperature of 103 ± 2°C and allowed to dry until constant weigh was reached (differences less 0.002g between two successive weighing). Solids content was calculated as in equation 1:

$$S_c = \frac{M_2 - M_0}{M_1 - M_0} \times 100\% \quad \text{Eq. 1}$$

where:

S_c: solids content (%);

M_0 : container's weight (g);
 M_1 : initial weight of container and oil (g);
 M_2 : weight of container and oil after drying (g).

The theoretical thickness of each coating layer was calculated with equation 2:

$$g_f = \frac{\Delta M \cdot S_c}{100 \cdot A \cdot \rho_i} \quad \text{Eq. 2}$$

where:

g_f : theoretical thickness of the coating film of each layer (μm)
 ΔM : mass of the applied liquid oil for the respective layer (g)
 S_c : solids content of the oil applied (%).
 A : surface of the finished test piece (m^2)
 ρ_i : density of the liquid oil (g/cm^3)

Wood finishing technology: 5 test pieces of wood were prepared for finishing with each of the oils. Finishing was achieved by brushing in 5 successive layers, the drying time between two successive layers being 24 hours. In the case of Tung oil, diluted material (2 volumes of Tung oil: 1 volume of white spirit) without sanding between layers was used for the first 3 layers; another 2 layers of diluted Tung oil (1:1) were applied with intermediary sanding (abrasive paper H=240 and 360). For linseed oil, diluted oil (2.5 volumes of linseed oil : 1 volume of white spirit) was used without sanding between layers for the first 2 applications; then 3 layers of no-diluted linseed oil were applied with intermediary sanding (abrasive paper H=240 and 360).

For the purpose of highlighting the aspect of the finished and unfinished wood surfaces, as well as of documenting ageing effects, all the samples were scanned at a resolution of 300 dpi employing a HP LaserJet ProCM1415 Colour Multifunction Printer. A 1 cm long measuring bar was marked on each test piece.

Ageing test: An artificial accelerated ageing test employing high temperature as ageing factor was carried out comparatively on not-finished and the finished samples. The testing conditions were temperature of $T = 100^\circ\text{C}$ at constant relative humidity $\text{RH}=55\%$, a Feutron FKS 400 climatic chamber being employed for this purpose. These testing conditions are in accordance to a reference publication on the matter of accelerated ageing in conservation research by Robert Feller (Feller 1994), showing that accelerated aging 72 hours (3 days) at 100°C is equivalent to about twenty-five years of aging under normal conditions (for paper). Accordingly, for materials classified as excellent in conservation, characterized by a minimum 100 years of intended useful lifetime, a total testing time of 12 days is recommended. In this paper ageing under the influence of temperature was evaluated following three cycles of 72 h (3 days) each, achieving exposure durations of 72, 144 and 216 hours.

Colour measurement: Colour measurement was made in the CIE Lab system. An AvaSpec-USB2 spectrometer, equipped with an integrating AVA sphere with a diameter of 80 mm, interconnected by optical fibres, linked to PC for data acquisition and processing, was employed. Colour was measured for all the unfinished and finished wood samples, both before and after ageing. For each test sample, colour measurements were performed in 4 points (actually circular areas of about 8 mm) and an average has been calculated. In order to repeat the measurements in the same areas, a sample fixing plate was designed and prepared. This allows reproductive colour measurements in terms of investigating identical areas. Otherwise, a much higher dispersion of the experimental values would be expectable as wooden surfaces do not have a uniform colour (i.e. differences between latewood and early wood). The dedicated AVASOFT, version 7.7 was employed to process the colour data.

