COMAT The 10th International Conference on ADVANCED COMPOSITE MATERIALS ENGINEERING

Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

22-23 October 2024

Viscous–elastic properties of varnished wood

Gall R. [1], Stanciu M.D. *[1], Savin A. [1,2]

1. Transilvania University of Brașov, Brașov, Romania, roxana.gall@student.unitbv.ro, mariana.stanciu@unitbv.ro
2. National Institute of Research and Development for Technical Physics, B-dul Dimitrie Man-geron, 47, Iași, Romania, asavin@phys-iasi.ro
*Corresponding author: mariana.stanciu@unitbv.ro

Abstract: *The varnish together with the wooden support forms a new layered mechanical system that has viscous-elastic properties different from the individual components. The work aims to investigate these properties through mechanical dynamical analysis, studying the influence of the wood species, the main direction, the type of varnish on the storage modulus, loss modulus and damping. The results showed that the wood species, the type of varnish (oil-based varnish and alcohol varnish), the thickness of the varnish film influence the viscous-elastic behavior at different stress frequencies.*

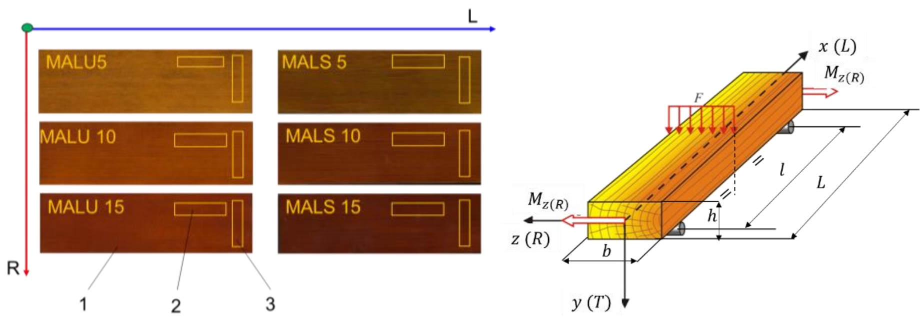
Keywords: *wood, viscous-elastic properties, varnish*

1. INTRODUCTION

Wood is a natural polymer made up of materials with a crystalline structure (cellulose), an amorphous structure (lignin) and a mixed structure (hemicelluloses and holocelluloses). As a result, the viscous-elastic behavior of wood over time can be modeled as a rheological model that takes into account elastic and plastic deformation, viscous-elastic creep, hygro-expansion deformation, Kelvin–Voigt element-wise mechano-sorptive strain tensor according to [1]. There are numerous approaches regarding the viscous-elastic behavior of wood from different species [3–5]. There are numerous approaches regarding the viscous-elastic behavior of wood from different species. An important problem in the acoustics of musical instruments is the system formed by wood and lacquer film, since, unlike unvarnished wood, the new system presents a different vibro-acoustic behavior because of the change in mechanical properties [6–8]. Determining the viscous-elastic parameters of varnished wood involves different measurement methods, among them, the dynamic mechanical analysis (DMA) which is a technique to analyze the mechanical response to the vibrational forces produced by the cyclically applied mechanical load. The dynamic properties of the wood are important because they characterize the material during the vibrations of the musical instruments, compared to the statically determined properties. The techniques for determining the dynamic modulus (MOED) and damping (tan δ) are based either on vibrational tests with non-contact force, or on damping methods (with impact), or with forced vibrations maintained with direct contact between the force and the wooden sample [8–13]. The purpose of the study was to characterize the dynamic behavior of the resonance wood through mechanical analysis in dynamic mode, determining the storage modulus, the loss modulus and damping for spruce wood samples varnished with oil-based varnish and spirit varnish.

