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Physical-acoustical characteristics of maple wood with wavy structure

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Abstract: This paper presents an assessment of the physical-acoustic characteristics of maple wood having wavy structure. Our experimental results have revealed that the maple wood with wavy structure/grain, compared to the standard maple wood, exhibited, apart from an attractive texture, also more favourable physical and acoustic properties. As such, the wavy maple wood is more suitable for back plates in violin making. We also studied how these characteristics were affected by density. The experimental results provided material for analysis of the influence of this parameter on modulus of elasticity; propagation of sound waves; and on acoustic constant. The analysis has identified differences between the maple wood with wavy structure and the standard wood.

Keywords: maple, wavy structure, physical-acoustical properties, density

INTRODUCTION

Making violins of high quality requires meeting appropriately the following three basic tasks – choice of material, strategy of design, choice and application of varnish.

The material for violin construction should primarily consider the part of the instrument. For top plates, spruce has been found as the most suitable. The quality of this wood has been discussed in KÚDELA and KUNŠTÁR (2011). Spruce wood whose parameters fulfil requirements for the construction of sounding boards is considered as resonance wood.

Back plates, ribs and necks are generally constructed of maple wood – meeting parameters just opposite to spruce wood. Violin manufacturers ask, for this purpose, for maple wood with wavy grain (wavy gloss effect) – so called w-maple. The presence of wavy grain in maple wood is high appreciated. It is not clear whether this maple species is required thanks of its specific wood texture or the w-maple wood exhibits better features that the wood of the sycamore maple without wavy structure – control maple (c-maple).

The quality of wood for violin making is assessed through its physical-acoustic properties. The most frequently measured parameters are: sound propagation in wood, acoustic constant, acoustic impedance, and damping decrement. All these characteristics are dependent on the modulus of elasticity along grain and on wood density.

The speed of sound in wood is determined according to the equation

$$c = \sqrt{\frac{E}{\rho}} \quad . \tag{1}$$

The equation shows that sound speed in wood increases with increasing modulus of elasticity and with decreasing wood density. The highest rate of sound propagation is along grain, followed by significantly lower speed in radial and the lowest in tangential direction.

For lower-quality maple wood, RAJČAN (1998) reports an average speed of 4 800 $\mathrm{m \cdot s^{-1}}$. The lower speed, the more suitable is the maple wood for manufacturing violin back plates.

Another indicator for wood quality from the viewpoint of musical instruments making is *acoustic constant*, called also sound emission constant A defined by the equation.

$$A = \frac{c}{\rho} = \sqrt{\frac{E}{\rho^3}} \quad . \tag{2}$$

High-quality maple wood requires acoustic constant as low as possible, as violin back plates primarily serve for the reflection of sound waves driven by top plates. RAJČAN (1998) reports average values for acoustic constant 6.71 $\mathrm{m^4 \cdot kg^{-1} \cdot s^{-1}}$ and 7.94 $\mathrm{m^4 \cdot kg^{-1} \cdot s^{-1}}$ for high-quality maple wood and lower-quality maple wood. According to POŽGAJ *et al.* (1997), the acoustic constant for common maple (*Acer campestre*) wood is 5.8 $\mathrm{m^4 \cdot kg^{-1} \cdot s^{-1}}$.

Acoustic impedance, expressing resistance against plane sound waves is determined by equation

$$Z = \rho \cdot c = \rho \sqrt{\frac{E}{\rho}} \quad . \tag{3}$$

Logarithmic damping decrement ϑ is measured experimentally, based on properties of forced oscillations (RAJČAN 1998). For maple wood, the author reports an average ϑ value of 0.029.