FTIR investigation: FTIR spectra were recorded employing an ALPHA FT-IR Spectrometer (BRUKER), equipped with ATR (attenuated total reflection) module. The spectra were recorded in the range of $4000 - 400 \text{ cm}^{-1}$, at a resolution of 2 cm^{-1} , each spectra representing an average of 24 scans. A number of 5 wood samples (no finished, finished with Tung oil and finished with linseed oil) was allocated for temperature ageing test, from these five two samples were investigated by FT-IR. Spectra from three randomly chosen measuring areas were recorded for each sample, resulting six spectra for each tested variant. Each spectrum was further processed as baseline correction and smoothing. An average spectrum of the six individually recorded ones was calculated. This average spectrum was further normalised (vector normalization). These normalised average spectra were further employed to compare chemical structural features of the surfaces before and after ageing.

RESULTS AND DISCUSSION

Finishing of wood samples

Details on the finishing technology (application rates/layer and total) and the theoretical thickness of the resulting film, computed based on these rates and the solids content of the oils (undiluted and diluted) are presented in Table 2.

Table 2

Wood finishing - application rates for Tung oil and linseed oil

Drying oils	Application rates ($\Delta M/A$) (g/m ²)					Total($\Delta M/A$) (g/m ²)	gf (μm)
	1	2	3	4	5		
Tung oil	28.62	25.48	24.10	26.36	33.80	138.36	47.58
Linseed oil	21.96	17.99	20.12	16.36	34.03	110.46	61.52

Note: Solids content of initial Tung oil was 46.31%, diluted Tung oil(2:1) was 30.87%, diluted Tung oil (1:1) was 23.15%, initial linseed oil 49.78%, diluted linseed oil (2.5:1) was 35.34%

General aspect and colour

Table 3

Visual assessment of colour changes for unfinished and finished samples

Ageing time → Finishes ↓	No aged	72h aged	144h aged	216h aged
Tung oil finished				
Unfinished				
Linseed oil finished				

Wood finishing with oils produced colour saturation and highlighted structural features of Chinese walnut wood, resulting in an enhancement of its natural beauty (see scanned images in Table 3). The surfaces were smooth and shiny. Temperature ageing induced colour changes for both uncoated and oils coated samples, but particularities and differences in terms of change extent were obvious for the different types of samples. The uncoated ones suffered the minimum colour changes, resumed as slight darkening and colour shift to red, more obvious after 72h. The oils coated samples suffered more advanced colour changes observed as progressive darkening and colour shade alteration with an initial shift to red (maximum after 72h for linseed oil), followed by yellowing (maximum for Tung oil after 144h). The overall colour change was more advanced for linseed oil compared with Tung oil.

A summary of CIELab colour data (average values) for the investigated unfinished and finished wood samples (before and after temperature ageing) is presented in Table 4.

The colour changes caused by temperature ageing are reflected in the modification of colour difference and the three CIELab colour coordinates relatively to the initial value for controls (ΔE , ΔL^* , Δa^* , Δb^*) as a function of exposure time, illustrated by the graphs in Fig. 1, comparatively for the unfinished and finished samples.