2. MATERIALS AND METHOD

The varnished spruce wood samples were cut from a varnished plate (1), in longitudinal (2) and radial (3) direction of wood as can be seen in Figure 1a. The dimensions of samples for dynamical mechanical analysis (DMA) were: 50 mm (length) x 10 mm (width) x 5 mm (thickness). In Table 1 are presented the types of studied samples and coding. The experimental set-up of DMA consists in applying of an oscillating force at different frequencies (f=1Hz; 5Hz; 10Hz; 50Hz), at constant temperature at 30°C. The spruce wood samples were subjected to three points bending (Fig. 2b). The magnitude of bending load was 6 N. The equipment used is DMA 242C Netzsch equipment.



a) b)

Figure 1: Experimental set-up: a) The samples in longitudinal (2) and radial (3) direction of wood extracted from varnished spruce plate (1); b) the bending loading of sample

Table1. Physical features of varnished samples

Sample	Wood direction	No. of varnish layers	Code	No. of samples
Spruce with oil-based varnish	Longitudinal	5	MALU5L	4
		10	MALU10L	4
		15	MALU15L	4
Spruce with oil-based varnish	Radial	5	MALU5R	4
		10	MALU10R	4
		15	MALU15R	4
Spruce with spirit varnish	Longitudinal	5	MALS5L	4
		10	MALS10L	4
		15	MALS15L	4
Spruce spirit varnish	Radial	5	MALS5R	4
		10	MALS10R	4

	15	MALS15R	4

3. RESULTS AND DISCUSSION

Figures 2 and 3 illustrate the simultaneous evolution of the storage modulus, loss modulus and damping in the case of spruce samples cut longitudinally and radially, varnished with 5, 10, 15 layers, subjected to different loading frequencies. It is observed that the storage modulus tends to increase over time, and the loss modulus to decrease in accordance with loading frequencies.

