Acousto-Optics and Applications

Modified Wood of Black Locust — Alternative to Honduran Rosewood in the Production of Xylophones

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Traditionally, exotic hardwoods are used for the production of xylophone or concert marimba. Mainly the Honduran rosewood shows the optimal properties (high density, high modulus of elasticity, speed of sound, hardness, low damping) considering the required acoustic quality of the xylophone. The Honduran rosewood is listed in CITES Appendix II, therefore it is necessary to look for possibilities of its replacement by other wood species. However, the density, hardness and strength properties of the European wood species are rated less than Honduran rosewood. Therefore it is clear that there is a need to search for alternative of exotic wood. Our research indicates that the Honduran rosewood can be replaced by European wood species; however it is necessary to modify their properties. As convenient modification of domestic wood species appear: mechanical modification (densification), thermal modification or a combination of these two methods. Thus we can obtain wood with properties similar to the properties of exotic wood. The study presents the comparison of physical and acoustical characteristics of modified wood of Black locust with the characteristics of the Honduran rosewood. Also, the sound quality of xylophone made from Black locust wood before and after modification was investigated.

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1. Introduction

Musical instruments which produce sound by vibrating a solid material which is free of tension are idiophones. They are ones of the oldest musical instruments. Xylophone also belongs to this group of musical instruments. The bars of the xylophone are principally made of wood, but they can also be made from a synthetic material. The sound is produced by striking a mallet on wooden bars. The vibrations can be altered according to the thickness and size of the bar (to shape the pitch of the note). Xylophone consists of a set of chromatically tuned wooden bars arranged in the manner of a piano keyboard. The bars are supported by a wooden frame over resonator tubes. The xylophone's resonators are short unlike other similar percussion instruments. Nowadays a standard xylophone has a range of three-and-a-half octave (f to c^4). Commercial sizes can have as few as three octaves and as many as five octaves.

Since the xylophone produces the tone through the vibration of wooden bars the sound quality depends directly on the wood properties [1, 2]. The basic requirements for the selection of suitable material for the production of xylophone bars are: the material has to be homogeneous without any growth defects or ruptures (homogeneity is ensured also by a regular distribution of the growth rings), the bars have to be radially sawn and the wood grains have to be parallel to the longitudinal axis of the bar, material should be hard and flexible (hard but brittle material, e.g. ebony, is not suitable).

The influence of material properties on the tone quality has been researched by various authors. They have studied properties influencing acoustical quality of a musical instrument. Physical and acoustical characteristics as density, modulus of elasticity, acoustical constant and speed of sound as well as logarithmic damping decrement belong to such properties. The main properties were selected by Brancheriau [3] and Brémaud [4] to describe the acoustic behaviour of wood for xylophone. According to Holz [5], the wood species used generally for the xylophone manufacture have a high density — ρ (800 kg m^{-3} to 950 kg m^{-3}), a high dynamic modulus of elasticity — E_{L} (15 GPa to 20 GPa), a high degree of hardness and durability and a low tendency to split and crack.

Based on the research into relevant physical and acoustical characteristics (PACH), the structure and colour of wood of the central European wood species the Black locust was selected. Its wood was modified through the mechanical densification; the densified wood was further

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modified thermally. The physical and acoustical characteristics were studied via the method of modal analysis with harmonic excitation using the Chladni patterns. Sound quality of xylophone was investigated using fast Fourier transform (FFT) analysis.

2. Material and methods

Wood samples have been prepared from Black locust growing in the central parts of Slovakia. After natural drying outdoor test specimens were prepared. The shape of the test specimen depends on the experimental method used. The rosewood bars were sawn radially into the shape of a thin right-angle plate (thickness $h = 5$ mm, width $b = 110$ mm and length $a = 180$ mm). The test specimens of the Black locust in the natural state had the dimensions of xylophone bars ($h = 20$ mm, $b = 54$ mm, and $a = 410$ mm).