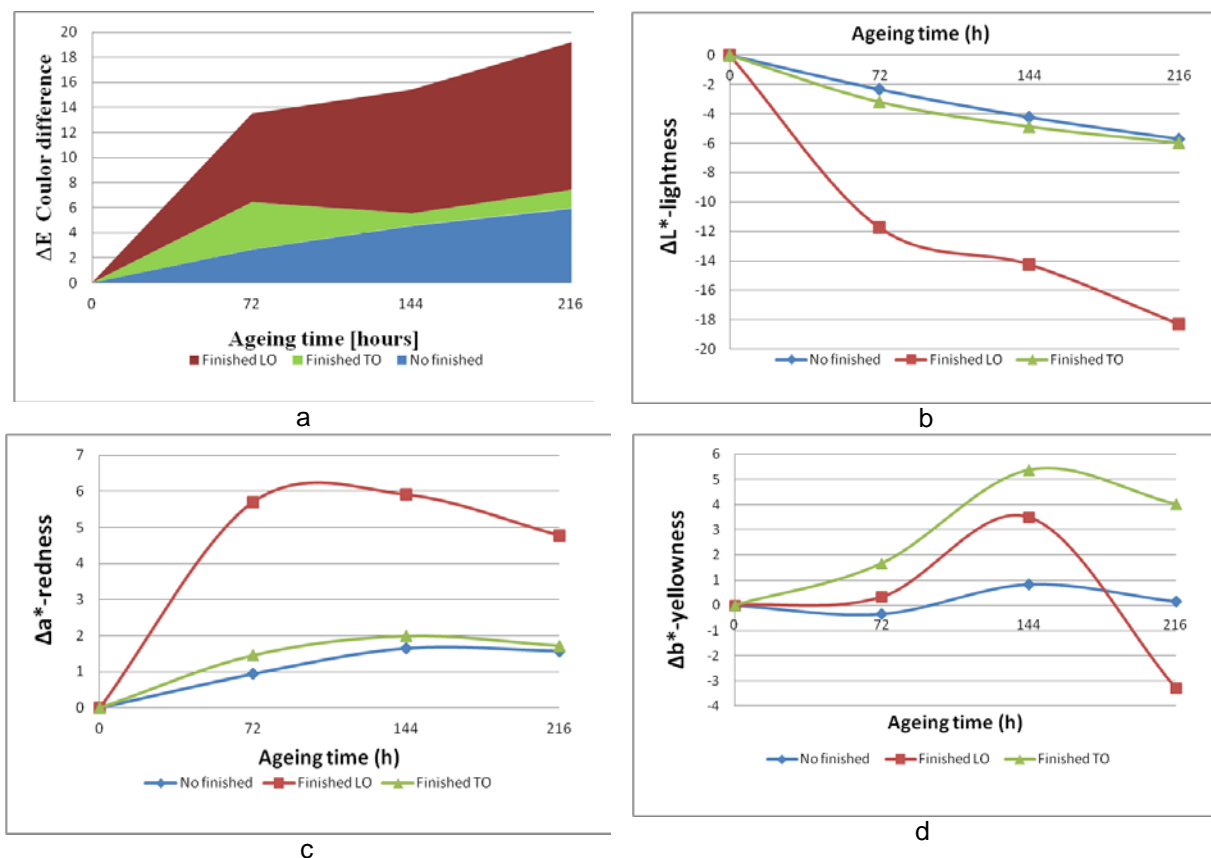


Fig. 1.

Comparative colour changes of Chinese walnut wood samples (unfinished and finished) following artificial temperature induced ageing: a. colour difference, b. lightness, c. redness, d. yellowness

Table 4

Results of colour measurements for control and aged samples (unfinished and finished)

Finishes	CIELab coordinates	Ageing time (h)			
		0	72	144	216
Unfinished	L*	66.05 ±2.51	63.71 ±2.11	61.82 ±1.75	60.33 ±1.99
	a*	7.28 ±0.79	8.22 ±0.63	8.93 ±0.52	8.86 ±0.55
	b*	16.90 ±1.70	17.73 ±0.91	16.55 ±1.90	17.05 ±0.86
Tung oil finished	L*	60.84 ±1.45	57.64 ±1.79	55.96 ±1.71	54.85 ±1.35
	a*	9.86 ±0.58	11.31 ±0.35	11.85 ±0.49	11.58 ±0.41
	b*	20.22 ±1.57	25.59 ±1.31	21.88 ±3.47	24.25 ±1.62
Linseed oil finished	L*	57.95 ±2.11	46.22 ±1.60	43.72 ±1.86	39.66 ±1.19
	a*	11.41 ±0.81	17.11 ±0.71	17.32 ±1.00	16.19 ±0.99
	b*	18.45 ±3.04	21.95 ±2.56	18.78 ±2.49	15.17 ±2.22