Equations 1–3 show that the discussed acoustic characteristics depend on the modulus of elasticity E and the density ρ_w of wood. The values of the modulus of elasticity are influenced by a range of factors (wood moisture content, density, structure). FABISIAK and MOLIŃSKI (2007), MOLIŃSKI and KRAUSS (2008) and several other authors suggest that the modulus of wood elasticity increases proportionally with increasing density. In most cases, this relation has been reported linear. With increasing moisture content within bound water range, the modulus of elasticity decreases. Significant effect on the modulus of elasticity results also from the method used. In general, it holds that the values of dynamic modulus of elasticity are higher than the values of static modulus of elasticity (ROHANOVÁ 2010). It has also been revealed that different dynamic methods for determining modulus of elasticity resulted in obtaining different values (ROHANOVÁ 2010). There is evidence that comparisons among modulus of elasticity require using the same method.

All discussed physical-acoustic parameters of wood, together with the modulus of elasticity, are also determined by the wood structure at all levels – macroscopic, microscopic and sub-microscopic. Quantitative and qualitative presence of particular cell types has a significant effect on wood density. That is why the influence of wood structure on its physical-acoustic properties is usually expressed through its density. The role of fibre waviness in maple wood has not been found unequivocal. PILAŘ and ŠRÁMEK (1986) declare that the density is not always higher in presence of wavy grain. BUCUR (1995) and VINTONIV (1981) also obtained lower density values for w-maple. HOLZ (1974) observed significantly higher density values in w-maple. RAJČAN (1998) reports maple wood density increasing with increasing wood quality.

For calculations of acoustic characteristics, we use wood density at a given moisture content ρ_w. Wood density and modulus of elasticity significantly vary with moisture content, It follows that these two values need to be related to the same moisture content.

The objective of this work was to carry out experiments for measuring selected physical-acoustic properties of w-maple wood and comparing them with the properties of c-maple.

METHODS

The research material was taken from two sample trees from a locality (Lieskovec, C Slovakia, 800–1000 m a.s.l.) with occurrence of sycamore maple (*Acer pseudoplatanus* L.) with wavy grain. From the bottom parts of stems, there were cut two logs, by one from each stem, having a length of 2m (Fig. 1a). The logs were cut to prisms (Fig. 1b) assorted into zones A, B, C, D (Fig. 1c). The wood's acoustic properties were tested on specimens with transverse dimensions of 12 × 12 mm, and a length of 800 mm, obtained from the zones A and C. An analogous set of specimens was prepared from maple wood without wavy structure. The specimens for testing the chosen properties were preliminary conditioned at a relative air humidity $\varphi = 65$ % and a temperature of 20 °C.

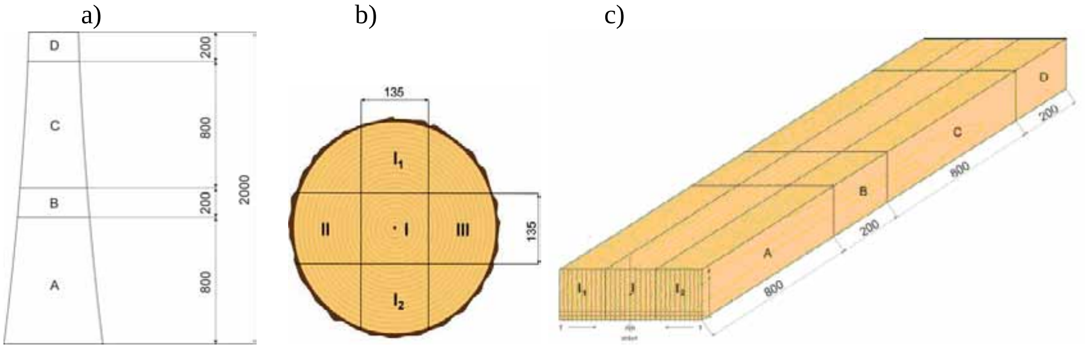

Fig. 1 Cutting layout for preparing test specimens

Physical-acoustic characteristics were assessed with the aid of our own measuring equipment RESONATOR – designed at the Department of Physics, Electronics and Applied Mechanics of the Technical University in Zvolen (Fig. 2). The underlying principle is described in KUBOVSKÝ (2007). The equipment served for measuring resonance frequency f_r (frequency corresponding to the maximum oscillation angle recorded by the recorder) and frequencies f_1 and f_2 (corresponding to 50% maximum oscillation angles right and left from f_r). In the following, we used Equations (1 and 2) for obtaining the speed of propagation of longitudinal wave c, and acoustic constant A. The modulus of elasticity E was calculated according to the equation

$$E = 4 \cdot l^2 \cdot f_r^{\,2} \cdot \rho_w , \tag{4}$$

where l is the specimen's lengths and f_r is resonance frequency corresponding to $k = 0$. Wood density corresponding to given moisture content was obtained from the rate of the test specimen's mass and volume (STN 490108). Moisture content was measured gravimetrically, following the Standard STN 490103.