Our experiment was divided into two parts. In the first part of the experiment the physical and acoustical characteristics (density ρ, modulus of elasticity along the wood grain E_{L}, acoustical constant A, speed of sound along the grain c_{L}) of the natural wood of the Black locust and the Honduran rosewood were found out.

Subsequently the specimens from wood of Black locust were modified through the mechanical densification. Moisture content of the specimens was $w \approx (8 \pm 1)\%$. Mechanical modification consists of: pre-heating of the specimens to $t = 100\,^{\circ}\mathrm{C}$ for 15 min; pressing degree 20% and pressing time 5 min. The physical and acoustical characteristics of modified wood were measured again after reaching the dimensional stability. After the densification the specimens were stabilised for 14 days in the laboratory conditions (humidity $\varphi = 40\%$, temperature $t = (20 \pm 2)\,^{\circ}\mathrm{C}$) and specimens reached moisture content $w \approx (8 \pm 1)\%$.

After stabilization the densified wood was thermally modified. For the thermal modification a similar process to ThermoWood process was chosen [6]. However the temperature was milder. Thermal modification of wood consisted of three steps: pre-drying at $t = 100\,^{\circ}\mathrm{C}$ for a 4 h period; thermal modification at $t = 160\,^{\circ}\mathrm{C}$ for a 4 h period and cooling for a 4 h period [7]. After decreasing the temperature of specimens to room temperature the specimens were air-conditioned to obtain approximately the same moisture content like before modification. Then the physical and acoustical characteristics were measured.

For obtaining the relevant characteristics modal analysis with harmonic excitation using the Chladni patterns was used. The Chladni patterns are effective for mapping the modes of free thin plates. The three vibrational modes (1st, 2nd, and 4th) are important for the calculation of four elastic constants: Young's moduli along (E_{L}) and across (E_{R}) the grain, shear modulus G_{LR} and two Poisson's ratios [8]. The plates are excited by loudspeaker placed under the plate. This method allows finding the resonance frequencies and computing of PACH. The formulae for calculating the modulus of elasticity E_{L}:

$$E_{\mathrm{L}} = 12\eta D_1, \quad \eta = 1 - \mu_{\mathrm{LR}}\mu_{\mathrm{RL}},$$

$$D_1 \approx 0.0789\frac{f_4^2 \rho a^4}{h^2}, \tag{2.1}$$

where f_4 is resonance frequency of the 4th mode (2,0), ρ is density, a is length (along the grain) and h is thickness, μ_{LR} and μ_{RL} are Poisson's ratios. Mode (2,0) is also used for tuning the fundamental frequency in the production of the bars. The acoustical constant (*sound radiation coefficient*) A is given by relation

$$A = \sqrt{\frac{E_{\mathrm{L}}}{\rho^3}} = \frac{c_{\mathrm{L}}}{\rho}, \tag{2.2}$$

where E_{L} is the Young modulus of elasticity, c_{L} is speed of sound.

Measuring device VIBROVIZER (Fig. 1) was used for the measurements. The measuring apparatus consists of a tone generator producing a sine harmonic signal that is amplified by a high-performance amplifier. A loudspeaker connected to the amplifier excites the plate vibrations. The measured data are stored in the computer memory and are subsequently used for the calculation of the wood characteristics by formulae (2.1) and (2.2).

Fig. 1. Measuring device VIBROVIZER.

The system for measuring the acoustic signal radiated via the wood specimens was designed to obtain an accurate analysis of the properties of the material [9], while also enabling the xylophone maker to classify the species. Impulse method was excited vibrations of xylophone bars tuned to the tone $C^4 = 264$ Hz before and after modification (dimensions of the arch were all identical). The sounds were produced and recorded in laboratory in free field. FFT analysis was performed using Adobe Audition programme.

3. Results

Table presents the basic statistical characteristics of the set of individual physical and acoustical characteristics of the Black locust (BL) — no modification, wood after the mechanical densification (BL — mechanical modification), wood after the combined modification (BL — mechanical/thermal modification) and Honduran rosewood (HR).

