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RHEOLOGICAL BEHAVIOUR OF CURLYMAPLE WOOD (*ACER PSEUDOPLATANUS*) USED FOR BACK SIDE OF VIOLIN

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Abstract
Stringed instruments are made of high quality wood species from physical, mechanical and acoustical point of view, being carefully selected, kiln dried and processed under specific conditions that assure micro-structural integrity. Maple wood (Acer Pseudoplatanus) for musical instruments is used to getting back plates and sides for string instruments (violin family). This species of wood is valued for both acoustic qualities but mostly for aesthetic, using a natural defect of maple wood characterized by wavy grain. The paper presents the research on visco-elasticity behavior of maple wood with different types of grain deviation in wood from very curly maple to common maple. The storage modulus, loss modulus, damping capacity in varying temperature conditions and for different loading frequencies were determined using dynamical mechanical analysis (DMA). It was found that specimens characterized by very wavy grain shows a high damping capacity of frequency range between 33.33 to 50Hz, unlike specimens of common maple which do not have the capacity of frequency selectivity.

Key words: *viscoelasticity; curly maple; dynamical mechanical analysis; damping.*

INTRODUCTION

Wood is one of the most popular materials both in terms of sound quality (resonance spruce, maple, sitka, cedar) and the aesthetically (mahogany, ebony, rosewood, maple appreciated for curly texture, pattern and color), the viability and resistance to wear (acacia, ebony, walnut) (Stanciu 2012). The resonant wood means wood material with physical and acoustic properties proper for musical instrument construction. From category of resonant wood species belong both softwood (spruce resonance, pine) and hardwood used in the structure of musical instruments. Since the mechanical and acoustic properties are closely related to macro and microstructure of wood, wood resonance is recognizable by certain features visually identified. Maple known as sycamore (Acer Pseudoplatanus, Acer Saccharinum - Bird Eye, Acer Platanoides) is spread all over the mountain and piedmont of Carpathian area. Uniform structure of maple wood with acoustic and aesthetic qualities and outstanding fit for manufacturing musical instruments comes from the Maramures and Gurghiu Mountains area. Most times it is acceptable and even preferred wavy grain (called "curly wood") or the effects of structure called "bird's eye" (Fig. 1). In terms of sound, maple produce and radiate sound with balanced tone, is considered by musicologists from mahogany (Swietenia macrophylla) tones characterized by mild, warm and zircote (*Cordia dodecandra*) - sounds hard, rough. In economic terms, the price of sycamore logs official of timber auctions in Europe is somewhere around € 640/m^3. The logs with diameters between 40 and 75*cm*, as rare species of curly maple, get prices ranging between 110 and € 3055/m^3.

Knowledge of the rheological behavior of wood for musical instruments is important for life prediction of wooden structures, the strains and their stability over time. The study aims to identify physical, mechanical and dynamic properties of wavy maple compared to maple wood with right fibers. This study is useful for manufacturers of musical instruments because they can obtain a proof of acoustic and elastic qualities of maple wood with varying degrees of the crimping fibers, the wavy fiber being used with acoustic value, not just aesthetic. In previous work, it was presented the complex modulus and damping which expressed the rheological behavior of two wood species (alder and beech) (Stanciu 2013).

a) **b)**

Fig. 1.
Aesthetic effects conferred by structural defects of maple wood: a) curly maple; b) maple - bird's eye