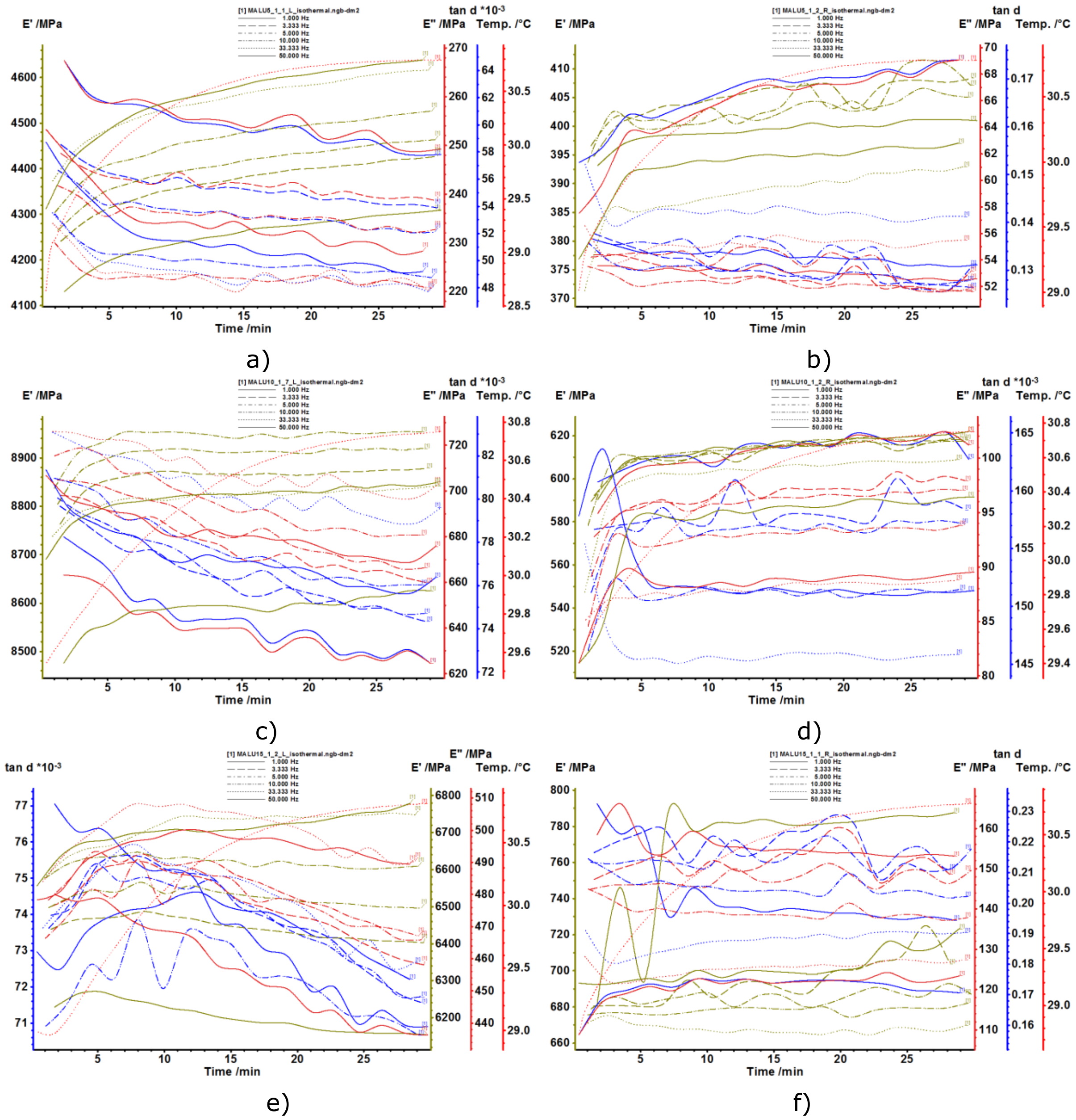


Figure 2: The variation of storage modulus, loss modulus and damping tand in case of spruce samples with oil-based varnish: a) longitudinal direction, 5 layers; b) radial direction, 5 layers; c) longitudinal direction, 10 layers; d) radial direction, 10 layers; e) longitudinal direction, 15 layers; f) radial direction, 15 layers.

