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ACOUSTIC PROPERTIES OF TROPICAL WOODS USED IN MARIMBA BARS

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Abstract:
Marimba is an idiophone musical instrument. The most frequently used species for marimba bars are the tropical ones, such as Palissandre, Padouk, Wengé (etc...). The reasons rest on particular values of mechanical and acoustic properties needed for idiophone instruments, such as density, stiffness, hardness, dimensional stability, damping, radiation and acoustic conversion efficiency etc. This paper present experimental evaluation of main properties as well as relations between the properties. The vibro-acoustic properties were measured in bending based on the first vibration mode, so that the free-free vibration method was involved. The species implicated were Padouk, Jatobá and Merbau; 45 specimens were used for each wood species. The results evinced particular high values of damping, but still in the limits shown in literature. Merbau got the best MOE value. ACEs were precisely inside the range of literature. A direct relation between damping and density wasn't found; yet, a linear regression of Young's modulus of elasticity and tanγ (in Merbau) was reached with a r^2 of 0.353. Eventually, Kruskal Wallis Anova evinced that MOE_B assumed significant reduction with a damping over 0.007.

Key words: *tropical hardwoods; damping; modulus of elasticity in bending; marimba.*

INTRODUCTION

In musical instruments, the function of wood may be wide, and depending by the production of sound different categories of instruments are classified. The typologies of instruments based on the function of wood and the making of sound are: aerophone, chordophone and idiophone. Marimba is a musical instrument that belongs to idiophones and wood is the main vibrating body that is excited mostly by mallets or hammers. The vibrating frame consists of a row of wooden bars arranged in the way of piano's keyboard. Marimba is bigger than a xylophone and is equipped with longer pipes under the frame to amplify the sound through the use of resonant air columns; these pipes are named resonators. The main difference between xylophone and marimba is the tuning of the keyboard. The underneath of a marimba bar is carefully shaped, so that each bar has a more defined pitch with a larger graduation of frequencies than xylophone. From the fundamental note frequency (f_0), marimba frame is tuned till two octaves (4 f_0) and even the third mode (octave) might be tuned (10 f_0).

Conversely, xylophone is tuned in a range of an octave plus a fifth (3 f_0) from the fundamental tone, and not all bars are tuned (Suits 2001). Consequently, xylophone has pitches not well defined; it is played with hard rubber or timber hammers and the sound produced has high frequency modes. Marimba bars are struck by mallet wrapped in felt that decreases the high tones to lower frequency modes. Due to his mellower sound, marimba is more involved in orchestras and a solo instrument as well. Bars for marimba have to be oriented with radial direction in the orthogonal section, and longitudinal continuity among the longer dimension. If the long dimension is on the x-axis, the width on z-axis and thickness along y-axis, the bars must be struck on the plane x-z (Suits 2001).

The requested qualities for idiophone instruments, therefore even for marimba, are linked to the density, modulus of elasticity in bending (MOE_B), hardness, and dimensional stability correlated with moisture content (Brémaud 2012). Acoustic properties and the factors correlated to internal friction (tanγ), radiation (or acoustic constant) and acoustic conversion efficiency (ACE) are the major parameters to define the qualities of acoustics of wood in idiophones (Baar *et al.* 2016; Sedik et al. 2010). Durability, low tendency to crack, to split and to twist are needed too (Straze *et al.* 2015). Thanks to Wegst (2006) it is possible to define the range values of some acoustic properties requested for idiophone bars (defined "xylophone" in her article): high density (between 810-980 $kg{\bullet}m^{-3}$). High stiffness from 15 to 20 GPa (Danihelová *et al.* 2015, Holz 1996). Low loss coefficient with values between 0.0025 and 0.0055 (Hase 1987) and even more restricted by Wegst (2006) with a range between 0.0034 and 0.0045. Low average sound radiation coefficient: between 3.8 and 4.9 $m^4kg^{-1}s^{-1}$ (Wegst 2006). ACE has to show high values, but still less than resonance spruce for soundboard (Brémaud 2012). These criteria are well performed by tropical species, so that the most wood species used in marimba are Rosewood (*Dalbergia* sp), Padouk (*Pterocarpus* sp) etc. (Holz 1996).

