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THE RELATIONSHIP BETWEEN THE PHYSICAL AND ACOUSTIC PROPERTIES OF AGED VARNISHED RESONANCE WOOD

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Abstract:
The paper aims to present the behavior of two groups of samples: resonant spruce samples and curly maple samples of quality class A (concert violin wood) and class D (student violin wood) varnished with alcohol varnish or oil-based varnish of different thicknesses (thickness of 5, 10 and 15 layers). The aim was to study the effects of UV radiation on the physical and acoustic parameters of the samples before and after 1000 hours of exposure to the aging treatment. Rectangular plates with dimensions of 240 x 80 x 4 mm (L x R x T) were investigated for three states: unvarnished, varnished and artificially aged, the vibrational properties being determined. The correlations between the determined parameters were statistically analyzed, exploring the relationship between the variables for the spruce and maple wood samples, respectively. The study highlighted the fact that variables that make the difference between the two species are: longitudinal and radial propagation speeds, both before and after varnishing, the frequency associated with the absorption coefficient, the resonance frequency and damping. From the size of the correlation coefficients, it results that the links between the variables are closer in spruce than in maple.

Key words: *resonance wood, aged varnished wood, resonance frequency spectrum, experimental modal analysis.*

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INTRODUCTION

There are many debates on the factors that influence the acoustic and vibrational quality of musical instruments. One of the factors is the aging of the wood, studies carried out by Yokoyama et al. 2009, Noguchi et al. 2012, Bucur 2016. proving that naturally aged wood has much better vibrational properties than new wood. Chemical and imaging investigations carried out by Tai et al. 2018, Cai & Tai 2020, Su et al. 2021, confirmed that the aging process of wood is based on the decomposition of hemicellulose and the rearrangement of cellulose, which would lead to an increase in the acoustic performance of old musical instruments. The authors of the study indicate a combination of the two factors - aging and chemical processing to obtain excellent acoustic effects. Stanciu et al. 2024 showed that artificial aging of spruce and maple wood, for 1000 hours, leads to changes in the crystallinity index, which depends on the anatomical structure of the samples. Nagyvary 1988, Nagyvary et al. 2009, Cai & Tai 2020 analyzed the influence of chemical modifications by rearranging cellulose microfibrils in the cell wall of the soundboard as a result of chemical reactions with potassium, sodium salts.

Not only the anatomical quality of the aged resonance wood is important, but also the type of varnish used to finish the musical instruments. Not only the anatomical quality of the aged sounding wood is important, but also the type of varnish used to finish the musical instruments. Thus, some researchers believe that the secret of the Stradivarius violins lies in the recipe of the varnish used. Research conducted by Bianu 1957; Schelleng 1968, Schleske, (2002) on the influence of the varnish film on the dynamic and acoustic properties of violins has shown that the varnish does not have a significant effect on modifying the acoustics of the instrument, but varying the thickness of the wooden plates influences the acoustic properties much more. However, the stiffness, mass and damping of the varnish film applied to the soundboard can differently modify the dynamic response of the wood in the longitudinal and radial directions. According to Sedighi et al 2016, sound radiation decreased by up to 6.5% along the fiber, but increased in the radial direction; Acoustic impedance decreased in both the longitudinal direction by up to 2.7% and in the transverse direction by 10.5%, and the internal damping of the wood increased in both directions. Artificial aging of lacquered wood led to an increase in the specific modulus of elasticity and a decrease in internal damping, due to the hardening of the lacquer. Lämmlein et al. 2017, Lämmlein et al. 2019 analyzed the vibrational properties of lacquered violins in correlation with the hygroscopic behavior of the wood in the analyzed structures.

From the presented analysis, it results that the study of the wood - finish - aging interaction is a subject that has not yet been sufficiently explored.

OBJECTIVE

The objective of the paper is to presents the experimental results regarding the dynamic behavior of two types of varnished wood species used for musical instruments, in different stages (unvarnished, varnished and artificially aged): resonant spruce and curly maple samples.

