EFFECT OF SOAKING PROCESS IN WATER ON THE ACOUSTICAL QUALITY OF WOOD FOR TRADITIONAL MUSICAL INSTRUMENTS

Mehran Roohnia,[a,*] Seyed-Fariborz Hashemi-dizaji,[a] Loïc Brancheriau,[b] Ajang Tajdini,[a] Amir-Hooman Hemmasi,[c] and Negin Manouchehri [a]

The damping coefficient of the first mode in the longitudinal vibration of mulberry and walnut woods was characterized to find justifications for the water soaking of woods in traditional musical instrument industries in Iran. Visually clear and sound beams were prepared from *Morus alba* and *Juglans regia*, and the damping coefficient in the temporal field was evaluated before and after three continuous cycles of soaking of specimens in distilled water (24 hours, pH 7, and temperature 50 ^{o}C). Experiments were conducted with free longitudinal vibration using the free-free bar method in 360×20×20 (L×R×T) dimensions. Soaking cycles homogenized and decreased the damping coefficient in both species. On the basis of such results, the suitability of water soaked specimens is discussed in traditional musical instrument industries in Iran, taking into the account the longitudinal sound velocity, modulus of elasticity, and density affecting the acoustic limits. These two series of testing specimens were suitable in resonators and xylophone bars for backs, sides, and ribs and not for top plates, unless as the outstanding piece, since they marginally meet the density, sound velocity and damping coefficient limits qualified for those applications.

Keywords: Damping coefficient; Internal friction; Acoustic quality; Mulberry; Walnut; Water soluble extractives

Contact information: a: Department of Wood Science and Technology; Karaj Branch, Islamic Azad University; P. O. Box: 31485-313Karaj-Iran; b: Agricultural Research Centre for International Development, UPR CIRAD 40, Production and Processing of Tropical Woods, 34398 Montpellier Cedex 5-France; loic.brancheriau@cirad.fr c: Department of Wood Science and Technology; Science and research Branch, Islamic Azad University; Poonak Sq., Toward Hesarak, Tehran-Iran;
**Corresponding author: mehran.roohnia@kiau.ac.ir*

INTRODUCTION

Mulberry and walnut are the most commonly used wood species for traditional Iranian musical instruments. Iranian luthiers traditionally soak wood in water to obtain a soft volume of wood to be rasped more easily, as they believe that the resonators made of soaked wood yield a better quality of sound. The acoustic effects of soaking in water, therefore, require the researchers to follow in the footsteps of traditional instrument makers to study the relevant acoustical parameters.

As an introduction, it is useful to state that when a sound wave reaches wood, part of its acoustic energy is reflected and the rest enters the wood mass (Tsoumis 1991). As wood vibrates, therefore, the original sound is intensified or becomes subject to partial or total absorption. Similar consonance or intensification of sound takes place when the wood is utilized in a resonator. Irrespective of air friction, acoustic energy is mostly consumed in wood. The efficiency in a wooden resonator is largely affected by factors such as damping coefficients due to internal friction (Tsoumis 1991) and speed of sound propagation (Wegst 2006; Longui 2010; Roohnia et al. 2011a,b). The location and rigidity of a support as an external interceptor falsely raises the damping coefficient, while ideally no supports should be provisioned in a free-free bar. But in the free vibration test of a free-free beam, an obligatory support must be located somewhere that the oscillation is at its lowest level. Practically, the nodal points seem to be the most suitable locations. Damping coefficient due to internal friction is dependent on various factors characterizing the wood, such as specific gravity, extractives content, grain, moisture content (positively affecting the damping coefficient), direction (that is, longitudinal, tangential, and radial), and the mode number of vibration (Roohnia et al. 2010). An individual external impact may excite a wooden free-free bar to vibrate in its natural frequencies, depending on the direction of the excitation; the vibration is gradually decayed, and the bar ceases to translate.

Every wooden part in various musical instruments exhibits some special sounding qualities. For instance, in a sounding board of a resonator (chordophones) it is usually intended to select a wood with lower damping coefficient due to internal friction and higher speed of sound propagation (Tsoumis 1991; Matsunaga et al. 1996; Wegst 2006; Bremaud 2008).