OBJECTIVE

Thanks to the literature, it is possible to define mechanical and vibro- acoustic properties to get good qualities of marimba bars. High values of density and low values of internal friction (damping) are desirable. Hence, we have asked in this article if there were relations between mechanical and vibro- acoustic properties. Consequently, density, damping, stiffness, and acoustic conversion efficiency were calculated to complete set data of vibro-acoustic properties on selected wood species.

MATERIAL, METHOD, EQUIPMENT

Table 1 specifies the tropical wood species involved in this manuscript: their common name, botanical name and the origin. The dimensions of specimens were 300x15x5 mm^3. 45 specimens were utilized for each wood species.

Table 1

Trade name, scientific name and origin of boards

Trade name	Scientific name	Region of origin
Padouk	*Prerocarpus soyauxii*	Tropical Africa
Jatobá	*Hymenae courbaril*	South America
Merbau	*Intsia* sp	South-East Asia

The samples were kept under controlled condition for one month at 19±1°C and 60±1% of relative humidity (long term conditioning).

The first step was to measure the density of each specimen. In this research the method of transitory excitation (also known as the free-free support method or resonance method) was used. This method has used a microphone AUDIX TM1PLUS that captured the sound produced by vibrating specimen after the hitting by a soft hammer. Thus, the signal was elaborated through a fire Wire Audio Capture EDIROL FA-101; the acoustic resolution of the fire Wire was 194 kHz at 24 bit. The system was linked to a software analysis based on the Fast Fourier Transform to process the impulse on the frequency domain. Specifically, the software was Fast Fourier Vibration analyzer, free product of Fakopp Enterprise. The frequency range of spectra was settled between 0 and 2204 Hz. The normal A tone frequency was set to 442 Hz. With the transitory excitation method, it was possible to achieve the Young's modulus in bending and with the internal friction measuring the fundamental frequency of bending in the first mode (Hassan *et al.* 2013).

The specimens were positioned on two foam rubber supports at nodal point (0.2 and 0.8 of length of the specimens). This free condition provides the best precise support conditions reachable (Haines and Leban 1997), and also a closer reproduction of real marimba bars' vibration. The mallet used was in rubber, and the bars were struck at the half of the longitudinal length with microphone kept close to it, as Figure 1 and 2 show.

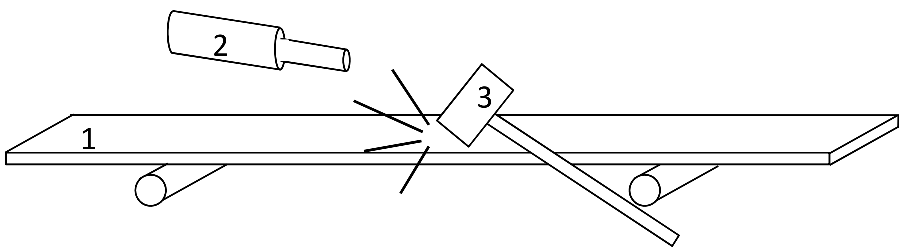

Fig. 1.
Transitory excitation method in bending
1: sample; 2: microphone; 3: mallet.

Fig. 2.
Microphone AUDIX TM1PLUS used to capture the beating of samples, rubber mallet and a Padouk specimen.

Thanks to measuring the first bending natural frequency and the logarithmic decrement of damping (LDD), it was possible to calculate the modulus of elasticity in bending (MOE_B) and the internal friction, also known as damping (tanγ), respectively as in the following equations 1 (Giordano 1981) and 2 (Buksnowitz *et al.* 2007).