MATERIAL, METHOD, EQUIPMENT

Materials

For this study, samples of spruce and maple wood were prepared for musical instruments. The rectangular samples were grouped into two categories according to anatomical characteristics - the width of the annual rings, the proportion of earlywood, latewood for spruce samples, and the degree of fiber curl for maple wood. Details regarding the anatomical characteristics of spruce and maple wood used for musical instruments from the violin family are presented in previous studies (Dinulica et al. 2021, 2023). In Fig. 1 the main technological operations for obtaining spruce and maple wood samples are presented (Stanciu et al. 2025a). In the first step, the samples were investigated to determine the dynamic response and frequencies spectrum.

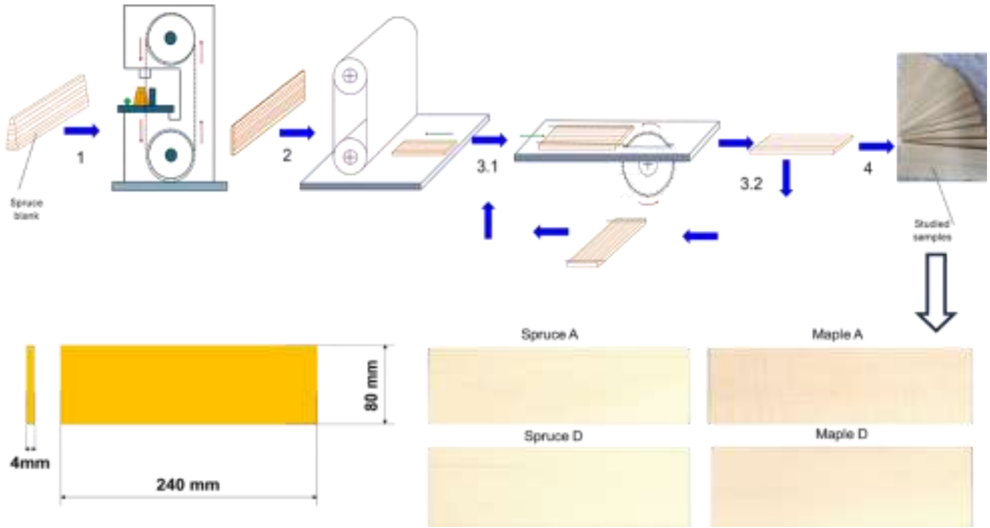

Fig. 1.
The main technological operations for obtaining samples, for the first step of experimental investigation: 1-slitting of the blank on a band saw; 2-calibration of the faces on a sanding calibrating machine (four passes with different grits of the sanding roller); 3.1-straightening the edges for basing; 3.2-cutting (sectioning) to length; 4-the samples at the final dimensions).

In the second stage of the research, the samples were divided into two groups from the point of view of the type of finish: one part was varnished with alcohol varnish, the other part was varnished with oil-based varnish, applied in 5, 10 and 15 layers. Thus, the new material obtained called coating system is composed of wood substrate (thickness h_w=4±0.2 mm), wood-varnish interface (thickness h_wv=40±10 μm) and varnish film thickness (v=60÷100 μm) and is obtained by applying successive layers. In Fig. 2 the categories of varnished samples are presented, resulting in a total number of 72 samples (3 from each category). Class A spruce wood samples (with narrow and regular annual rings) were marked Spruce A, class D ones (with annual ring widths 1.5 - 3.5 mm) were marked Spruce D, and for maple wood samples the notations Maple A and Maple D were used. The codes related to the type of finish were: LU - for those varnished with oil-based varnish (with 5, 10, 15 layers), LS - alcohol varnish (with 5, 10 15 layers). Thus, the research analyzed the same set of samples in three stages: before varnishing; after varnishing and after artificial aging for 1000 hours.