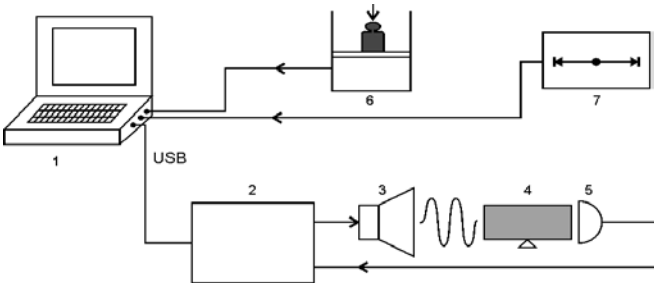

Fig. 2 Computer-controlled equipment RESONATOR with DDS: computer, 2 – electronic modulus, 3 – acoustic modulator 4 – test specimen, 5 – scanner, 6 – digital scale, 7 – digital appliance for measuring specimen dimensions (KUBOVSKÝ 2007).

RESULTS AND DISCUSSION

The results are summarised in Table 1. All the values relate to a moisture content of 11.3 % – the moisture content of the test specimens after conditioning.

Wood density for w-maple wood ranged from 600 to 685 kg·m^{-3}, meaning significantly higher values than for c-maple. These values meet the criteria set by RAJČAN (1998) for high-quality wood in violin making. The density values of c-maple were within 520–630. As such, they did not reach the values required for violin back plates. Our average density values for c-maple are in accord with the results reported by RAJČAN (1998) and KURJATKO *et al.* (2010).

Wood density primarily depends on the morphology and number of fibres. The morphology of fibrous cells in maple wood shows a number of atypical features. Maple fibres are thin-walled. With more than 70 % of diameter owing to lumen, maple wood should be classified as a wood with low density. Nevertheless, fairly high density of maple wood is the result of a high presence of wood fibres and a low portion of vessels (ČUNDERLÍK 2010). This holds especially for w-maple.

Table 1 Basic statistical parameters for the studied haracteristics of maple wood

Characteristics	**Statistical parameters**	**w-maple**	**c-maple**
Density ρ_w $[kg{\cdot}m^{-3}]$	$\bar{x}$	641	582
	s	27	34
	n	30	30
Modulus of elasticity E [GPa]	$\bar{x}$	12.10	12.40
	s	1.23	1.38
	n	30	30
Speed of sound propagation c $[m{\cdot}s^{-1}]$	$\bar{x}$	4337	4613
	s	170	256
	n	30	30
Acoustic constant A $[m^4{\cdot}kg^{-1}{\cdot}s^{-1}]$	$\bar{x}$	6.77	7.97
	s	0.31	0.72
	n	30	30

The differences in the modulus of elasticity between the two maple wood types tested were not found significant. As the modulus of elasticity increases with increasing density, we expected that this parameter should be higher in w-maple tan in o-maple. The trend, however, was revealed just opposite. Such results support that not all variance in wood structure which affects the modulus of elasticity, necessarily reflects also in wood density. If the modulus of elasticity depended on density exclusively, the two relations would copy each other. For w-maple, a linear dependence of the modulus of elasticity on wood density has been confirmed; on the other hand, the correlation between these two parameters was observed relatively low (Fig. 3). Our results, apart from density, point to several other factors whose effects are at least such strong (50 %) as the effect of density. In case of c-maple, dependence of the modulus of elasticity on density has not been proven. So, well-reasoned is the identification of additional factors affecting the modulus of elasticity.