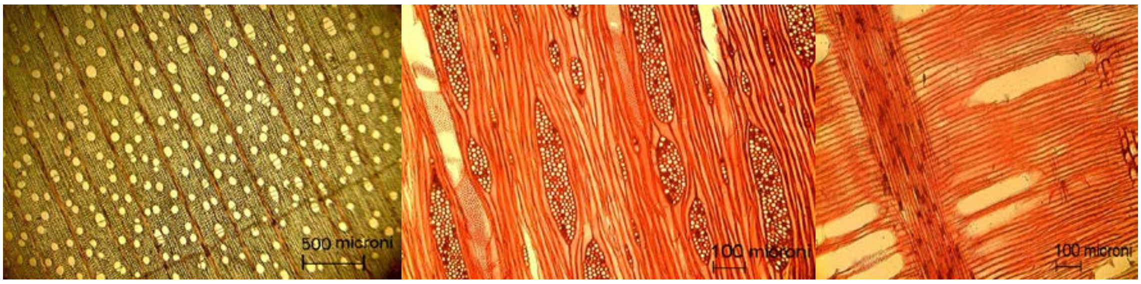
OBJECTIVE

The paper aims to analyze comparative rheological properties of maple wood in radial direction, with varying degrees of curl of the fiber. The method is based on the experimental investigation of the dynamic mechanical analysis, under isothermal conditions, different frequencies of the cyclic bending stress of maple wood specimens as well as linear increase of temperature conditions. This study is based on the idea that wood from the musical instruments structure is cyclic stressed with sinusoidal load with different frequencies resulting from musical playing.

MATERIAL

Macro and micro-structural aspects of wood maple (Acer Pseudoplatanus)

Maple wood is a species with complex structure, distinct annual rings with regular shape without marked difference between early wood and late wood. Presents diffuse porous, small, non-visible to the naked eye, relatively rare, homogeneous radial rows or partially filled with shiny tyloses. Medullary rays are of two sizes: wide, relatively rare, non-obvious and narrow medullary rays, visible with a magnifying glass (Fig. 2). On radial section, they form numerous and very shiny mirrors (Timar 2009). Curled maple wood fiber is an abnormality of structure which does not affect the mechanical properties of wood and is appreciated for its aesthetic value. There are two assumptions about curly fiber formation: a hypothesis supporting the hereditary nature of this type of maple, and another hypothesis is based on the mechanical aspect of the days of the tree, when the fibers of the stem shaft undergoes a phenomenon of mechanical instability (buckling) giving rise wavy fiber structure due to the weight of the crown. In section radial and tangential particular, the aspect of wood gives the impression of a three-dimensional drawing.



a) b) c)

Fig. 2.
Microstructural view: a) transversal section; b) radial section; c) tangential section

Types of studied samples

Dynamic mechanical analysis (DMA) was performed on prismatic specimens sawing in radial longitudinal direction (Fig. 3,a), with varying degrees of grain deviation, with dimensions of L*b*h (L – lentgh; b – width; h – thickness) and moisture content range between 6-8% (Table 1). The samples were taken from timber (from S.C. Hora S.A. Musical Instruments Factory) which was air drying during of 5 to 10 years, until its moisture content reaches the equilibrium moisture content of 12-14% corresponding to surrounding atmosphere (Cismaru 2003). Before mechanical wood processing, the timber was conditioned to 6-8% moisture content because musical instrument construction requires these moisture content in wood. In Table 1 are presented physical features of studied samples. Five types of maple samples regarding grain deviation were studied: samples with very curly and dense grain, samples with very curly grain, but rare, samples with slightly wavy and dense grain, samples with slightly wavy and rare grain, sample with straight grain.