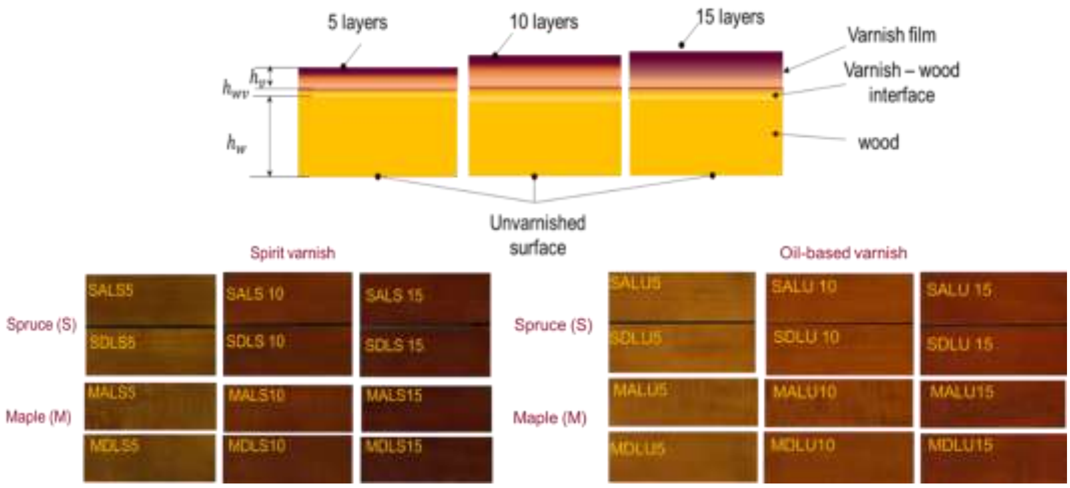

Fig. 2.
The varnished samples.

Method & Equipment

Obtaining the lighting system consisted of several stages, the most important of which are highlighted in the diagram in Fig. 3.

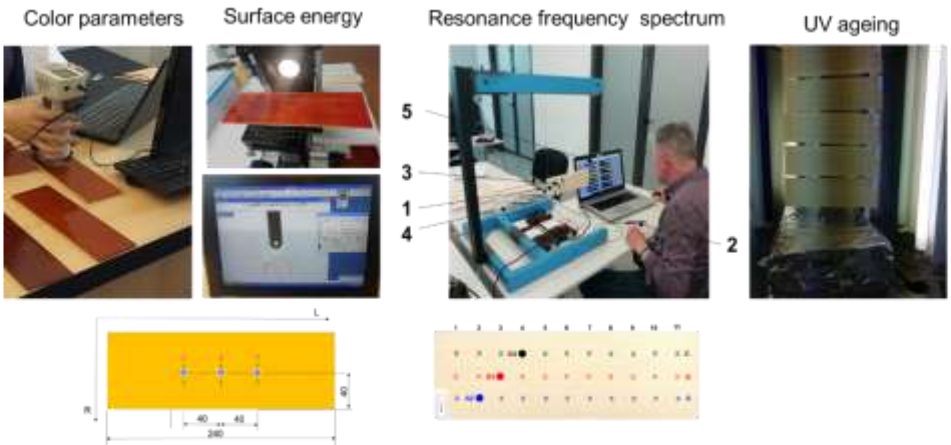

Fig. 3.
The types of experimental researches.

Color measurements

Color measurements in the CIE Lab system were performed with Konica Minolta CR-400 chroma meter. In Fig. 3, bottom row, left, the scheme for measuring color parameters at three points on the sample is presented. In order to be able to repeat the measurements in the same area, on the edge of the samples, the positions of the measurement points were marked, avoiding the dispersion of the values as a result of the native non-uniformity of the wood color. The main parameter calculated based on known mathematical relation was the color differences denoted ΔE* (Timar et al. 2016, Capobianco et al. 2017, Liu et al.2019).

Contact angle – surface energy

The contact angle determination was performed using System OCA-20 equipment (Data Physics Instruments, L7 Laboratory – ICD Transilvania University of Brasov), using successively distilled water and glycerin for the drop with a volume of 10 µL, in the same points marked for the color parameters. The contact angle is a quantity that provides information about the surface energy of the analyzed material, respectively about the classification of the surface as hydrophilic or hydrophobic.

The experimental modal analysis

The modal analysis was performed using an experimental stand in which the sample was positioned with elastic supports, the dynamic response of the sample being captured by means of accelerometers fixed to the sample, following excitation with the impact hammer. The signals acquired with the acquisition board were processed with an application developed in MatLab.