The overall colour difference (ΔE) increased with the time of ageing (Fig. 1a) for all the samples. The ΔE curves show that colour difference was maximum for linseed oil finished samples,

followed by Tung oil finished samples, while the minimum colour differences were calculated for the uncoated samples, for which the evolution of ΔE values with the time of ageing was almost linear. In contrast, in the case of finished samples, the maximum colour change was registered after the first 72h of temperature exposure, after which the process of colour change slowed down. These global colour changes resulted from the changes in lightness (Fig 1b), redness (Fig. 1c) and yellowness (Fig.1d). The lightness of all the samples decreased as result of temperature induced ageing, negative ΔL^* values being registered after 72h of exposure. The lightness continued to decrease, though neither uniformly nor similarly for the different type finishes. The highest decrease of the L^* value after 216h was recorded for samples finished with linseed oil, whilst the lowest reduction of lightness was determined for unfinished samples, close values being measured also for samples finished with Tung oil, results which correlate well with visual assessment. The chromaticity parameters a^* and b^* also changed as result of temperature ageing. The increasing Δa^* and Δb^* values indicate colour shift to red and yellow up to 144h temperature ageing, thenafter (up to 216h) an apparent trend of decreasing being registered.

FTIR investigation

In Fig. 2 are presented the FTIR-ATR spectra experimentally recorded for Tung oil and linseed oil (liquid form and hardened film), while in Table 5 are summarised the main absorbance bands in these spectra and their assignment in accordance to the literature. The FTIR spectra reflect the chemical structural features of two oils and changes occurring during their oxidative curing.

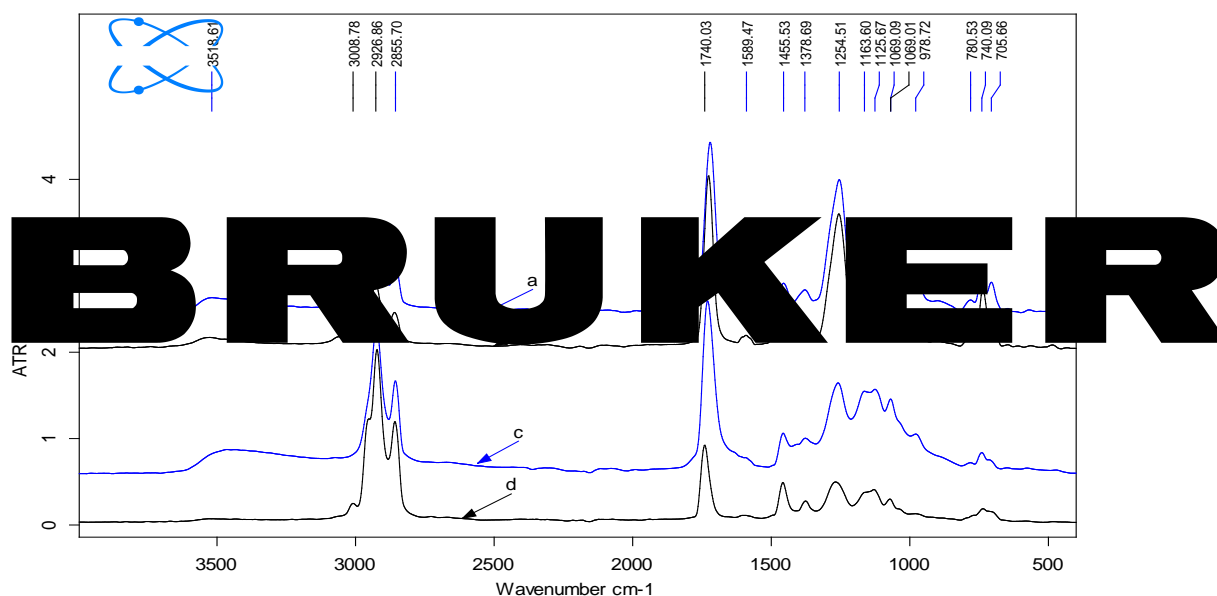


Fig. 2.
Comparative FTIR spectra of investigated oils samples: a) Tung oil hardened film, b) Tung oil liquid form, c) linseed oil hardened film, d) linseed oil liquid form