$$MOE_B = \left(\frac{f \cdot l^2}{3{,}56 \cdot r} \right)^2 \cdot \rho \qquad \text{[GPa]} \qquad (1)$$

where: f is the first frequency mode in bending in Hz
l is the length of samples in m
ρ is the density in kg•m^{-3}
r is the radius of inertia in m

$$\tan\gamma = \frac{LDD}{\pi} \qquad \text{[/]} \qquad (2)$$

where: *LDD* is the logarithmic damping decrement

The Acoustic Conversion Efficiency (ACE) was calculated with the equation number 3 (Brémaud 2012):

$$ACE = \frac{\sqrt{MOE_B / \rho^3}}{\tan\gamma} \qquad [m^4kg^{-1}s^{-1}] \qquad (3)$$

where: MOE_B is the modulus of elasticity in bending calculated on the first mode
ρ is the density in kg•m^{-3}
tanγ is the internal friction

RESULTS AND DISCUSSION

In Figure 3, a comparison of time domain (top of pictures) and frequency domain (bottom of pictures) is shown, measured for each species. The range of frequency was set up between 0 and 2204 Hz. The first peak in the frequency domain corresponded to the first bending vibration mode.

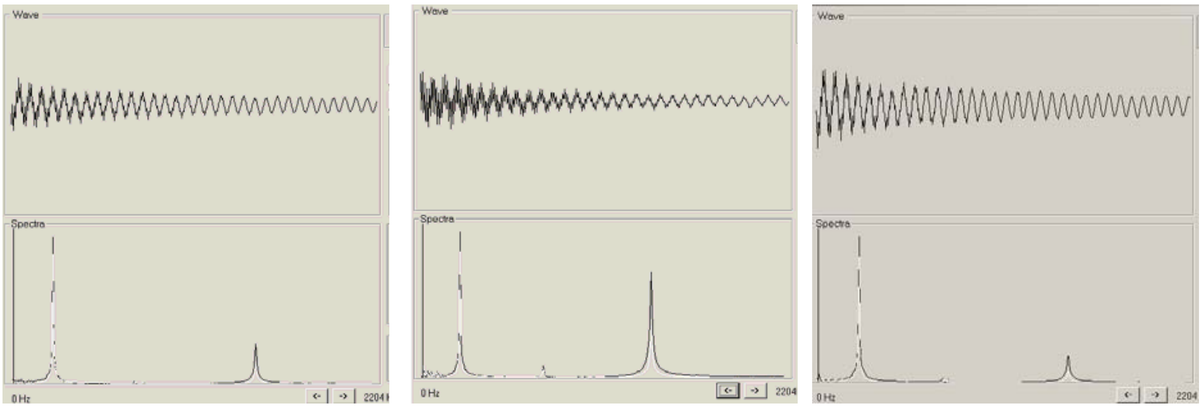

Fig. 3.
Examples of time domain and frequency domain signal of Padouk, Merbau and Jatoba samples, respectively (from left to right side).

The results of measurements are shown in the table 2. Mean, standard deviation (σ) and coefficient of variation (*CV*) of the acoustic properties are divided per each species.

Table 2

Acoustic properties of 3 selected species

	ρ [kgm^{-3}]			tanγ [/]			MOE$_B$ [GPa]			ACE [m^{4}kg^{-1}s^{-1}]		
Species	**Mean**	**σ**	**CV (%)**	**Mean**	**σ**	**CV (%)**	**Mean**	**σ**	**CV (%)**	**Mean**	**σ**	**CV (%)**
Padouk	699	108	15	0.0076	0.0080	11	13.02	2.17	17	839	163	19
Jatobá	1034	396	38	0.0080	0.0012	15	21.19	8.54	40	589	173	29
Merbau	769	67	9	0.0083	0.0020	24	15.14	14.75	22	739	697	28

Jatobá was the species with higher values of variation coefficient in every property, except for damping factor which showed the highest variability in Merbau.