Damping coefficient of woods as an important factor in musical instrument industries has concerned many scientists compared to other acoustic indicators. Bremaud (2008), for example, studied damping coefficients for African wood species in musical instruments. She introduced significant power correlations between damping coefficients and specific modulus of elasticity. Sugiyama et al. (1994), Bucur (1995), and Matsunaga et al. (1996), however, denied this correlation in some species, such as *Guilandina echinata*. This species, which has traditionally been used in making violins, has a lower damping coefficient compared to hard and soft woods with similar specific modulus of elasticity. Holz (1996) reported that suitable woods for xylophones have a proper range of density, modulus of elasticity, and damping coefficients. Norimoto (1982) showed that spruce specimens (*Picea excelsa*, *P. glehnii*, *P. sitchensis*) as suitable in sound boards of musical instruments exhibit higher sound velocity and lower longitudinal damping coefficients. Matsunaga (1999) showed the dependence of damping coefficients on the extractive content and type. He reduced the damping coefficients of spruce woods saturated with extractives from *Guilandina echinata*. Obataya et al. (1999) certified the importance of extractives in rigidity and damping of vibration in porous materials. Rujinirun (2005) studied the damping coefficients followed by specific modulus of elasticity in woods suitable for the Thai xylophone. Brancheriau et al. (2006) focused on 58 tropical wood species used in xylophone-type percussion instruments. Every wood species was classified by individual xylophone makers, and based on an analysis of radiated sound signals, these separate classifications were compared with one another to determine the key signal parameters that have possible impacts on the acoustic quality of woods. Relationships among perceptual classifications, signal parameters, and wood anatomical characteristics were analyzed. Aramaki et al. (2007) showed the importance of damping coefficients in selecting suitable xylophone bars. Alavi-tabar et al. (2009) studied the specific modulus of elasticity and damping coefficient of Iranian Beech wood (*Fagus orientalis*). They also reported a weak but significant power correlation between damping and specific modulus of elasticity. Roohnia et al. (2010) elaborated on the damping coefficients of pine wood in free vibrations of the free-free bars (in longitudinal, flexural and torsional vibrations). The lowest damping was reported for longitudinal and the highest was for torsional-free vibration. Longui et al. (2010) compared *Guilandina echinata* to six other potential Brazilian wood species for bows of string instruments. They all accounted the specific gravity, speed of sound propagation, and dynamic modulus of elasticity as the acoustic properties. In the current study, the damping coefficient associated with the first mode of the longitudinal vibration was evaluated for mulberry and walnut woods to find some justifications for the water soaking of woods in traditional musical instrument industries in Iran.

EXPERIMENTAL

Materials

Twenty-five and 40 pieces of absolutely clear and sound beams of mulberry *(Morus alba)* and walnut *(Juglans regia)* woods, respectively, with 20×20×360 mm (along the material's axes radial, tangential, and longitudinal) nominal dimensions were selected with a random technique from raw logs used for traditional resonator boxes in Iranian musical string instruments. The specimens were selected in accordance with ISO3129 International Standard. Conditioning operations were practiced at 65% of relative humidity and a temperature of 22 ^{o}C in a climatic chamber beginning from the fiber saturation point until the specimens were stabilized at the air-dry equivalent moisture content (equilibrium moisture content of 12%).

Methods

LSTRESS Portable System Setup, a new release of NDT-lab® (Roohnia et al. 2006), developed using MATLAB® 7.1 was used to perform longitudinal free-free vibration tests. For minimizing external bias on the damping coefficient assessment, a thin elastic support (Fig. 1) was placed at the middle of the bar (vibration node of the first longitudinal mode). Percussion at one free end excited the bar to vibrate longitudinally, while sound recording was done at the opposite free end using a microphone. The recording sample rate for the audio files was adjusted to 44100 Hz with 16 bits encoding (bit depth).

The damping coefficient (internal friction) tanδ was calculated from the logarithmic decrement, λ, in temporal field following Bodig and Jayne (1993), Aramaki et al. (2007), and Bremaud (2008). The logarithmic decrement was computed as the natural log of the amplitudes of any two successive positive peaks (Eq. 1) where X_0 is the greater of the two amplitudes and X_n is the amplitude of a peak n periods away (vibration associated with the first mode):

$$\lambda = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right) \quad \text{and} \quad \tan\delta = \frac{\lambda}{\pi} \tag{1}$$

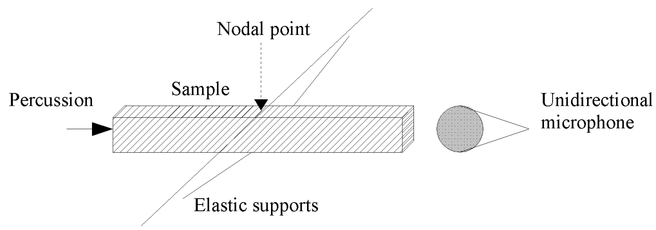


Fig. 1. Experimental setup, free-free bar in longitudinal vibration (Inspired from US-Patent 2004/0144158 Al)

In addition, the longitudinal wave velocity was evaluated using Eq. 2,

$$V = 2Lf_1 = \sqrt{E_{sp}} \tag{2}$$

where V is the longitudinal wave velocity, L is the total length of the beam, f_1 is the fundamental resonance frequency in longitudinal vibration, and E_{sp} is the specific modulus of elasticity that is defined as the ratio of modulus of elasticity to density.