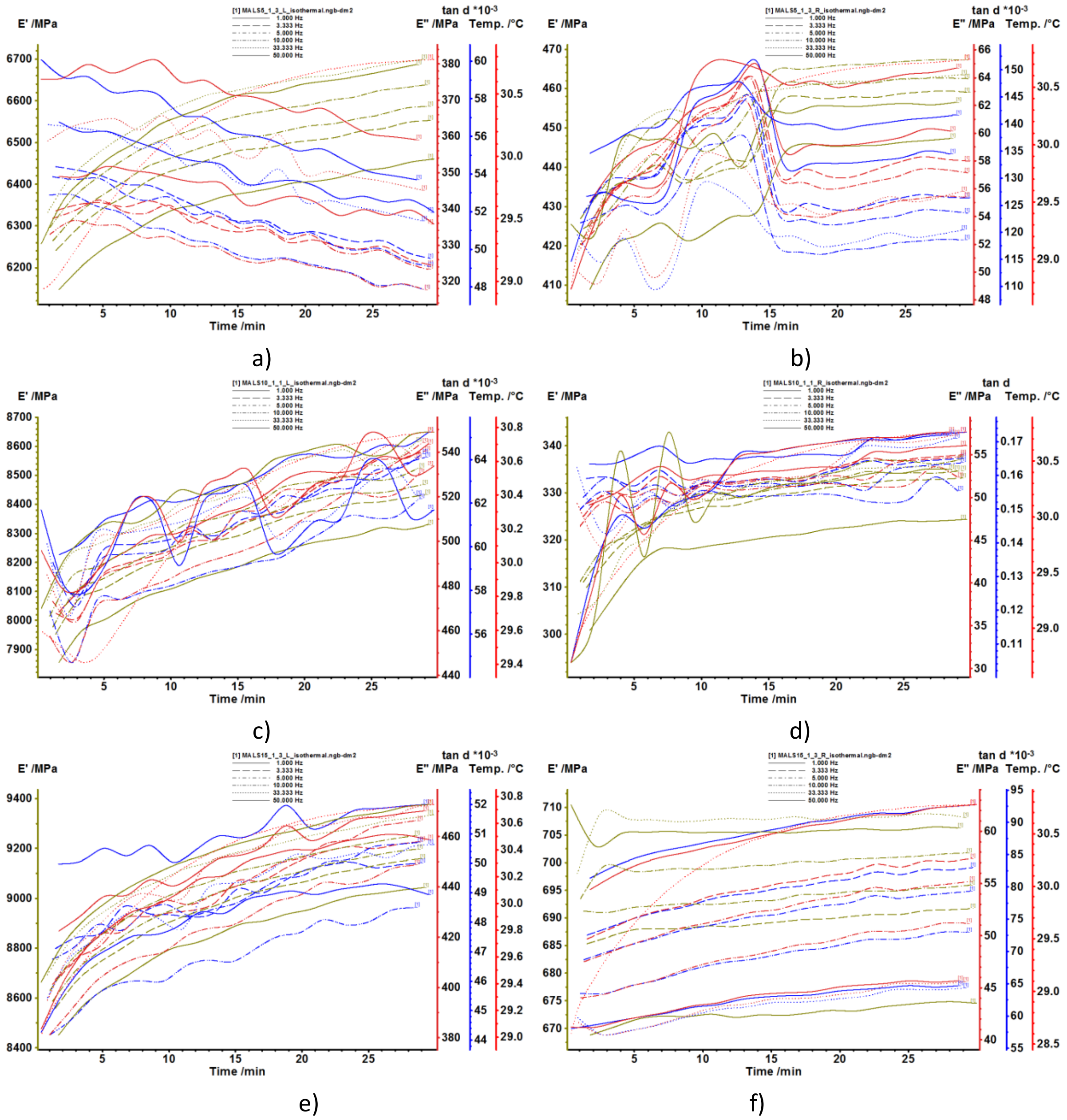


Figure 3: The variation of storage modulus, loss modulus and damping tand in case of spruce samples with spirit varnish: a) longitudinal direction, 5 layers; b) radial direction, 5 layers; c) longitudinal direction, 10 layers; d) radial direction, 10 layers; e) longitudinal direction, 15 layers; f) radial direction, 15 layers.

For the quantitative analysis of the changes in the viscous-elastic properties of the samples, the values of the storage modulus, loss modulus and damping were extracted at the initial moment (t_0) and at the final moment, after the 30 minutes of loading (t_{30}). Comparisons and trends of storage modulus with increasing loading frequencies are shown in Figure 4. It is observed that the behavior of the samples differs depending on the direction of the spruce wood fibers (longitudinal and radial), but also depending on the type of varnish applied. In the case of spruce wood varnished with oil-based varnish, the conservation modulus shows lower values compared to spirit varnish, but the differences from one application frequency to another are more pronounced (Figure 4a). Thus, the samples varnished with spirit varnish register the greatest changes (increases) of the storage modulus after exposure to different loading frequencies (approx. 6 - 7% for 5 layers, approx. 7 - 8.5% for 10 layers and between 8 - 9.5% for 15 layers) (Figure 4b). The samples with 5 layers, regardless of the type of varnish, have a similar behavior. Instead, the samples with 10 layers and 15 layers show peaks at the frequency of 3.33 Hz, in the case of samples with oil-based varnish and decreases in the case of samples with spirit, and at the frequency of 33.3 Hz, the behavior is reversed (Figure 4c,d).