Table 1

Physical characteristics of maple samples at 6-8% moisture content of wood

Nr. Crt.	Type of grain devation	Sample code	Variable parameter of tests	Dimensions			Mass m *g*	Density (U= 6-8%) *ρ g/cm³*
				L *mm*	b *mm*	h *mm*		
1	Samples with very curly and dense grain	1.1.	Frequency	10,62	50	4,58	1,49	0,613
		1.2.	Frequency	10,58	50	4,57	1,40	0,579
		1.3.	Temperature	10,61	50	4,57	1,39	0,573
		1.4.	Temperature	10,61	50	4,58	1,49	0,613
2.	Samples with very curly and rare grain	2.1.	Frequency	10,63	50	4,68	1,77	0,712
		2.2.	Frequency	10,62	50	4,58	1,74	0,715
		2.3.	Temperature	10,61	50	4,68	1,71	0,689
		2.4.	Temperature	10,65	50	4,58	1,72	0,705
3.	Samples with slightly wavy and dense grain	3.1.	Frequency	10,56	50	4,62	1,35	0,553
		3.2.	Frequency	10,63	50	4,73	1,37	0,545
		3.3.	Temperature	10,63	50	4,64	1,36	0,551
		3.4.	Temperature	10,53	50	4,71	1,37	0,552
4.	Samples with slightly wavy and rare grain	4.1.	Frequency	10,61	50	4,55	1,38	0,572
		4.2.	Frequency	10,61	50	4,43	1,32	0,562
		4.3.	Temperature	10,61	50	4,53	1,33	0,553
		4.4.	Temperature	10,56	50	4,58	1,37	0,567
5.	Sample with straight grain	4.1.	Frequency	10,58	50	4,52	1,35	0,565
		4.2.	Frequency	10,58	50	4,48	1,33	0,561
		4.3.	Temperature	10,60	50	4,53	1,38	0,575
		4.4.	Temperature	10,58	50	4,58	1,37	0,565

Experimental Method

The samples were subjected to a load of 6 *N* with a periodical variation, applied midway between the supports (distance between the supports is 40*mm*) (Fig. 3,b). The loads and the reaction forces produce three-point bending. During the sinusoidal load, the sample is deformed by a sinusoidal function (Menatd 2008). The applied stress σ is given by:

$$\sigma = \sigma_0 \sin \omega t \ , \quad (1)$$

where: σ is stress at time *t;* σ_0 – maximum stress; $\omega = 2\pi\vartheta$ - pulsation, ϑ frequency, *Hz*.

The resulting deflection depends on viscoelastic properties of the specimen tested. Since the wood contains cellulose, hemicellulose and lignin, it may be considered as a polymer or specifically a polysaccharide consisting of more than 3000 molecules of glucose (C6H12O6). Because of this, the wood has a viscoelastic behavior occuring the out of phase between the applied stress σ and the strain ε, denoted by *δ*. The strain ε at time *t* is given by:

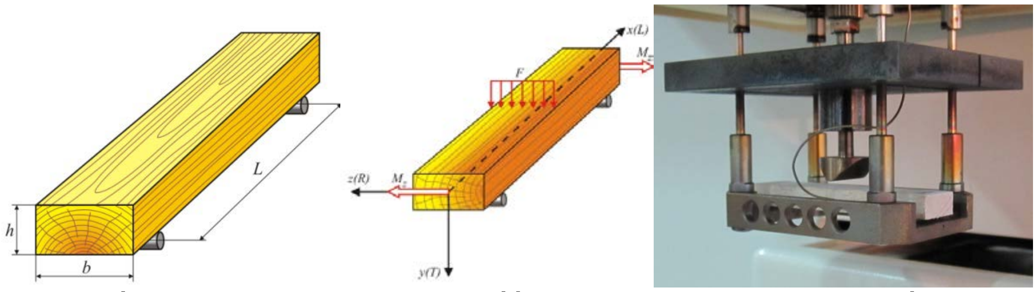
$$\varepsilon(t) = \varepsilon_0 \sin(\omega t + \delta). \quad (2)$$

Wood deformation consists of deformations ε' in phase and strains in lag phase, ε'' , the two components being given by the relationship:

$$\varepsilon' = \varepsilon_0 sin\delta\ ; \quad (3.a)$$

$$\varepsilon'' = \varepsilon_0 cos\delta\ . \quad (3.b)$$

Similarly, express complex module consists of two components - the storage modulus denoted E' (elastic feature of the wood) and loss modulus (E") (viscous characteristic representing internal friction from material). Principle of method is based on applying a certain force with intensity of 6N by means of force generator which produce a sine wave through force head. The sample strain is measured with electronic sensor (Variable Differential Transformer LVDT -Linear) (Fig. 3,c) (Stanciu 2013).