Artificial aging

Accelerated aging consisted of exposing the samples simultaneously to UV radiation and VIS (visible light), as well as to a temperature of 50 C, for 1000 hours, in an artificial aging reactor. The samples were monitored periodically (Teacă et al. 2013, Gall et al. 2022).

RESULTS & DISCUSSION

Color change of varnished samples before and after aging

Fig. 4 shows the comparative evolution of the color difference depending on the thickness of the varnish film and the type of varnish, both in the case of spruce and maple samples. The most important ΔE* variations are in samples with the thinnest varnish film (5 layers) and are more pronounced in oil - based varnish than in spirit- based varnish. Wood species also influence the color change ΔE*. Thus, the aging leads to decrease ΔE* by 75 - 93% for samples with 10 layers compared to those with 5 layers. A reduction of about 40% for 10 to 15 layers is observed in both wood species samples.

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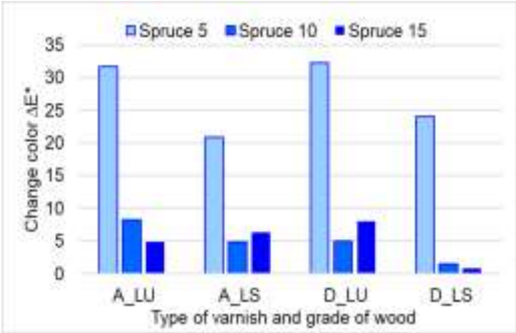
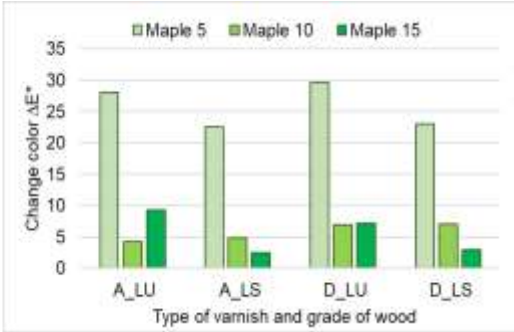


(a)

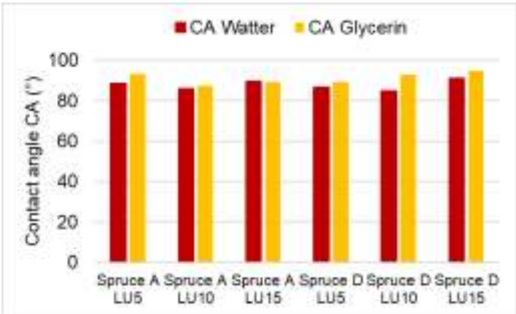


(b)

Fig. 4.
Color change of varnished samples before and after aging: (a) spruce samples; (b) maple samples.

Results of contact angle measurement

The variation of the contact angle depending on the thickness of the varnish film and the type of varnish is presented in Fig. 5, for all types of samples tested. It is observed that regardless of the fluid used, the contact angle is higher in the case of samples varnished with LU, so they present a hydrophobic surface, compared to spirit varnished samples. Since the varnish film completely covers the wood fiber, intra-species and inter-species anatomical characteristics do not influence this parameter. The differences between the two quality classes are not statistically assured in terms of contact angle with water and glycerin.



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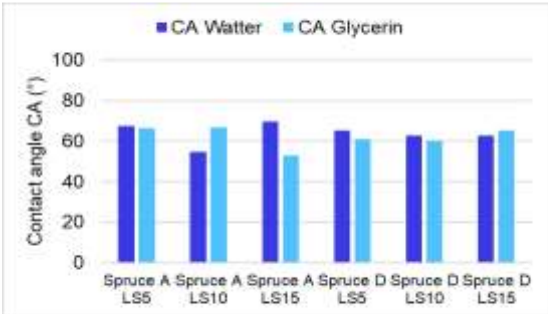