The main absorption bands in the two drying oils spectra are those for hydroxyl ($\sim 3400 \text{ cm}^{-1}$), methylene (2922 and 2853 cm^{-1}), carbonyl (1740 cm^{-1}) and $\nu(\text{C}-\text{O})$ in $\text{C}-\text{O}-\text{C}$ in esters (~ 1255 , 1171 and 1125 cm^{-1}). Comparing the spectra of two oils' in liquid form with those of cured films, some alterations are visible. For Tung oil the most obvious is a slight increase of hydroxyl related band at 3400 cm^{-1} , possibly due to formation of oxidised products (Meiorin 2013). At the same time, the bands at 1456 cm^{-1} , attributed to bending vibration of the CH_2 , CH_3 aliphatic, and 978 cm^{-1} attributed to $\omega(\text{CH})$ wagging in isolated *trans* $\text{CH}=\text{CH}$, are slightly increasing. The shoulder at about 2956 cm^{-1} of the methylene band 2925 cm^{-1} , assigned to the C-H stretching in methyl groups disappeared after curing. Similar alterations of the bands 3400 and 2925 cm^{-1} occurred for linseed oil. The small peak at around 3009 cm^{-1} due to $\nu(\text{C}-\text{H})$ in unconjugated *cis* $\text{C}=\text{C}-\text{H}$ disappeared, while bending vibration of the CH_2 , CH_3 aliphatic at 1456 cm^{-1} visibly decreased. A strong increase of carbonyl band at 1740 cm^{-1} and of peak at 1254 cm^{-1} , assigned to oxiranes, also occurred being related to oxidative processes in the chemical mechanism of curing. A slight band at 975 cm^{-1} gives the indication of the formation of isolated *trans*-configured double bonds (Schonemann 2011).

Table 5

Main absorption peaks in the FTIR spectra of two oils and assignment based on literature

Wave number, (cm ⁻¹)		Peak assignments	Absorption range literature (cm ⁻¹)	References
Tung oil	Linseed oil			
3368	3364	O-H stretching	3451,3471, 3446,3440	(Schonemann 2011) (Guillen 2003), (Pereda 2010) (Huang 2013) (Meiorin 2013) (Chang 2013)
3009	3010	v (C-H) in <i>cis</i> C=C-H unconjugated	3008, 3012, 3010	(Schonemann 2011) (Guillen 2003)
2925	2925	C-H stretching (asymm), CH ₂ aliphatic	2927	(Schonemann 2011) (Guillen 2003) (Pereda 2010)
2856	2856	C-H stretching (symm), CH ₂ aliphatic	2854	(Schonemann 2011) (Guillen 2003) (Pereda 2010)
1720	1730	Carbonyl group ester groups	1740, 1746	(Schonemann 2011) (Guillen 2003) (Zhu 2013), Chang 2013 (Meiorin 2013) (Pereda 2010)
1456	1457	Bending vibration of the CH ₂ , CH ₃ aliphatic	1461, 1450	(Schonemann 2011) (Guillen 2003) (Tellez 2009)
1379	1377	the CH ₃ groups symmetrical bending vibrations	1378, 1377	(Schonemann 2011) (Guillen 2003)
1254	1258	C-O-C stretching from oxirane vibration	1250,1238,1240	(Schonemann 2011) (Tellez 2009) (Guillen 2003) (Chang 2013)
1171	1171	bending vibration of the CH ₂ group	1163	(Guillen 2003)
1125	1125	C-O group stretching vibration in esters	1118 -1120	(Guillen 2003)
973	970	ω(CH) in CH=CH wagging isolated <i>trans</i>	978, 971, 993	(Schonemann 2011) (Pereda 2010), (Huang 2013)
740	740	Stretching of <i>cis</i> CH=CH C-H rocking in methylene	728, 735	(Schonemann 2011) (Pereda 2010)