a) b) c)

Fig. 3.

a) Geometry of samples; b) schematic representation of load; c) testing device

The research aimed to determine the variation of storage modulus, E', and loss modulus, E", depending on the frequency of applied load and temperature. It was also determined the degree of wood damping tanδ expressed by the ratio of E"/ E'. Thus, for each category of samples (1, 2, 3, 4) were tested two samples at frequency variation of force (1; 3.3; 5; 10; 33,33 and 50*Hz*) for 30 minutes and two other were subjected to periodical force in variable temperature range between 30 to 120°C, for 45 minutes. Kaboorani A, Blanchet P (2014) carried out similarly tests on specimens of common wood maple, to determine liniar viscolelastic region in the three main directions of wood.

RESULTS AND DISCUSSION

The maple wood specimens with very wavy grain (1 and 2) shows a higher density (range between 0,6 to 0,7g/cm^3) than other types of specimens which recorded a density range between 0,55 to 0,566g/cm^3. Visco-elastic behavior of maple wood with different degree of wavy grain was analyzed through two type of test: variation of stress frequency and variation of temperature for a constant stress and frequency. The behavior of maple samples at different frequencies varies depending on the degree of curly fiber and their density (Backmann 2001). The specimens with straight grain (samples 5.1. and 5.2) show a specific viscoelastic behavior of wood: storage modulus increases trend with frequency and with time (Fig. 4). Also it is found that at the frequency of 33.3*Hz* and 50*Hz*, wood shows periodic variations in the value of storage modulus. This response is observed for specimens of very wavy wood grain too whose variation curve shows peaks for frequencies of 3.3*Hz*; 5*Hz*; 33.3*Hz* and 50*Hz* (Fig. 4 and 5, a and b).

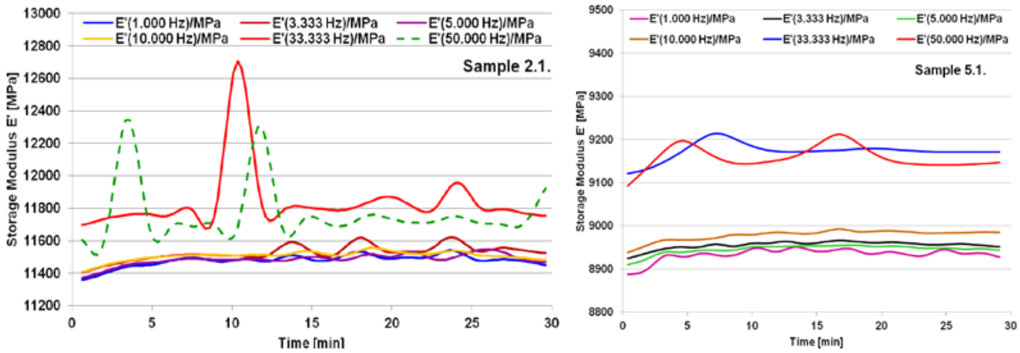
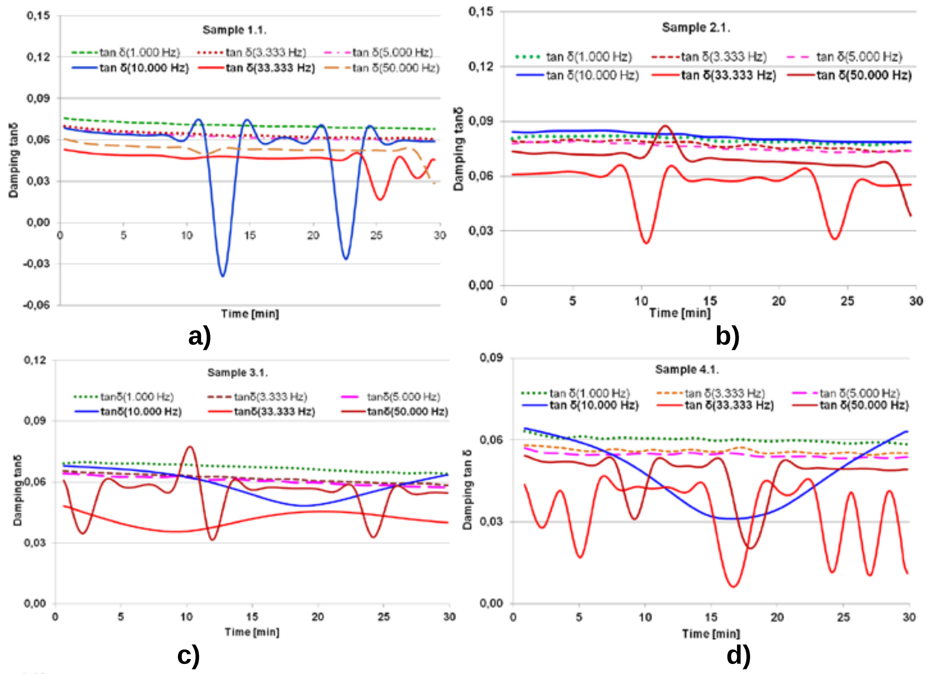