Next the specimens were soaked in the distilled water (PH=7, 50^{o}C) for 24 hours, as advised by an Iranian traditional luthier for existed dimensions of the specimens. Then the specimens were dried in a smooth procedure and stabilized at the above-mentioned air-dried moisture content. Similarly, two more soaking treatments were repeated, and at every time the damping coefficients of the air-dried specimens were evaluated for the first mode of longitudinal free-free vibration. During the cycles of soaking some specimens were omitted after some failures occurred due to the cyclic drying and wetting treatment. Considering these failures, we were forced to believe that the studied effect on damping is not only the effect of soaking but rather the complete cycle of soaking and drying.

RESULTS AND DISCUSSION

Results

The effects of soaking cycles on damping coefficients of the bars were studied with use of one way Analyses of Variances (ANOVA) followed by Duncan multi-comparison tests, and the related values before and after soaking were correlated through linear trends to obtain a better understanding of variation in damping coefficients. The treated specimens were compared with the untreated ones in terms of their suitability in the musical instrument industry. Failures occurred mostly, warping defect, in seven specimens of both mulberry and walnut species after the 1st cycle of wetting and drying. The number of samples was then reduced to 18 for mulberry and 33 for walnut.

Table 1 shows the effects of soaking cycles on damping coefficients for the mulberry and walnut samples. Eighteen unsoaked pieces of mulberry and 33 unsoaked pieces of walnut were taken into account. Based on the analysis presented in Table 1, for both species, soaking was effective in modifying the damping coefficient values.

Duncan multi-comparison tests were then performed to categorize the damping values in separate groups (Table 2). For both species the traditional soaking cycles reduced the longitudinal damping coefficients. In the case of mulberry, the native unsoaked specimens were categorized in one group. All specimens after three soaking cycles were grouped together in another category with lower damping coefficient. For walnut species, three categories were distinguished: the unsoaked specimens in the first group, the specimens after the first soaking cycle in the second group, and the specimens after the second and the third soaking cycles together in the third group. The damping coefficient values decreased from the first to the third group.

Table 1. One Way ANOVA for the Effects of Soaking Cycles on *tanδ* (longitudinal vibration) for Mulberry and Walnut Samples

Species	Source	d.f.	F	*p* value
Mulberry	Between Groups	3	6.12	< 0.001
	Within Groups	68		
Walnut	Between Groups	3	15.498	< 0.001
	Within Groups	128		

Table 2. Duncan Multi-comparison Test for the Effect of Soaking Cycles on *tanδ* (longitudinal vibration) for Mulberry and Walnut Samples

	Mulberry	Subgroups (α=0.05)		
Soaking Cycle	Sample volume	1	2	
0	18	0.0118		
1	18		0.0105	
2	18		0.0098	
3	18		0.0097	
	Wallnut	Subgroups (α=0.05)		
Soaking Cycle	Sample volume	1	2	3
0	33	0.0130		
1	33		0.0111	
2	33			0.0096
3	33			0.0096

Table 3. Longitudinal Wave Velocity Before and After Soaking Cycles (m/s)

Soaking Cycle	Mulberry		Walnut	
	Average	SD	Average	SD
0	3508	389	4136	293
1	3467	393	4100	294
2	3480	358	4152	297
3	3509	378	4177	293

The relationship between damping coefficients of the specimens after soaking cycles with those of unsoaked ones showed no significant correlations. The effect of soaking cycles on the damping coefficient ratio ($tan\delta_n$ after n[th] soaking cycle to $tan\delta_0$ of the preliminary unsoaked specimens) was illustrated in Fig. 2. More soakings after the first cycle has not any more significant effect (p<0.01) on the decrease or increases of $tan\delta_n$ (Damping coefficient of n[th] soaking cycle) in comparison with $tan\delta_0$ (damping coefficient of preliminary unsoaked specimens). But considering the p<0.05 the 2nd soaking cycle might be more effective on the decrease of damping coefficient especially in walnut specimens. It was assumed that the presence of water soluble extractive contents might be helpful to explain the observations.