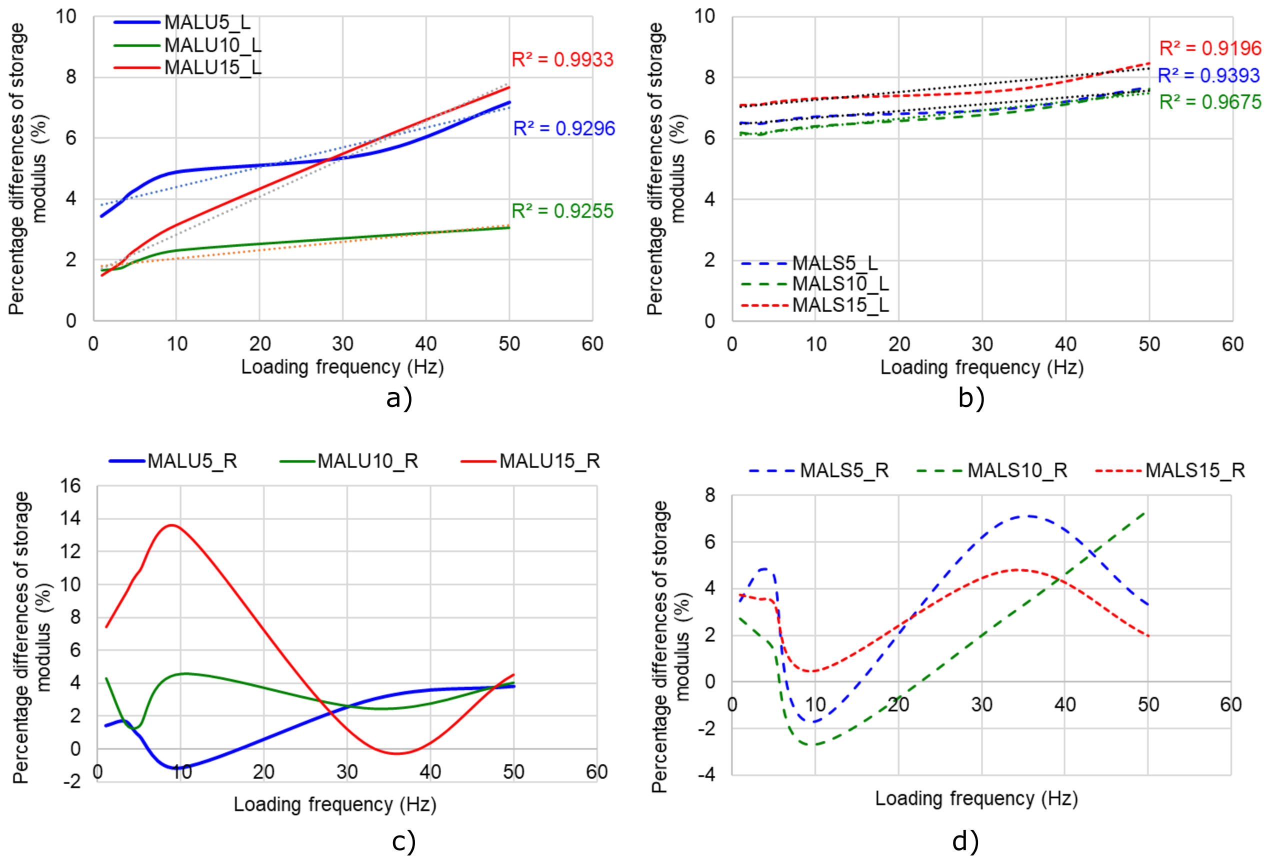


Figure 4: The variation of storage modulus, in case of spruce samples: a) oil-based varnish, longitudinal direction; b) spirit varnish, longitudinal direction; c) oil-based varnish, radial direction; d) spirit varnish, radial direction.

The loss modulus tends to decrease with increasing loading time in the longitudinal samples, varnished with oil-based varnish, registering the extreme values for 10 layers (Figure 5a). In the other samples, the tendency of the viscous modulus is to increase after exposure to dynamic loading (Figures 5b,c,d). In the radial direction, the type of varnish and the thickness of the varnish film determine the viscous behavior of the material. Thus, the loss modulus for the samples with oil-based varnish increases with the increase in the thickness of the varnish layer, while for the samples with spirit varnish, the loss modulus decreases with the increase in the thickness of the film (Figure 5, c and d). The ratio of the loss modulus to the storage modulus represents the logarithmic damping or decrement (tand). This is a sensitive indicator of mechanical or thermal conditions during the input of mechanical energy that is dissipated as heat through internal friction. During the vibrations of the violin plates, this energy dissipation occurs in the wood in the longitudinal and radial direction. In Figure 6, the variation of damping is presented.