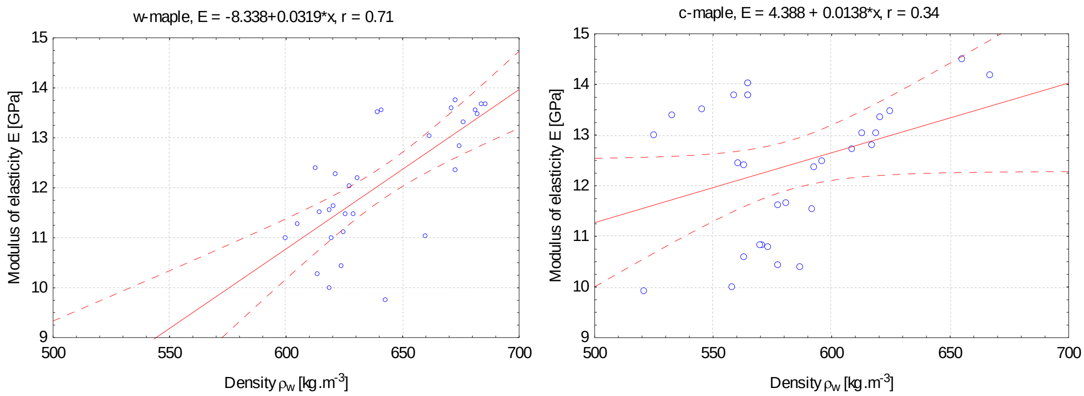

Fig. 3 Dependence of modulus of elasticity on wood density

In case of w-maple, the modulus of elasticity is considered mostly affected by wavy fibres. The wavy structure forces the fibres to turn aside from the longitudinal axis in both directions. The result is the decrease of the modulus of elasticity. POŽGAJ *et al.* 1997) also inform that the modulus of elasticity together with acoustic constant is, apart from density, also influenced by irregular fibre arrangement and fibre twisting. Significant influence is presupposed also for the submicro-structure cell walls. Cell walls consist of three layers differing in their chemical structure and the angle of their cellulose micro-fibrils. For wood properties, S2 layers of secondary cell layers are dominant, as they represent 70–80 % of cell walls (ČUNDERLÍK 2010). It follows that, also in this case, it is necessary to study the S2 layers of secondary walls of wood fibres at sub-microscopic level. ONO and NORIMOTO (1983) report that the internal friction force and longitudinal modulus of elasticity are significantly affected by the angle of deviation of micro-fibrils in S2 layers of secondary walls in wood fibres.

The values of wood density and modulus of elasticity were responded by the values of the sound propagation speed and the values of acoustic constant. Equations 1 and 2 show that the two characteristics are functions of density and the modulus of elasticity. In the w-maple wood, the speed values were significantly lower. The values increased proportionally with increasing wood density but showed only a weak correlation (Fig. 4). According to Eq. (1), the speed should decrease with increasing density. The increase in the speed of sound wave propagation with increasing density was driven by the steeper increase in the modulus of elasticity with increasing density. In case of c-maple, we have not recorded the dependence of the modulus of elasticity on density. Consequently, no effect of density on the speed of sound propagation has been confirmed. Figure 4 gives more evidence for a decreasing trend. It follows that the dependence of the modulus of elasticity on density determines also the dependence of sound wave propagation on density.