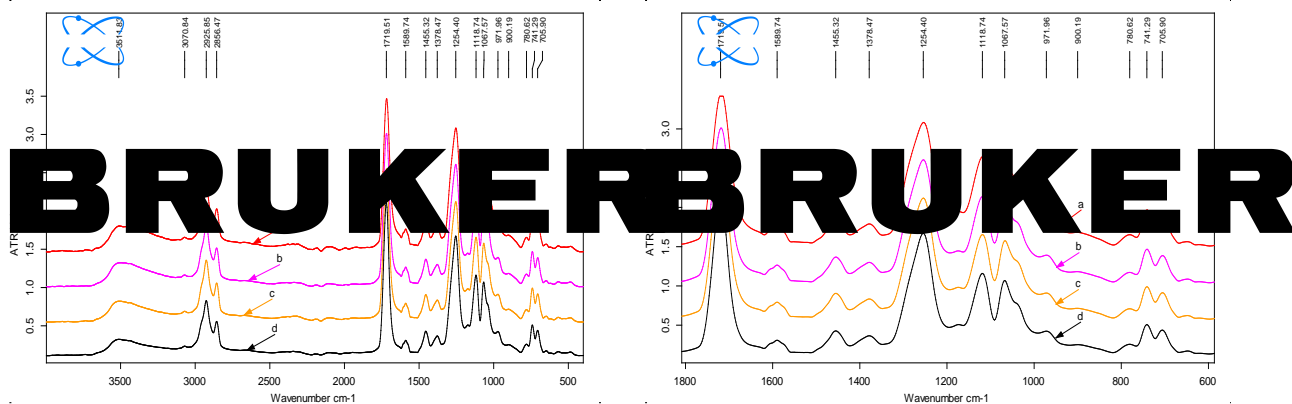


Fig. 3.

Comparative FTIR spectra of Tung oil finished on Chinese walnut samples: a 216 hours aged, b- 144 hours aged, c 72 hours aged, d no aged; whole range 4000-400 cm⁻¹ spectra (left) and expanded spectra in the fingerprint region 1800-600 cm⁻¹ (right)

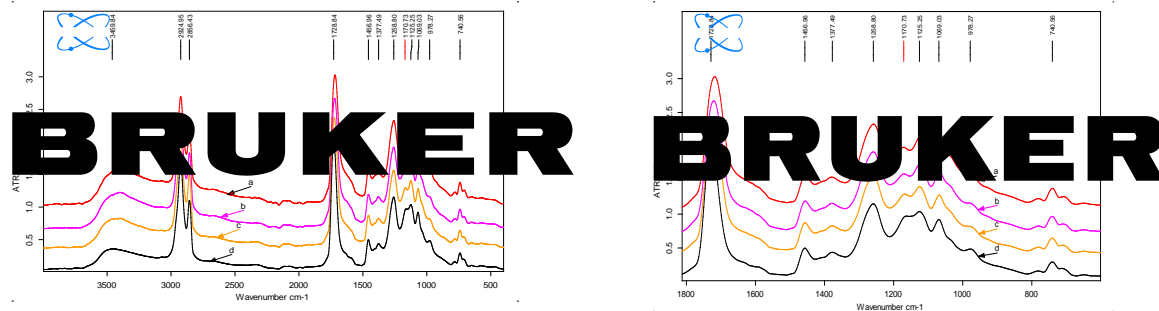


Fig. 4.