Fig. 4.
Storage modulus E' versus frequency f in isothermal condition

These variations are due to inhomogeneous structure and wavy grain that provide elastic behavior of wood. The capacity of wood to store the strain energy at a certain frequencies give not only the aesthetic quality of curly maple wood but also the ability to recover the strain in rheological domain which in musical instruments is necessary to receive and quickly transmit the sound waves (Ranta 1993; Horvath 2011). Fig. 5 exhibits the damping *tanδ* as function of frequencies for a constant temperature (T=30˚*C*) for each type of studied sample. The homogeneous behavior regardless of the stress frequency is recording by maple wood with normal fiber (Fig. 5,e). In other cases, the defect structure - curled fiber - visible through variation of damping curves whose trend differs from one frequency to another and from one type of specimen to another (Fig. 5,a,b,c,d). It is found that at frequencies above 5*Hz*, the visco-elastic response of wood with varying degrees of curl fiber is different but it can be seen that in case of sample 1.1 there is a periodically decreases of damping recorded for 10*Hz* (Fig. 5,a).



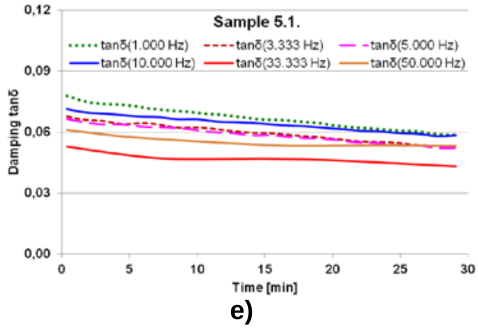


Fig. 5.
Evolution of damping tanδ versus frequency: a) samples with very curly and dense grain; b)samples with very curly and rare grain; c) samples with slightly wavy and dense grain; d)samples with slightly wavy and rare grain; e) sample with straight grain