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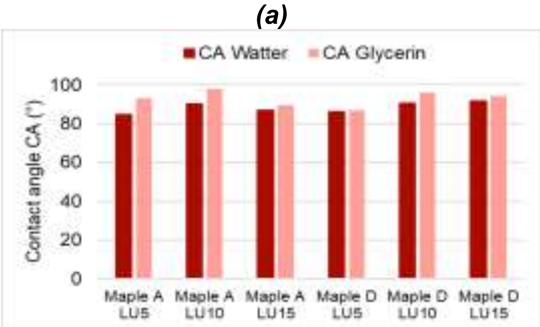

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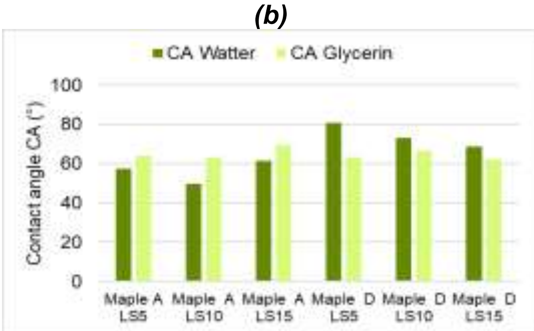


(d)

Fig. 5.
Variation of contact angle: a) spruce samples, varnished with oil based varnish; (b) spruce samples varnished with spirit varnish; (c) maple samples, varnished with oil based varnish; (d) maple samples varnished with spirit varnish.

Dynamic behaviour – modal analysis of wooden plates

Following the experimental modal analysis, numerous time and frequency analysis graphs of the plates in the three study stages resulted. In Fig. 6 an example of a frequency spectrum obtained by Fast Fourier Transform (FFT) analysis for the same sample, before, after varnishing and after aging is presented. The information obtained in this type of graph refers to the resonance frequencies (1 - n), the dominant frequency representing the frequency with the highest amplitude in the entire spectrum, the vibration modes - represented in the upper part of the graph and resulting from the interpolation of all frequency spectra - and amplitudes as a result of the excitation of the structure at all points established on the plate according to Fig. 2. From this type of graph, the values of the logarithmic decrement (damping) could be extracted according to the method highlighted by Zhou et al. 2024, Stanciu et al. 2025b.

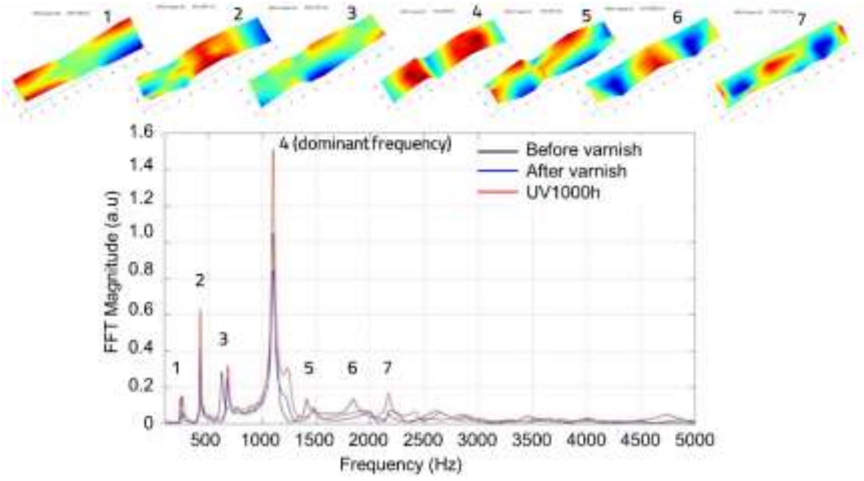
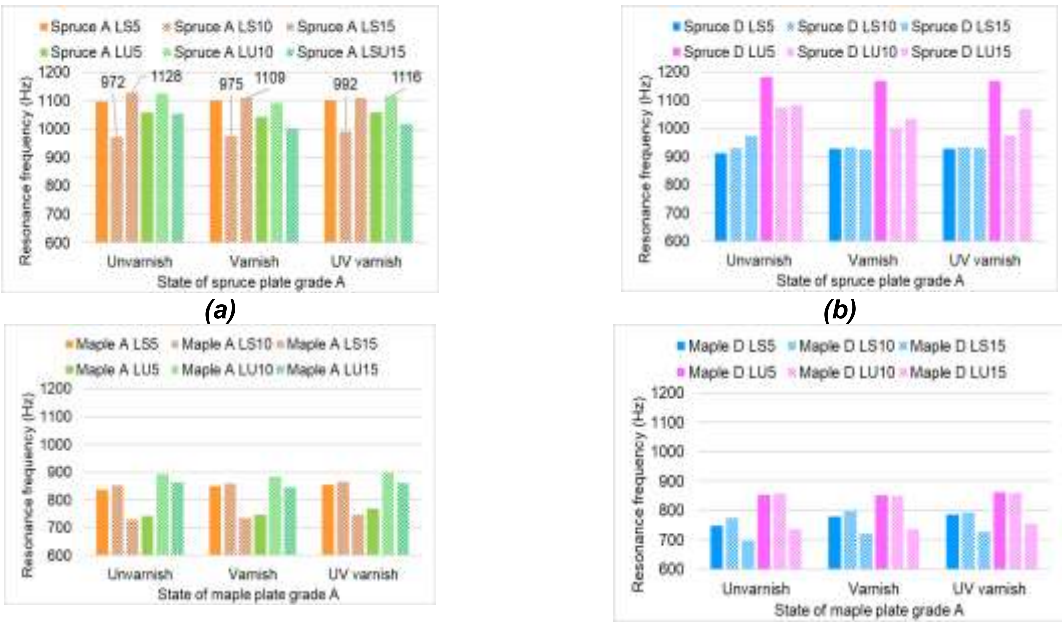