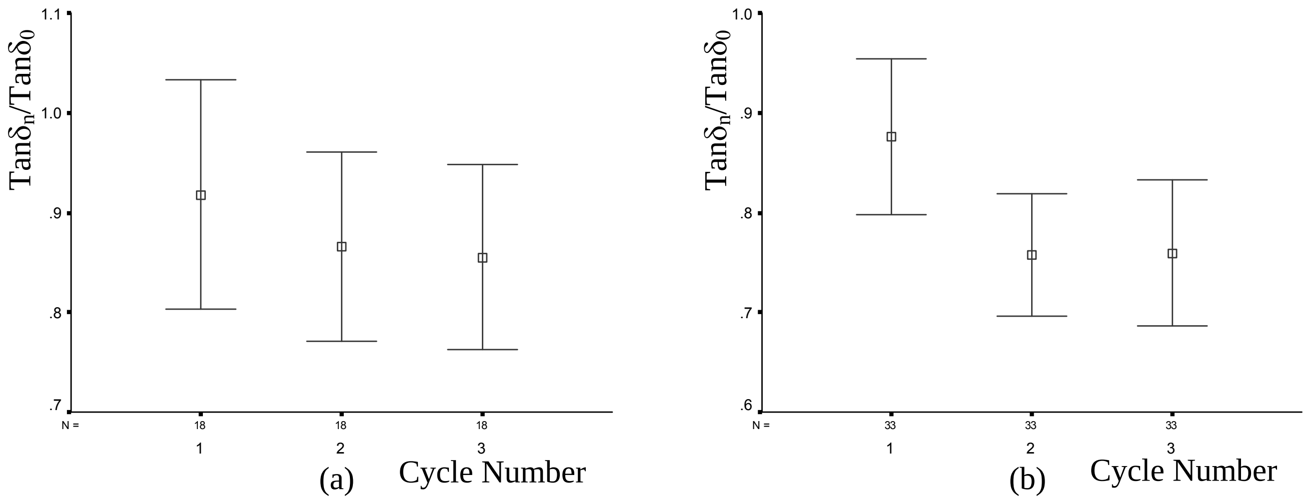
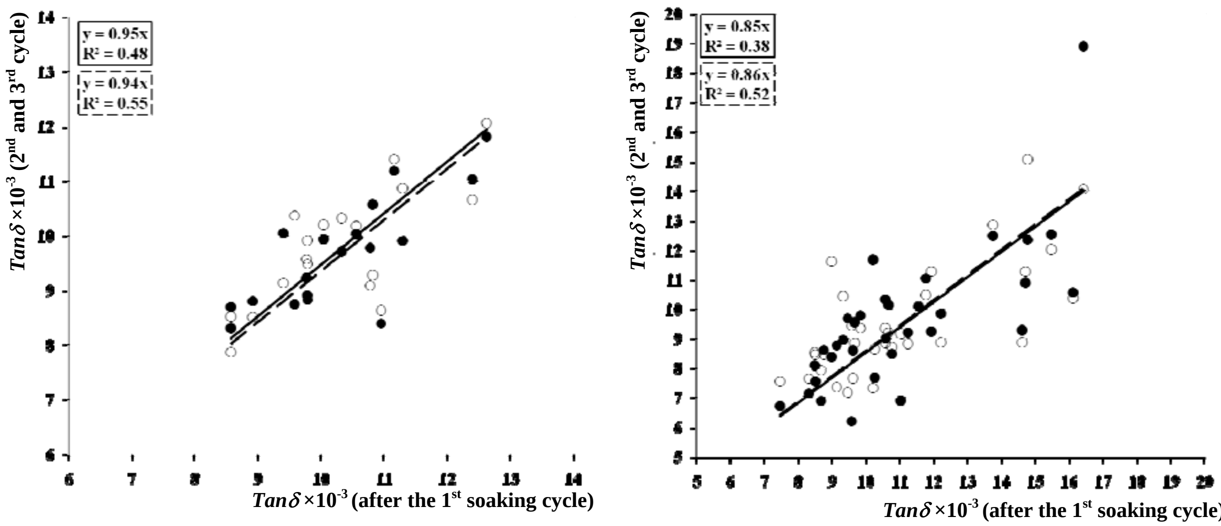


Fig. 2. Effect of soaking cycles on the mean value of the damping coefficient ratio ($tan\delta_n$/ $tan\delta_0$) for (a) Mulberry and (b) Walnut. With $tan\delta_n$: damping coefficient after n[th] soaking cycle and $tan\delta_0$: damping coefficient of the preliminary unsoaked specimens. Standard deviations marked by the error bars

This approach was continued in Fig. 3 (a, b), which compares the second and third soaking cycle with the first one. Figure 3 showed significant correlations and suggested that during the first soaking cycle the main stage of the probable extraction must have been done. It was certainly found out that the 3[rd] soaking cycle was not necessary.