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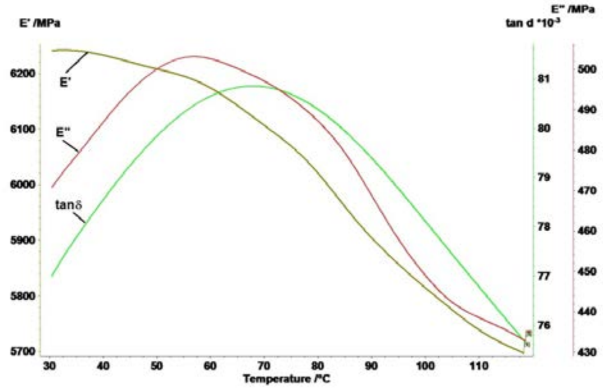
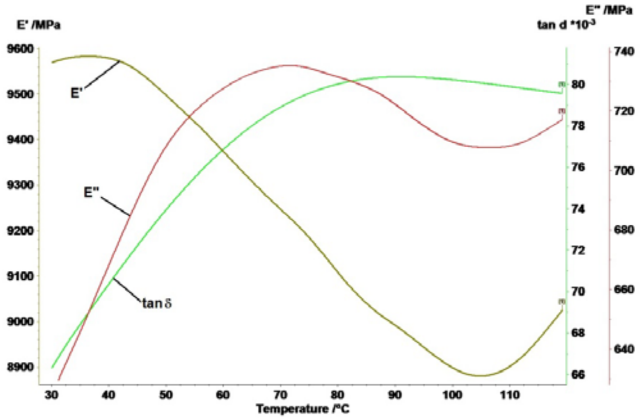
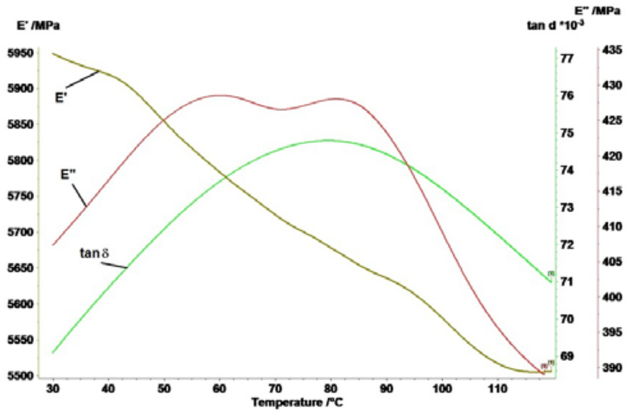
Rheological behavior of maple wood was analyzed under conditions of varying temperature from 30-120˚C. Jiang J, Lu J (2009) evaluate the impact of temperature on the linear viscoelastic region of wood and they found that critical strain generally decreased with increasing temperature except at –80, –20, 40, 120, and 220°C when occurrence of relaxation processes. It is known that inhomogeneous structure of maple wood with very wavy fiber, is characterized by a higher content of lignin than species with normal fiber where the lignin is 25,3% (Timar 2003). The higher content of lignin which is a complex aromatic polymer influences the transition temperature denoted Tg, which varying from 75 to 100°C. The transition temperature of lignin is around 75 to 100°C (Pilate et al. 2004; Irvine 1985). Comparing the wood with dense fiber to the rare fiber is observed that the transition temperature Tg is more higher in case of wood with lower content of lignin reaching around 85 - 90˚C compared with dense grain that reaches the transition temperature around 70-80˚C (Fig. 6).



a) Sample 1.3. – *curly maple with dense grain*



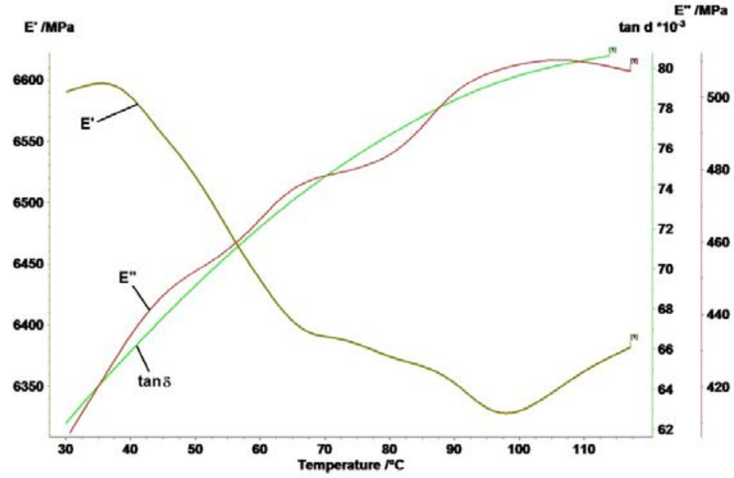
b) Sample 2.4. – *curly maple with rare grain*