Fig. 6.
Example of frequency analysis in case of spruce LS5 sample.

In Fig. 7, comparatively analyzing the evolution of the dominant frequency of the samples in the three studied states (before, after finishing and after aging), it is observed that the value of the resonance frequency differs, depending on the number of varnish layers and the type of varnish, but from one state to another, the values of the resonance frequencies did not change significantly (below 3%). This behavior is manifested in both species - spruce and maple. Comparing the values of the resonance frequencies between the two wood species, it is observed that the maple wood samples generally present lower values of the dominant frequency (below 900 Hz), unlike spruce wood with frequencies ranging between 900 - 1200 Hz.



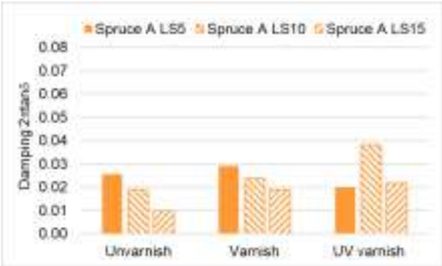
(a) ***(b)***

(c) ***(d)***

Fig. 7.
Variation of resonance frequency with sample state: a) spruce samples, grade A; (b) spruce samples grade D; (c) maple samples, grade A; (d) maple samples grade D (Stanciu et al. 2025b).

The type of varnish, the thickness of the film, the quality of the wooden support and the degree of aging mainly influence the evolution and values of the damping, as can be seen in Fig. 8. The values of the damping are higher for the class D spruce wood samples, varnished with spirit varnish, compared to those of class A. At higher film thicknesses (10 or 15 layers), the damping increases for wood with narrow annual rings (class

A) for both the samples varnished with spirit varnish and with oil-based varnish (Fig. 8a,c). For class D spruce wood (with a higher proportion of early wood), the damping decreases with exposure to aging. The range of values of the logarithmic decrement varies between 0.02 - 0.04 for the spruce samples.