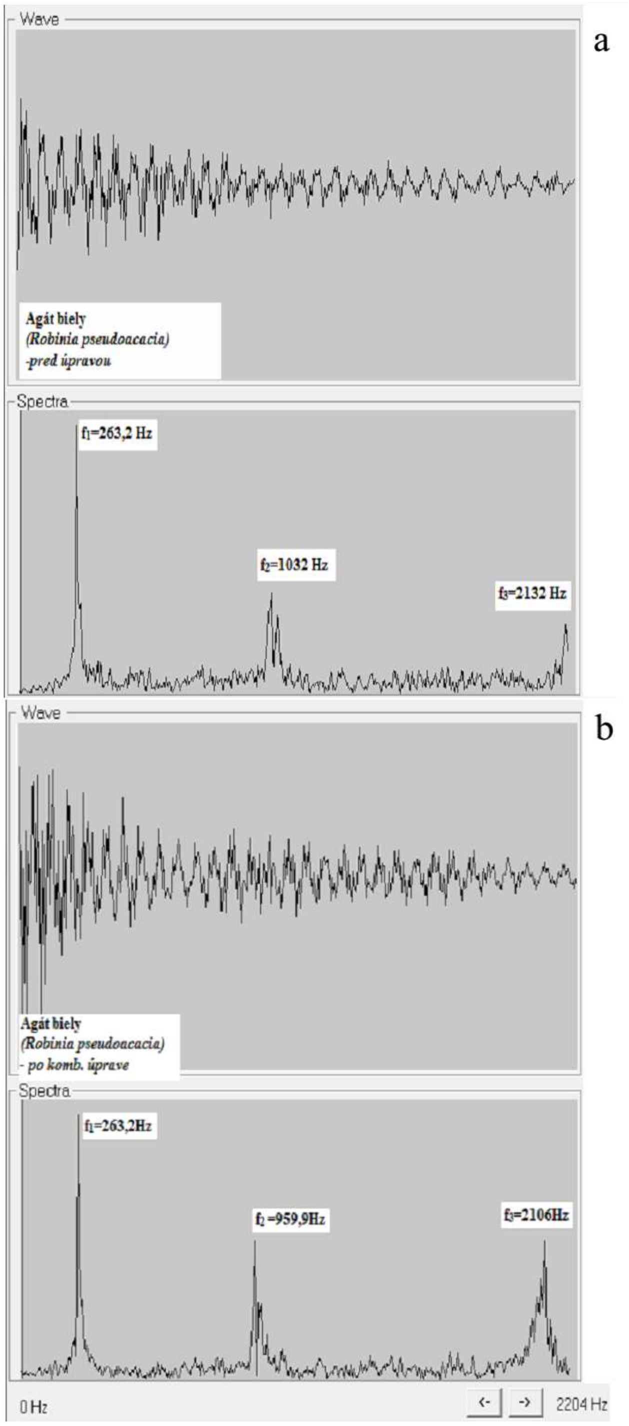

Fig. 2. (a) FFT analysis tuned C^4 (= 264 Hz) bar of BL (a) in nature and (b) after combined modification.

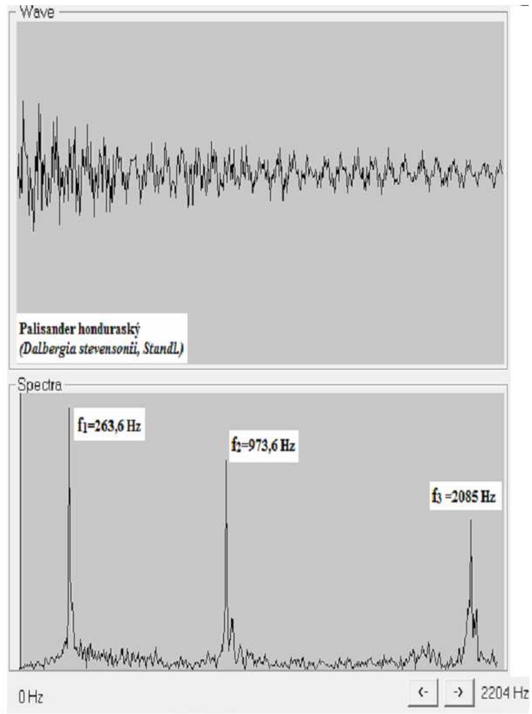

Fig. 3. FFT analysis tuned C^4 (= 264 Hz) bar of HR.