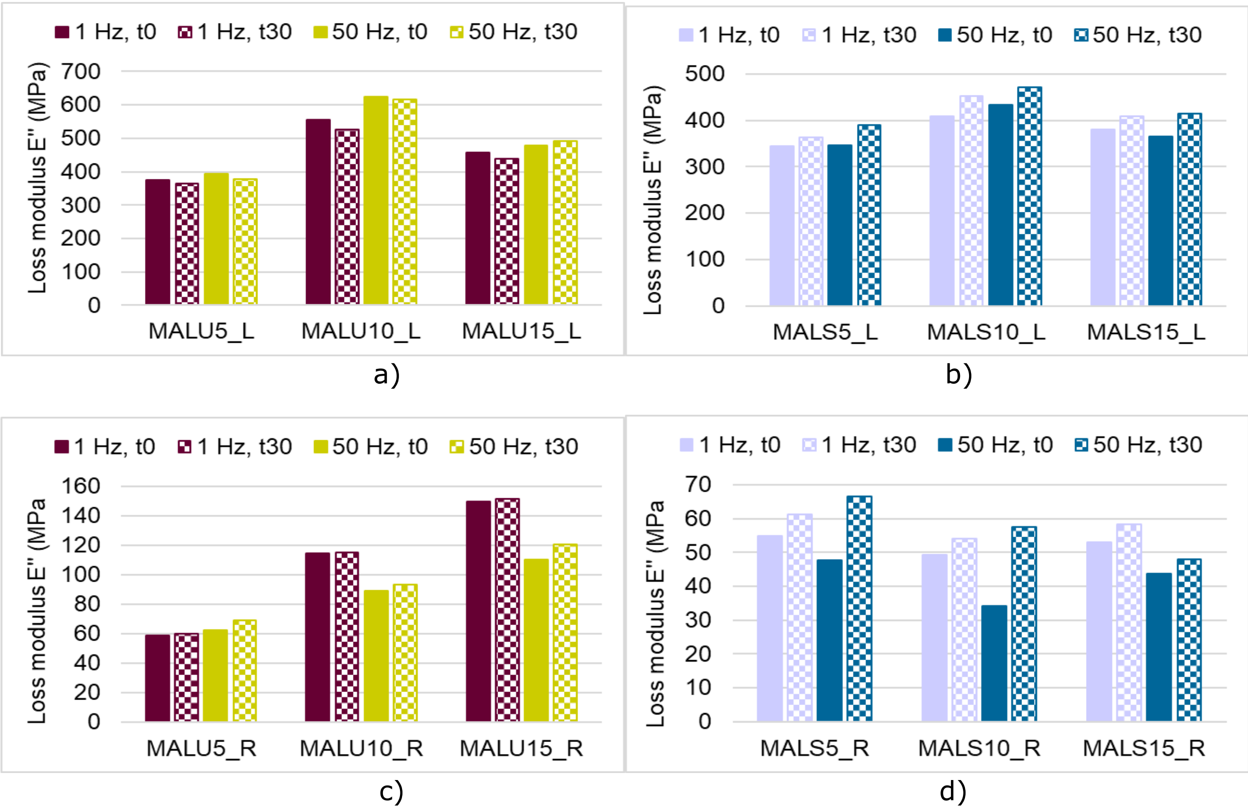


Figure 5: The variation of loss modulus, in case of spruce samples: a) oil-based varnish, longitudinal direction; b) spirit varnish, longitudinal direction; c) oil-based varnish, radial direction; d) spirit varnish, radial direction.