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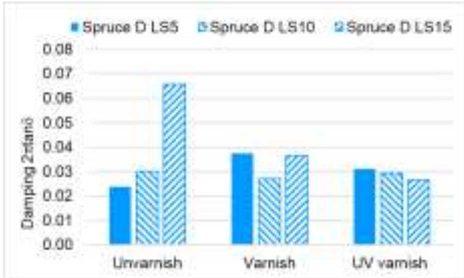

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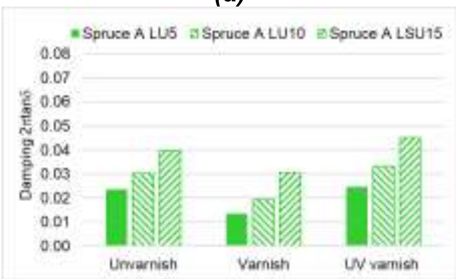

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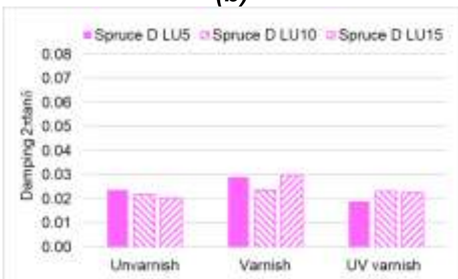
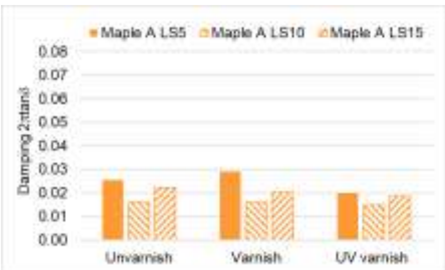


(d)

Fig. 8.

Variation of damping with sample state: a) spruce samples, grade A, spirit varnish; (b) spruce samples grade D, spirit varnish; (c) spruce samples, grade A, oil based varnish; (d) spruce samples grade D, oil based varnish.

In Fig. 9, the variations of the damping in relation to the states of the maple samples are presented. The behavior is more predictable and homogeneous in the case of maple samples with curly grain compared to the one with straight grain. And in the case of maple wood, the damping varies between 0.02 - 0.04, a variation with the degree of varnishing and aging being especially noticeable in the samples varnished with 5 layers.



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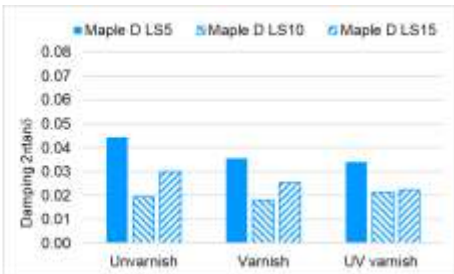

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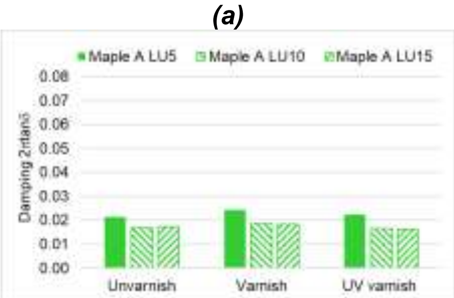

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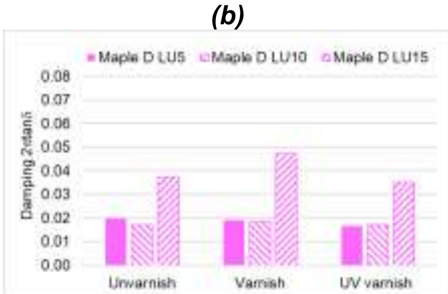

(d)

Fig. 9.

Variation of damping with sample state: a) maple samples, grade A, spirit varnish; (b) maple samples grade D, spirit varnish; (c) maple samples, grade A, oil based varnish; (d) maple samples grade D, oil based varnish.

CONCLUSIONS

The paper dealt with the influence of the type of varnish and the number of layers on a series of acoustic properties of resonant wood (spruce and maple, classes A and D), corroborated with the changes that occurred as a result of artificial aging. The application of more than 10 layers of varnish leads to sound damping in the case of oil varnishing and to sound sharpening when alcohol varnishing was applied to the soundboard. Therefore, the acoustic performance of soundboard can be adjusted by choosing the appropriate varnishing systems, depending on the appropriate number of layers applied to the wood surface and by applying a light accelerated aging treatment.

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