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Modification of wood acoustic, hygroscopic and colorimetric properties due to thermally accelerated ageing

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ABSTRACT

A mild hygro-thermal treatment was applied to wood, as a first step of pre-treatment/coating systems for musical instrument making. Longitudinal ($L=150 \times R = 12 \times T=2.5$ mm) and radial Spruce specimens ($R=150 \times L=12 \times T=2.5$ mm) were treated in reactors maintained at a temperature of 130 or 150°C, and a relative humidity (RH) of 0% or varying between 0% and 25%. Weight loss (WL), equilibrium moisture content (EMC), density (ρ) and vibrational properties in bending (E/ρ , $\tan\delta$), were measured before and after treatment, while colour parameters were recorded also at intermediate steps. Although WL was small ($\leq 5\%$), some properties were significantly modified: EMC was reduced by up to -30%; $\tan\delta_R$ was reduced by as much as -30% and E/ρ increased by more than 5% in radial direction. There was a correlation between the intensity of the treatment and the results of the tests, and also a correlation between the results of colorimetric tests (expressed as CIELab and CIELCh), vibration tests and weight and dimensional measurement.

Keywords: acoustical properties, musical instruments, varnish, accelerated ageing

1 INTRODUCTION

The weakness and fragility of aged wood need to be taken into consideration for the maintenance of old wooden constructions. However, the effect of ageing on wood is of interest to musicians and artisans dealing with classical musical instruments such as violins. One part of the interest is to understand, if acoustic properties of wood are significantly affected with time, another part to reproduce aesthetic features of old wood. On the other hand, many wooden musical instruments are coated with a protective layer that plays an aesthetical role as well, but its acoustical consequences, although often claimed, is not fully asserted, especially during the curing time of various varnishes (Minato *et al.* 1995). Artificial ageing treatments are often performed before the application of coating, either for aesthetical or protection purpose, without strict control of the treatment condition or a clear understanding of the consequences on mechanical and vibrational properties. The improved stiffness and stability obtained through thermal treatment of wood leads to its consideration as “artificial ageing” and an ecological method for the modification of new wood (Noguchi *et al.* 2012). Recent work by Froidevaux (2012) suggested that mild thermal treatment, below 150°C but at a non-zero relative humidity, produces chemical variations close to that of naturally aged wood, with consistent reduction of radial strength and lightness.

In this work, we will investigate the modification of wood acoustic, hygroscopic and colorimetric properties due to thermally accelerated ageing. This is as a first step of a broader study on the mechanical consequences of pre-treatment/coating systems commonly used for musical instrument making.

2 EXPERIMENTAL METHODS

2.1 MATERIAL

This study was carried out on spruce (*Picea abies* (L) Karst.), as this species is the main material for European classical instruments soundboards. 30 specimens in longitudinal direction (150×12×2.5 mm, L×R×T) and 30 in radial direction (12×120×2.5 mm, L×R×T)

were used. They came from 3 trees with longitudinal matching of specimens between 5 different treatment modalities, and control groups.

2.2 CONDITIONING AND PHYSICAL MEASUREMENTS

Measurements of acoustical and hygroscopic properties were performed after at least 3 weeks stabilization at 25°C and 65% relative humidity (RH), as vibrational properties are highly dependent upon moisture content and its variations (Obataya *et al.* 1998). Before treatment, specimens were conditioned without prior oven-drying. After treatment, equilibrium was reached after oven drying (24h at 65°C then 2h at 103°C). The difference between these two kinds of conditioning is taken into account in the results by subtracting the variations observed on control groups. At each step, mass and dimensions were measured, and density (ρ) and equilibrium moisture content (EMC) were calculated.

2.3 TREATMENTS

After primary measurements, specimens were submitted to hydro-thermal-treatment. Two automatic thermo-hydrous reactors have been used for this purpose (by RINO Sàrl, Blonay, Switzerland). Three groups were treated at 150°C with, respectively, 0% (constant) RH, 25% constant RH, and cyclic variations between these two RH (Fig. 1). The same protocol was applied to three other groups at a temperature of 130°C.

For each treatment, intermediate data from dimension, weight and colorimetric measurements were obtained. After finishing treatments, all measurements except vibrational ones were performed. Then all measurements were performed after at least 3 weeks stabilization at 25°C and 65% RH.

2.4 COLORIMETRIC MEASUREMENTS

Colour was measured with a spectrophotometer “spectro-guide sphere gloss” from BYK, type 6834, with a diameter of aperture of 10 mm. Standard Illuminant D65 and standard observer curve of 10°C were used. Data were collected in the CIELab system, where L^* (lightness) is 0 for black, 100 for white, axis a^* ranges from green ($-a^*$) to magenta ($+a^*$)

and axis b^* ranges from blue ($-b^*$) to yellow ($+b^*$). Data are also expressed in the more intuitive CIELCh system, where C^* ($= \sqrt{a^{*2} + b^{*2}}$) is chromaticity (intensity of colour) and h° ($= \arctan((b^*) / (a^*))$) is hue angle.