Comparative FTIR spectra of linseed oil finished on Chinese walnut samples: a 216 hours aged, b- 144 hours aged, c 72 hours aged, d no aged; whole range 4000-400 cm⁻¹ spectra (left) and expanded spectra in the fingerprint region 1800-600 cm⁻¹ (right)

Table 6
Variation of Tung oil and linseed oil main absorption peaks values as a function of ageing time

Oils	Peaks	Ageing time [h]											
		0			72			144			216		
		Abs.	w	A	Abs.	w	A	Abs.	w	A	Abs.	w	A
TO	3512	0.003	217	0.326	0.005	238	0.595	0.008	253	1.012	0.007	265	0.928
	2926	0.045	74	1.665	0.048	73	1.752	0.047	75	1.763	0.046	82	1.886
	2856	0.022	21	0.231	0.024	21	0.252	0.023	20	0.230	0.024	20	0.240
	1720	0.153	43	3.290	0.144	46	3.312	0.141	47	3.314	0.134	50	3.350
	1590	0.001	37	0.019	0.003	36	0.054	0.003	36	0.054	0.004	35	0.070
	1455	0.011	36	0.198	0.012	36	0.216	0.012	36	0.216	0.012	38	0.228
	1378	0.006	38	0.114	0.006	38	0.114	0.006	38	0.114	0.006	38	0.114
	1254	0.116	66	3.828	0.11	70	3.850	0.109	71	3.870	0.105	73	3.833
	1119	0.073	38	1.387	0.072	39	1.404	0.072	39	1.404	0.072	39	1.404
	1068	0.065	35	1.138	0.066	44	1.452	0.066	46	1.518	0.067	51	1.709
972	0.011	22	0.121	0.012	20	0.120	0.013	20	0.130	0.016	19	0.152	
LO	3460	0.005	271	0.678	0.012	290	1.740	0.016	296	2.368	0.014	302	2.114
	2925	0.106	59	3.127	0.1	64	3.200	0.097	68	3.298	0.088	74	3.256
	2856	0.06	22	0.660	0.058	22	0.638	0.056	21	0.588	0.053	21	0.557
	1729	0.129	50	3.225	0.119	56	3.332	0.112	59	3.304	0.11	61	3.355
	1457	0.015	28	0.210	0.015	28	0.210	0.014	28	0.196	0.014	27	0.189
	1377	0.011	31	0.171	0.011	33	0.182	0.011	34	0.187	0.012	36	0.216
	1259	0.063	268	8.442	0.063	274	8.631	0.062	280	8.680	0.064	284	9.088
	1169	-	-	-	0.044	25	0.550	0.04	25	0.500	0.041	25	0.513
	1125	0.055	82	2.255	0.052	75	1.950	0.05	45	1.125	0.051	41	1.046
	1069	0.046	22	0.506	0.043	25	0.538	0.042	29	0.609	0.044	39	0.858
978	0.014	20	0.140	-	-	-	-	-	-	-	-	-	

Notes: Abs.-absorbance intensity, w- width of peak at the baseline, A-approximate area (A=0.5*Abs.*w)

Fig 3 and Fig 4 present comparative FTIR spectra of Tung oil and linseed oil finished samples after temperature ageing. The spectra show that some slight changes occurred after temperature ageing. In table 6 are listed the main absorption peaks, alongside their registered absorbance values and width, for the two oils. From the spectra and the values it can be observed that the band at 1740 cm⁻¹ attributed to carbonyl became broader, with a shoulder shifted towards lower values, due to the formation of free fatty acids and other carbonyl compounds by oxidative degradation of oils (Izzo 2010). The formation of fatty acids is supported by a broad absorption attributed to the hydroxyl stretching vibration in the region ~ 3400cm⁻¹. Trans - configured double bonds (~972-975 cm⁻¹), which are formed during the curing of linseed oil, are degraded by temperature ageing. These bonds,

present in the structure of Tung oil in both liquid and cured film, degraded affected by ageing in the case of Tung oil.

CONCLUSIONS

Tung oil and Linseed oil as finishing materials change natural wood colour and enhance its beauty. Artificial, accelerated, temperature induced ageing caused further colour changes of oils finished surfaces and chemical structure changes. Colour measurement data showed that oils finished surfaces darkened progressively when exposed to temperature, while colour shifted to red and yellow. up to 144 hours of exposure. From 144 hours to 216 hours, redness and yellowness decreased, though lightness continued to decrease slowly. Linseed oil changed colour much more than Tung oil.