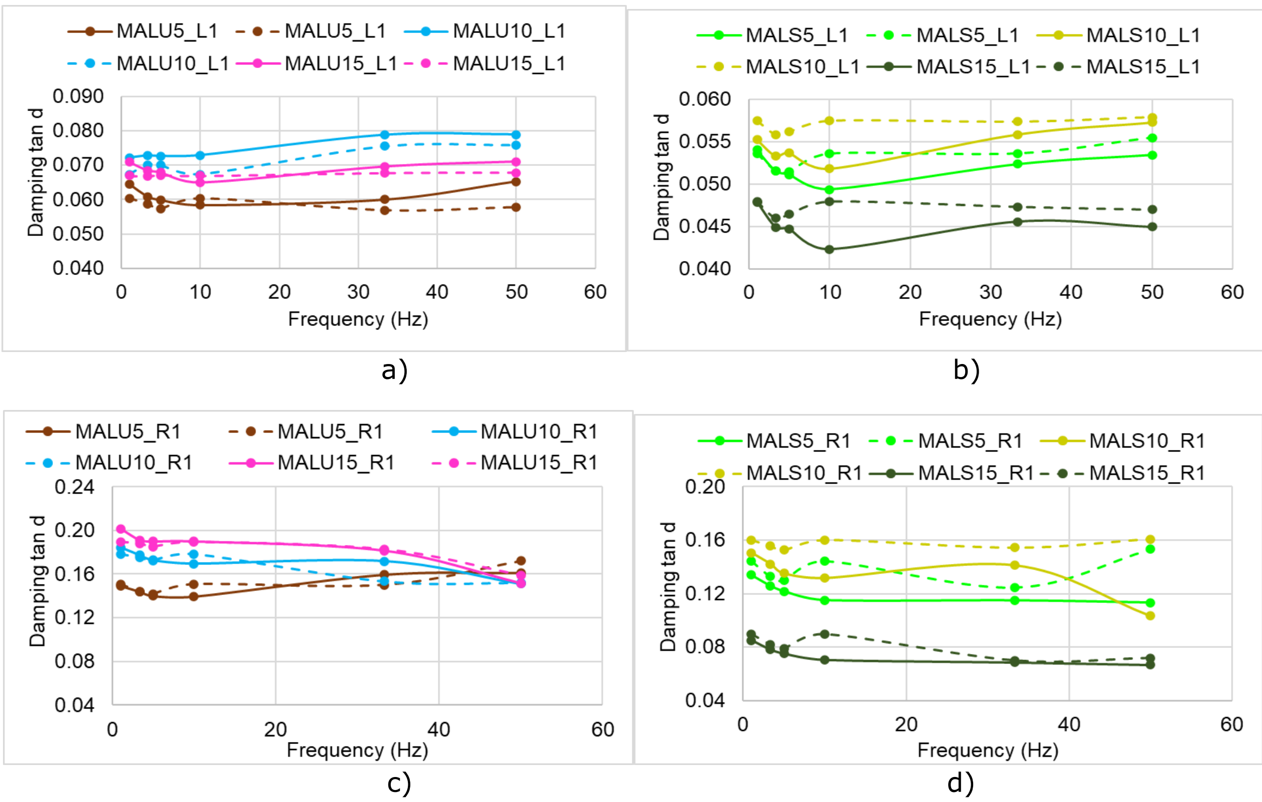


Figure 6: The variation of damping, in case of spruce samples: a) oil-based varnish, longitudinal direction; b) spirit varnish, longitudinal direction; c) oil-based varnish, radial direction; d) spirit varnish, radial direction.

4. CONCLUSIONS

In conclusion, the paper focused on the analysis of the viscous-elastic response of the resonance spruce wood varnished with different types and thicknesses of varnish, the results obtained being relevant to both musical instrument manufacturers, musical instrument varnish manufacturers, instrumentalists and researchers. Varnishes applied to the plates of musical instruments influence the acoustics of the instrument by changing the properties of the wood, for example mass, stiffness and damping as they are amorphous polymers with high molecular weight below their glass transition temperature. According to [14, 15], it can be observed that in the case of samples with oil-based varnish, the increase in internal friction precedes the increase in stiffness, being more pronounced in the radial direction than in the longitudinal direction. Samples with spirit varnish show a lower damping compared to the other type of varnish, but higher in the radial direction than in the longitudinal direction. A similar behavior for both types of varnishes is observed in relation to the number of layers. The highest damping occurs for samples with 10 layers of varnish.

ACKNOWLEDGEMENT

This research was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI – UEFISCDI, project number 61PCE/2022, PN-III-P4-PCE2021-0885, ACADIA – Qualitative, dynamic and acoustic analysis of anisotropic systems with modified interfaces.