All density values are out of the range determined by West (2006): 810-980 kg•m^{-3}. Yet, Brémaud's contribution (2012) affirmed that density trend changes between different native countries in tuned idiophone. She distinguished wood density values from Africa (Padouk), South America (Jatobá) and South-Est Asia/Oceania (Merbau) respectively: 700-900, 750-1.150 and 450-900 kg•m^{-3}. Hence, our density data were included in these ranges, except for Padouk that resulted lightly under the lower value (with mean value 699 kg•m^{-3}). The reached internal friction had major values if compared with those from oldest data literature (Wegst 2006; Holz 1996). Though, if we consider Brémaud data (2012), the damping range is between 0.0029- 0.0085. Consequently, our data were tending to high values but still acceptable in the range. In the case of Young's modulus, Merbau fixed precisely with values given by Danihelová *et al.* (2015) and Holz (1996) suggested, but Padouk had less modulus of elasticity. Jatobá has shown the highest value of MOE. Yet, Holz (1996) mentionedthat values of MOE higher than 20 GPa were suitable if density exceeded 1.100 kg•m^{-3}. Because of Jatobá had Young's modulus of 21,2 GPa and density 1.034 kg•m^{-3}, the result of MOE is acceptable. Acoustic conversion efficiency showed high values as requested by literature and they were perfectly included in the range suggested by Brémaud (2012) for tuned idiophone bars: 550-1.650 m^{4}kg^{-1}s^{-1}.

Correlation analysis was the first statistical processing of data and it was made for each species. To have a 0.05 level of significance with 45 sample, r had to be > ±0.288. Consequently, we observed a tight negative correlation between Young's modulus in bending and damping in Merbau (r = -0.586). Due to a coefficient value > ±0.372, it was possible to affirm that the level of the correlation significance was even 0.01. The reason of this result could be due to the equation to carry out the Young's modulus. As the formula number 3 shows, the modulus of elasticity is calculated through the frequency. Consequently, we supposed that the MOE had a relation even with the internal friction measured on the frequency. Other interesting correlations were not found. Thus, we could not define a relation between the other vibro- acoustic properties.

Because of these first results, the second processing of data was focused on a linear regression between modulus of elasticity and damping of Merbau (Figure 4).

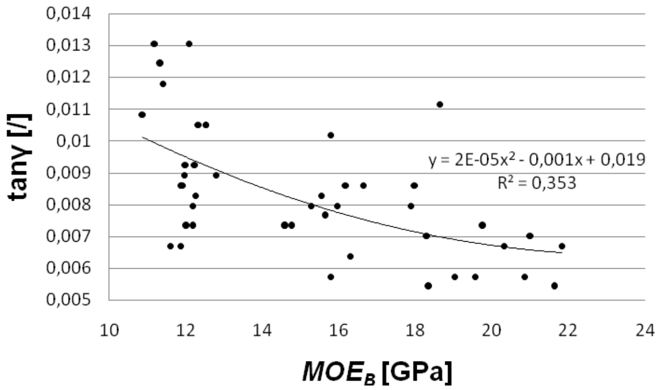

Fig. 4.
Linear regression between modulus of elasticity in bending and damping of Merbau.

The value of the determination coefficient was 0.353. As the figure 4 shows, the higher the Young's modulus in bending, the less the damping of the first bending mode was. Therefore, there was a negative relation between these two properties.

A third elaboration was still focused on the relation between Modulus of elasticity in bending and internal friction of Merbau. The MOE_B values were divided in three groups based on damping's ranges: 0.005-0.007, 0.007-0.008 and 0.008-0.013. The distribution of the three MOE_B groups was not normal (p-value less than 0.05). Afterwards, Kruskal Wallis Anova (box plot, figure 5) was reached, and differences between first and second group and first and third group were proved. Thanks to this result, we could affirm that a notable influence of internal friction on modulus of elasticity in bending was observable when damping is over 0.007.

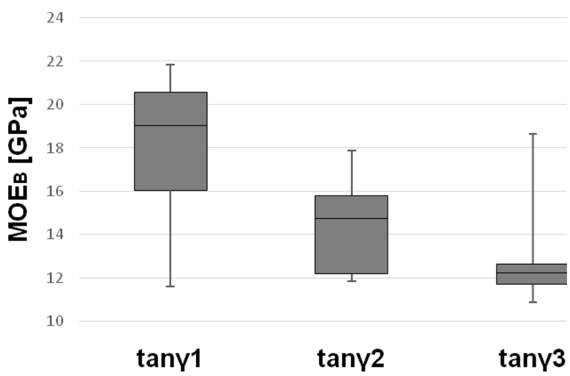

Fig. 5.
Box plot of Kruskal Wallis Anova of MOE_B according to internal friction ranges.