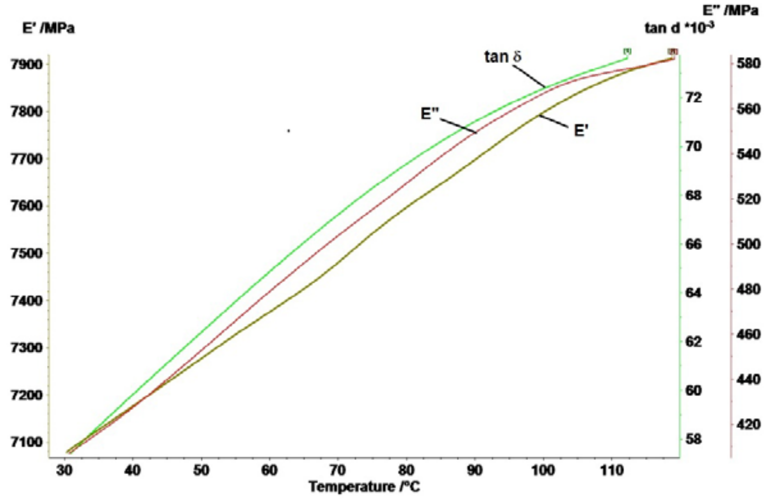
c) Sample 3.3. – *slightly wavy and dense grain*

Fig. 6.

Visco-elastic behaviour of maple wood with different types of grain against temperature



d) Sample 4.3. – *slightly wavy and rare grain*



e) Sample 5.4. – *straight grain*

Fig. 6. (Continuation)

Visco-elastic behaviour of maple wood with different types of grain against temperature

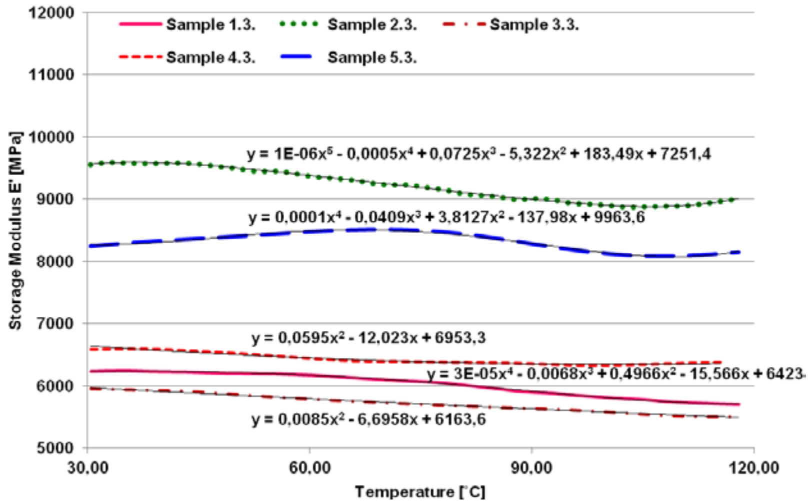


Fig. 7.

Variation of storage modulus E' depending on temperature and type of specimen, at frequency of 1 Hz

CONCLUSIONS

The results demonstrated that the wooden structure even within the same species plays an important role in its viscoelastic behavior. The maple wood with wavy grain has not only created an aesthetically aspect appreciated by specialists, but has a viscoelastic behavior different from common wood, with high elastic properties (Fig. 7). This is exploited in the stringed instruments using maple plates in the acoustic body of violin which plays Helmholtz resonator. Due to the high elasticity, maple wood with curly and dense fibers created quickly reacts to mechanical vibration of string, entering into resonance with them.

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