FTIR investigations for two types of oils highlighted similarities and differences in their chemical composition, curing and aspects of the thermally induced ageing mechanism. The later proved to be mainly an oxidative degradation process leading to formation of free fatty acids and other carbonyl containing compounds, as suggested by the broader carbonyl (1740 cm^{-1}) and hydroxyl bands (3400 cm^{-1}). Trans-configured double bonds ($\sim 972\text{-}975\text{ cm}^{-1}$), which are formed during the curing of linseed oil, are degraded by temperature ageing. These bonds, present in the structure of Tung oil in both liquid and cured film, are not degraded by ageing in the case of Tung oil.

REFERENCES

- Chang CW, Lu SKT (2013) Linseed-oil-based waterborne UV/air dual-cured wood coating, *Progress in Organic Coatings*, 76:1024-1031.
- Feller RL (1994) Accelerated aging photochemical and thermal aspects, *The Getty Conservation Institute, United States of America*, Pp. 161
- Greenfield J (1959) Lectures of the 1959 short course on drying oils, *The Journal of The American Oil Chemists' Society* 36(11):565-574.
- Guan CY (1999) A preliminary study of Chinese tung tree planting history. *Ancient and Modern Agriculture* (4):21-28.
- Guillén MD, Ruiz A, Cabo N, Chirinos R, Pascual G (2003) Characterization of Sacha Inchi (*Plukenetia volubilis* L.) Oil by FTIR Spectroscopy and ^1H NMR Comparison with Linseed Oil, *Journal of the American Oil Chemists' Society*, 80(8):755-762.
- Huang Y, Pang L, Wang H, Zhong R, Zeng Z, Yang J (2013) Synthesis and properties of UV-curable tung oil based resins via modification of Diels-Alder reaction, nonisocyanate polyurethane and acrylates, *Progress in Organic Coatings*, 76:654-661.
- Izzo FC (2010) 20th Century artists'oil paints: A chemical-physical survey, PhD thesis, university Ca'Foscari, Venice.
- Lazzari M, Chiantore O (1999) Drying and oxidative degradation of linseed oil. *Polym Degrad Stabil* 65:303-313.
- López T, Santiago EV, López SH (2009) Characterization of linseed oil epoxidized at different percentages, *Sociedad Mexicana de Ciencia y Tecnología de Superficies y Materiales*, 22(1):5-10.
- Meiorin C, Mosiewicki MA, Aranguren MI (2013) Ageing of thermosets based on tung oil / styrene/ divinylbenzene, *Polymer Testing* 32:249-255.
- Pereda M, Aranguren MI, Marcovich NE (2010) Caseinate films modified with tung oil, *Food Hydrocolloids* 24:800-808.
- Samadzadeh M, Boura SH, Peikari M, Ashrfi A, Kasiriha M (2011) Tung oil: An autonomous repairing agent for self-healing epoxy coating, *Progress in Organic*, 70:383-387.
- Schonemann A, Howell G, Edwards M (2011) Raman and FTIR microspectroscopic study of the alteration of Chinese tung oil and related drying oils during ageing, *Anal Bioanal Chem* 400:1173-1180.
- Sharma V, Pradhan RC, Naik SN, Bhatnagar N, Singh S (2013) Evaluation of a centrifugal impaction-type decorticator for shelling tung fruits *Industrial Crops and Products* 43:126-131.
- Thanamongkollit N, Miller KR, Soucek MD (2012) Synthesis of UV-curable tung oil and UV-curable tung oil based alkyd, *Progress in Organic Coatings* 73:425- 434.
- Xiong Z, Li C, Ma SQ, Feng JX, Yang Y, Zhang RY, Zhu J (2013) The properties of poly(lactic acid)/starch blends with a functionalized plant oil: Tung oil anhydride, *Carbohydrate Polymers* 95:77-84.