The last data processing involved ANOVA analysis and was carried out between damping and acoustic conversion efficiency of Merbau (divided in three groups based on the same ranges of damping used for the previous elaboration). The reason of the ANOVA elaboration was because of the normal distribution of ACE values. The results showed p- values < 0.05, hence significant differences between each group (Tukey test). We confirmed that the more the damping increased, the more the ACE decreased. This result was predictable due to the acoustic conversion efficiency equation, which has damping on denominator.

CONCLUSIONS

The three species analyzed showed density values close to the literature of Brémaud (2012). The values of internal friction tended to high values. Padouk got the lowest values of MOE_B and Merbau exactly those suggested by the literature (Danihelová *et al.* 2015, Holz 1996). Values of ACE were totally acceptable if compared to Brémaud (2012). The higher variability was shown for MOE_B of Jatobá with 40%.

The most interesting relation between factors was in Merbau through modulus of elasticity according to internal friction with significance level of 0.01. The determination coefficient r^2 was 0.353, thus the equation between these two properties could suggest the calculation of damping according to MOE_B. Probably, this result was due to a connection between damping factor and vibrating frequency present in the

Young’s modulus equation. With increasing of Young's modulus in bending, damping decreased. Through Kruskal Wallis Anova, it was possible to identify an interesting value of damping (0.007) of Merbau wood: when internal friction was > 0.007, MOE_B assumed significant reductions.

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REFERENCES

Baar J, Tippner J, Gryc V (2016) Wood anatomy and acoustic properties of selected tropical hardwoods. International Association of Wood Anatomists 37(1):69-83.

Brémaud I (2012) Acoustical properties of wood in string instruments soundboards and tuned idiophones: Biological and cultural diversity. Acoustical Society of America 131(1):807-818.

Buksnowitz C, Teischinger A, Müller U, Pahler A, Evans R (2007) Resonance wood [Picea abies (L.) Karst.] – evaluation and prediction of violin makers’ quality-grading. Acoustical Society of America 121(4):2384–2395.

Danihelová A, Čulik M, Němec M, Gejdoš M, Danihelová Z (2015) Modified Wood of Black Locust – Alternative to Honduran Rosewood in the Production of Xylophones. ACTA Physica Polonica A 127(1):106-109.

Giordano G (1981) Tecnologia del legno. Vol.1, Edn. Hoepli, Milano p 314.

Haines DW, Leban JM (1997) Evaluation of the MOE of Norway spruce by the Resonance Flexure Method. Forest Products Journal 47:91–93.

Hase N (1987) A comparison between acoustic physical factors of Honduras rosewood for marimbas and xylophones and a sensory evaluation of these instruments (in Japanese). Mokuzai Gakkaishi 33: 762–768.

Hassan KTS, Horaček P, Tippner J (2013) Evaluation of Stiffness and Strength of Scots Pine Wood Using Resonance Frequency and Ultrasonic Techniques. BioResources 8(2):1634-1645.

Holz D (1996) Acoustically important properties of xylophone-bar materials: Can tropical woods be replaced by European species? ACUSTICA Acta acustica 82:878-884.

Sedik Y, Hamdan S, Jusoh I, Hasan M (2010) Acoustic Properties of Selected Tropical Wood Species. Journal Nondestructive Evaluation 29:38–42.

Straže A, Mitkovski B, Tippner J, Čufar K, Gorišek Ž (2015) Structural and acoustic properties of African padouk (*Pterocarpus soyauxii*) wood for xylophones. European Journal of Wood Production 73:235–243.

Suits BH (2001) Basic physics of xylophone and marimba bars. American Journal of Physics 69(7):743-750.

Wegst GK (2006) Wood for sound. American Journal of Botany 93(10):1439–1448.