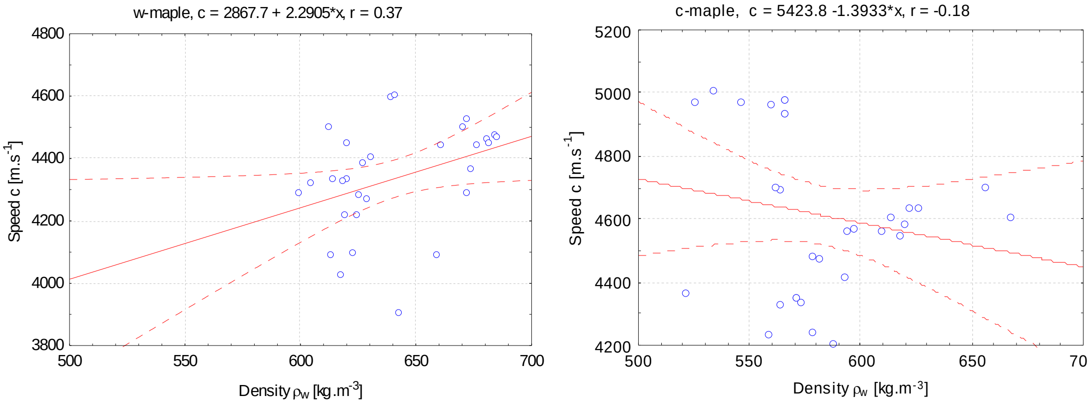

Fig. 4 Dependence of sound wave propagation on wood density

Also the acoustic constant for w-maple was significantly lower than for c-maple. The experimental results have also confirmed that the acoustic constant values decreased proportionally with increasing wood density. More remarkable change was observed in case of c-maple. As the wood density value in Eq. (2) figures in its third power, the influence of this parameter has been intensified in detriment of other factors. This has been reflected in closer correlation between the acoustic constant and density (Fig. 5).

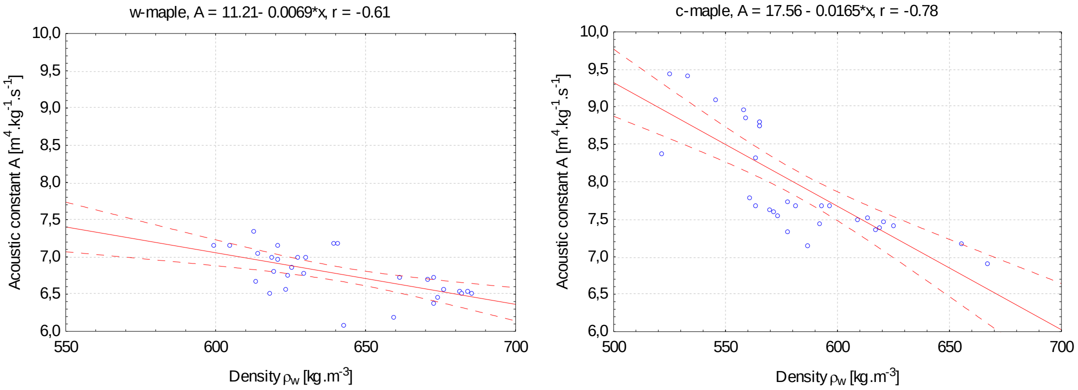

Fig. 5 Dependence of acoustic constant on wood density

Comparing the values of all the examined physical-acoustic characteristics between w-maple wood and c-maple wood, we may declare that w-maple wood exhibits higher quality. It meets all requirements for manufacturing back plates of violins according to RAJČAN (1998). Another advantage is wavy grain inducing the wavy gloss effect.

CONCLUSION

The maple wood with wavy grain featured, on average, better physical-acoustic parameters than the maple wood without wavy structure. As such, the wavy wood complies with the criteria set for material for making back plates of high-quality violins.

It was demonstrated that the discussed physical-acoustic properties were, apart from density, influenced by wood fibre waviness. Thus, this gives evidence that further research on the influence of this factor on the discussed properties, as well as the study of other differences in structure between these two types of maple wood is necessary.

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Streszczenie: *Fizyczne i akustyczne własności jaworu falistego*. Praca prezentuje ocenę fizycznych i akustycznych własności jaworu falistego. Z porównania wynikło że jawor falisty oprócz interesującej struktury posiada lepsze własności fizyczne i akustyczne od zwykłego jawora. Falista struktura drewna nadaje sięlepiej na płyty dolne instrumentów smyczkowych. Badano także jak te własności zależą od gęstości. Badania zapewniły materiał do analiz wpływu tego parametru na moduł sprężystości, propagację fal i stłą akustyczną. Wykazano istotne róznice pomiędzy drewnem falistym i zwykłym.

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