BIBLIOGRAFIE

[1] Hassani, M.M., Wittel, F.K, Hering, S., Herrmann, H.J. Rheological model for wood, Computer Methods in Applied Mechanics and Engineering, 283, 1032-1060, 2015.

[2] Kawahara, K., Ando, K. & Taniguchi, Y. Time dependence of Poisson's effect in wood IV: influence of grain angle. J Wood Sci 61, 372–383, 2015. https://doi.org/10.1007/s10086-015-1477-8

[3] Hofer, U., Pichler, C., Maderebner, R. et al. Lomnitz-type viscoelastic behavior of clear spruce wood as identified by creep and relaxation experiments: influence of moisture content and elevated temperatures up to 80 °C. Wood Sci Technol 53, 765–783, 2019. https://doi.org/10.1007/s00226-019-01099-8

[4] Trcala, M., Suchomelová, P., Bošanský, M. et al. A constitutive model considering creep damage of wood. Mech Time-Depend Mater 28, 163–183, 2024. https://doi.org/10.1007/s11043-024-09679-3.

[5] Lämmlein S L, Van Damme B, Mannes D, Schwarze F, Willis M R, Burgert I Vi-olin varnish induced changes in the vibro-mechanical properties of spruce and maple wood. Holzforschung, 74(8), 765-776, 2020, https://doi.org/10.1515/hf-2019-0182

[6] Stanciu M D, Cosnita M, Gliga G V, Gurau L, Timar C M, Guiman M V, Năstac S M, Roșca I C, Bucur V, Dinulică F Tunable Acoustic Properties Using Different Coating Systems on Resonance Spruce Wood. Adv. Mat. Interfaces, 1, 2300781, 2024, https://doi.org/10.1002/admi.202300781.

[7] Gall, R. Stanciu, M.D., Savin, A., Campean, M., Gliga, V.Gh. The influence of the type of varnish on the viscous-elastic properties of maple wood used for musical instruments, 11th Hardwood Conference Proceedings, Sopron, Hungary, 30-31 May 2024, Eds.

Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder, University of Sopron Press, 426 – 434, 2024
[8] Bucur V. Acoustics of wood, 2nd ed.; Springer, Germany, Berlin, 2006.
[9] Danihelova A, Spisiak D, Reinprecht L, Gergel T, Vidholdov Z, Ondrejka V. Acoustic properties of Norway spruce wood modified with staining fungus (Sydowia polyspora). BioResources 14(2), 3432-3444, 2019. https://doi.org/10.15376/biores.14.2.3432-3444
[10] Brémaud, I. Acoustical properties of wood in string instruments soundboards and tuned idiophones: Biological and cultural diversity. J. Acoust. Soc. Am. 131(1), 807-818, 2012, DOI: 10.1121/1.3651233
[11] Nop, P., Cristini, V., Tippner, J., Zlámal, J., Vand, M.H., Šeda, V. Dynamic Properties of Wood Obtained by Frequency Resonance Technique and Dynamic Mechanical Analysis, Wood and Fiber Science, 55(2), 131-142, 2023.
[12] Obataya, E., Ono, T., Norimoto, M. Vibrational properties of wood along the grain. J. Mater. Sci. 35(12), 2993-3001, 2000. DOI: 10.1023/A:1004782827844
[13] Crețu, N., Roșca, I.C., Stanciu, M.D. et al. Evaluation of Wave Velocity in Or-thotropic Media Based on Intrinsic Transfer Matrix. Exp Mech 62, 1595–1602, 2022. https://doi.org/10.1007/s11340-022-00889-9.
[14] Schelleng J.C. Acoustical Effects of Violin Varnish. The Journal of the Acoustical So-ciety of America. 44(5), 1175 – 1183 (1968
[15] Minato K, Akiyama T, Yasuda R, Yano H. Dependence of vibrational properties of wood on varnishing during its drying process in violin manufacturing. Holzforschung 49(3), 222–226 (1995). https://doi.org/10.1515/hfsg.1995.49.3.222