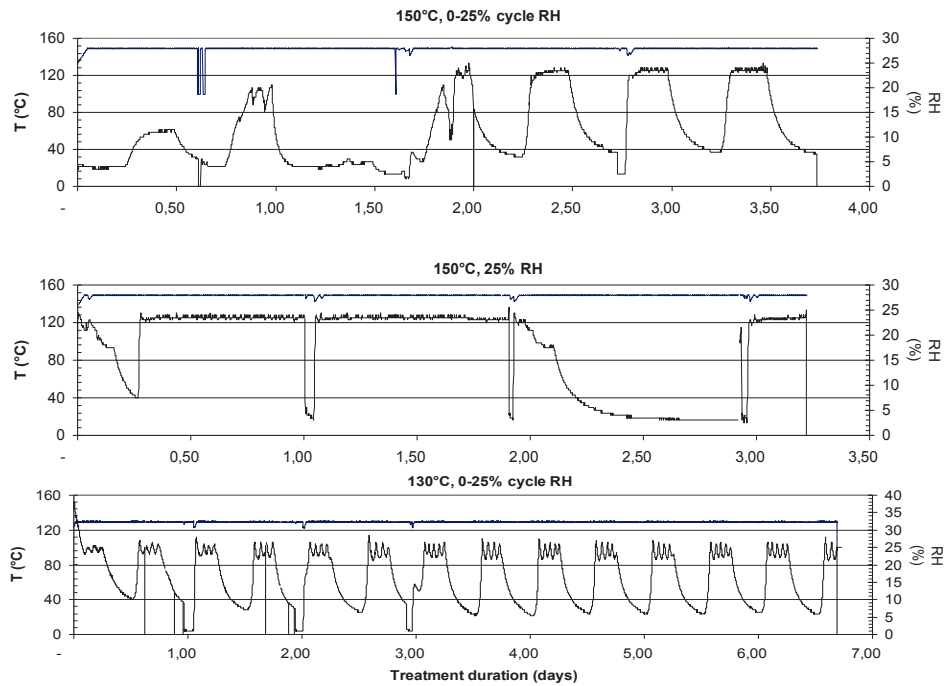


Figure 1: Evolution of temperature and relative humidity during tests for 25% and cyclic conditions.

2.5 VIBRATIONAL TEST

Vibrational tests were conducted on the principle of non-contact forced-released vibrations of free-free bars (e.g., Obataya *et al.* 2000), using the experimental protocol and device and computer interface described in (Brémaud 2012, Brémaud *et al.* 2012). Damping coefficient (or internal friction) expressed as $\tan \delta$ was calculated as the inverse of the “quality factor” Q or half-power bandwidth. The specific dynamic elastic modulus (E'/ρ) was deduced from the first resonance frequency according to Bernoulli equation. Frequency range was 100-200 Hz for radial specimens and 550-650 for axial ones.

3 RESULTS AND DISCUSSION

3.1 KINETICS OF MODIFICATION DURING TREATMENTS

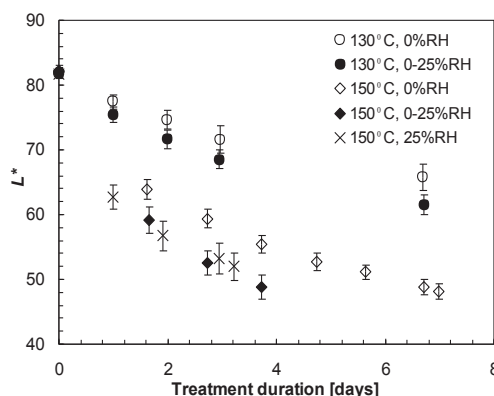


Figure 2: Evolution of colour Lightness L^* along treatment duration.

The kinetics of modification was monitored during treatment through oven-dry weight and colorimetry. In the absence of treatment, the colorimetric values measured on anhydrous wood are not much different for lightness (-1%), but oven-dry wood appears less saturated ($\Delta C^* = -9\%$) and more “yellow” ($\Delta h^\circ = +7\%$). The parameter L^* from colorimetric tests is presented in Fig. 2 as a function of treatment duration for different treatment conditions (130°C or 150°C , 0% - 25% - cycle between 0% and 25%). The expected decrease with treatment duration is enhanced as well as a clear effect of temperature treatment (after 7 days at 130°C in dried condition, L^* is reduced by 20% whereas after 7 days at 150°C in dried condition, L^* is reduced by 41%). For the same temperature, the decrease of L^* is enlarged by treatment at constant or variable humidity. It seems that a cycling in humidity induces a larger effect on L^* , nevertheless this effect has to be confirmed by further study.