Results of FFT analysis (time course of signal, a sound spectrum of tone C^4) of tuned bars of Black locust before and after combined modification are presented in Fig. 2 and of Honduran rosewood in Fig. 3. As is evident from Table, variability of measured PACH increased after modifications. The cause is different degree of pressing (after release of pressure).

TABLE

PACH of wood of BL and HR (ρ — density, E_L — modulus of elasticity, A — acoustical constant, c_L — speed of sound, n – number of test specimens, MV – mean value, SD – standard deviation, CV – coefficient of variation)

Wood species	n	Stat. char.	ρ $[\frac{kg}{m^3}]$	E_L [GPa]	A $[\frac{m^4}{kg\,s}]$	c_L $[\frac{m}{s}]$
BL —		MV	749	17.12	6.40	4 785
no mod.	15	SD	33.85	1.85	0.39	220.15
		CV	4.52%	10.76%	6.13%	4.60%
BL —		MV	892	20.27	5.35	4 758
mech.	15	SD	48.24	2.52	0.36	251.65
mod.		CV	5.41%	12.44%	6.77%	5.29%
BL —		MV	811	19.23	5.99	4 853
mech./	15	SD	49.69	3.11	0.33	285.45
th. mod.		CV	6.13%	16.16%	5.45%	5.88%
		MV	992	24.19	4.98	4 936
HR	18	SD	22.68	1.17	0.12	89.69
		CV	2.29%	4.83%	2.42%	1.82%

Density and elastic modulus has increased more after mechanical modification than after the combined modification and, on the other hand, acoustical constant has decreased after combined modification (Table). The cause of a milder increase in density and modulus of elasticity after the combined modification was the thermal modification. This process caused that mainly hemicelluloses were degraded and a loss of mass ($\Delta m \approx 4.7\%$) and volume reduction ($\Delta V \approx 4.1\%$) were recorded.

Modulus of elasticity increased due to the influence of temperatures not higher than 160 °C, but it increased less than after the mechanical modification (which can be explained by the dependence of the modulus on density). The result corresponds also to the results of other authors [10]. Duncan's test showed a statistically significant difference between PACH (except speed of sound after combined modification) of Black locust (after both modification) and Honduran rosewood.

Our results indicate that the Black locust, after the combined modification on the basis of PACH and wood colour (colour of wood was changed into darker shades resembling the colour of rosewood), can be a suitable alternative to Honduran rosewood.

As can be seen from sound spectrum of tone C^4 (Fig. 2 and Fig. 3) the Black locust after combined modification approached the spectrum of Honduran rosewood through the ratio of aliquot frequencies. At the reference species Honduras rosewood (Fig. 3) ratio was (1:3.7:7.9). It is obvious (Fig. 2) that combined (mechanical/thermal) modification of the wood of Black locust decreased the ratio frequencies (BL in nature (1:3.9:8.1) and BL after combined modification (1:3.7:8)). For the higher notes (F^4 upwards) the 3:1 tuning is applied to xylophone bars, while 4:1 tuning characterizes the sound of the instruments of the lower register [9], i.e. BL after combined modification can be used in manufacture of xylophones of the lower register.

4. Conclusions

Wood used in the production of idiophonic musical instruments — xylophones (e.g. Honduran rosewood) needs to have high density and high modulus of elasticity, yet a low acoustical constant. Moreover, the wood has to meet also certain aesthetic requirement. Following the experiment results it can be stated that the wood of Black locust (after the combined modification), can be used as an alternative to the Honduran rosewood for xylophones of lower quality.

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