3.2 CHANGES IN PROPERTIES AFTER COMPLETE TRATMENT

The average values of physical (air-dry density and equilibrium moisture content), vibrational and colorimetric properties (in CIELCh system) are compared in table 1 between control groups and specimens that underwent the most “efficient” treatment. Incidentally, for control groups (that only underwent 103°C oven-drying and

reconditioning at 65% RH), the effect of drying mainly resulted in a decrease in subsequent EMC (by 11% relative change, that is, from 12.4 to 10.9% EMC), with only minor changes in properties ($\leq 1\%$ for density and moduli of elasticity, $\leq 3\%$ for damping).

After hygrothermal artificial ageing, the biggest effects are observed on EMC (reduced by up to -30%), on colour lightness but also hue angle (the wood becomes more “red”), and on radial damping. Axial damping is also reduced, to a smaller extent, and radial modulus increased. Nevertheless, concerning the very important decrease observed here for EMC, it should be useful in a next stage to study this after reconditioning at high relative humidity, to check the proportion of reversible, and irreversible, effects of the applied treatment (Obataya and Tomita 2002).

Table 1: Physico-mechanical properties for the most efficient treatments

Treatment	ρ stab (air-dry density)	EMC (%)	E'_{\perp}/ρ (GPa)	E'_{\parallel}/ρ (GPa)	$\tan\delta$ (Q^{-1}) L	$\tan\delta$ (Q^{-1}) R	L^*	C^*	h°
Control groups	0.465	10.9%	32.6	1.42	0.0059	0.0220	82	24	80
150°C, 0-25% cyclic	0.448	7.2%	32.6	1.51	0.0055	0.0153	49	26	63

In Fig. 3, the actual changes in physical properties can be compared between the different treatment modalities. Higher temperature obviously accelerates the processes. Cyclic humidity conditions also appears to accelerate the process, although, as can be seen in Fig. 2, the fact that this modality was run for only half the duration of the oven-dry one for 150°C treatment, partly masks the final effects in Fig. 3. The decrease in EMC is closely followed by a decrease in radial partial shrinkage. When comparing the effects of different modalities of treatment on vibrational properties, the same trends can be observed. Properties in radial direction are significantly more affected than those in axial direction, thus leading to a reduction in anisotropy. It was already reported that up to now, most treatments able to reduce damping are usually assorted with a reduction in anisotropy (Obataya *et al.* 2000, Noguchi *et al.* 2012).

Concerning the correlations between changes in the different properties, weight loss is a good indicator of changes in EMC and in colour, but not so for changes in vibrational properties which are much better correlated with changes in colour (L^* and h° , not C^*

which is a poor indicator in this case). Finally, changes in damping are better correlated with changes in EMC or with L^* and h^* than with changes in elastic moduli.

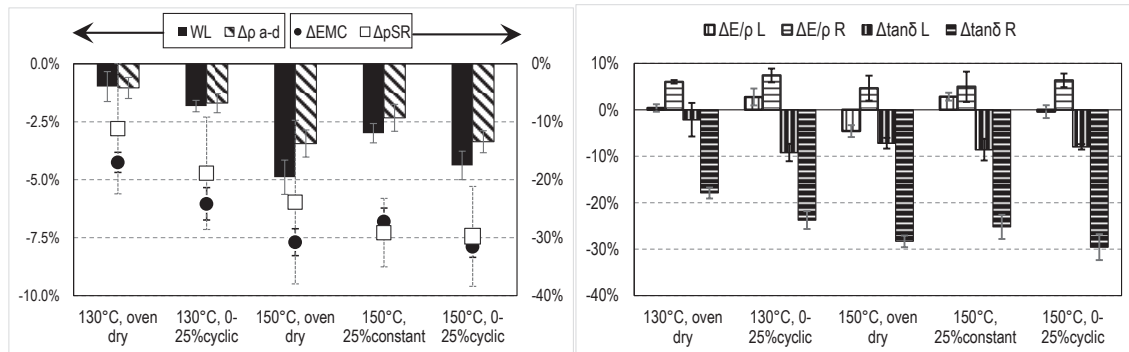


Figure 3: Changes of properties after completion of the different hygrothermal treatment procedures. (a) physical properties (weight, air-dry density, equilibrium moisture content and partial shrinkage) ; (b) vibrational properties (in axial and radial directions) after completion of the different hygrothermal treatment procedures.

4 CONCLUSION

Thermal treatment of wood under varying humidity conditions was successfully applied to Spruce specimens. The mild level of the treatment, shown by small weight loss obtained, was nevertheless accompanied by significant changes, such as reduction of hygroscopicity, colour lightness and damping. The tests aimed at exploring the possibilities of the equipment to induce in wood features similar to those of naturally aged wood, rather than producing systematic data for the characterisation of the modifications. A new experiment with improved control of humidity would allow evaluating the effect of unsteady conditions, compared to the sole effect of humidity level.

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