The effect of soaking cycles on the longitudinal wave velocity was also investigated. Table 3 showed the averages for every set of specimens. There were no significant velocity shifts for the first mode of longitudinal vibration due to soaking in distilled water. So the longitudinal specific modulus of elasticity which is defined as the square value of the sound velocity in Eq. 2, remained quasi-constant after soaking cycles. As there was no significant change in densities after soaking cycles, it could be found out that even the main extraction during soaking in distilled water had not affected the densities.



(a) (b)

Fig. 3. Relationship between damping coefficient *tanδ* after the first, second and third soaking cycle (a: Mulberry, b: Walnut, o: after the 2cd cycle, •: after the 3rd cycle)

DISCUSSION

The presence of soluble water extractives seemed to be an important factor in the acoustic properties of the woods. The damping coefficient is primarily known to be influenced by the microfibril angle (Ono and Norimoto 1984). Furthermore, Obataya (2000) showed that the damping coefficient can be expressed with the viscoelastic parameters of the cell wall constituents. This acoustic parameter was also influenced by the presence and the chemical composition of extractives (Yano 1994; Obataya 1999). As the testing specimens in different soaking steps were the same, indeed, the soaking in water (the sole independent factor that was varied) significantly reduced the damping coefficient for both species under study. In the case of mulberry, the unsoaked specimens were categorized in a separate group and all the three soaking cycles were categorized in another group. This showed that a 24 hours soaking treatment under defined conditions might be sufficient for mulberry specimens. Besides, the walnut specimens might be soaked in two consecutive cycles (excessive drying between two initial cycles might be omitted) to reach their lower damping coefficient. Furthermore, soaking continuation will not decrease the damping coefficient, and more failure may occur as a result of excessive wetting and drying.

Based on the asserted experience of Iranian traditional instrument makers and musicians, mulberry and walnut have been considered among the best woods for resonator boxes. However, practice shows that wood pieces in the absence of water soaking but processed in the same way by similar luthiers can result in instruments of varying qualities. One soaking cycle may decrease the damping coefficient but also might homogenize this property. In other words, the unsoaked specimens showed different irrelevant damping values, while this property changed to similar relevant values after soaking in water.

Walnut and mulberry are frequently used in sides, ribs, backs, and top plates of resonator boxes in tar (an iranian bowl-shaped string instrument), setar (an iranian bowl-shaped string instrument), santour (an iranian trapezoid-shaped string instrument), and tombak (an iranian percussion instrument). But based on previous studies, every wooden part in varieties of musical instruments must exhibit some special sounding qualities (Wegst 2006); a piece of wood suitable for bows may be unsuitable for sound boards. As a result, one of the above-mentioned applications might be improperly interpreted and reported for the top plate. Wood for sound boards must exhibit damping coefficients between 0.003 and 0.01 with 4000 to 6500 m/s speed of sound propagation (Weigst 2006). So, even the soaked mulberry with 0.0097 damping and 3400 m/s longitudinal sound velocity would not be a suitable wood to be used in making the top plates in resonator boxes (it is used traditionally for the top plate e.g. in setar). It might be replaced with a potentially more suitable species in Iranian traditional instruments. Soaked walnut may occasionally be appropriate at a lowest margin ($\tan\delta$=0.0096, V=4150 m/s). This species sometimes sounds suitable as the top plate of Iranian traditional santours. Regarding to the acoustic and mechanical characteristics of soaked mulberry and walnut specimens introduced in this study, and considering the quality limits provided by Wegst (2006), both the mulberry and walnut are suitable for backs and ribs of resonator boxes, and their outstanding pieces might marginally meet the qualifications for sound boards or wind instruments. These two species are not recommended to be ever used in violin bows, xylophone bars, or piano actions due to their smaller modulus of elasticity, sound velocity, and inappropriate density and damping coefficient, accepted for these special applications. it is also suggested that for obtaining more clarity, the extractives soluble in hot water and alcohol and acetone should be studied. Finding any manipulation methodologies to adjust the acoustic properties of wood species is highly appreciated by the authors.

CONCLUSIONS

Specimens of mulberry and walnut were tested in free-free longitudinal vibration in order to assess the damping coefficient (or internal friction associated with the first mode) and the longitudinal wave velocity. These vibration tests were performed to study the effect of water soaking of woods in traditional musical instrument industries in Iran. It was shown that:

1. The water soaking of mulberry and walnut had a significant effect on the damping coefficient values. The damping coefficients were lower after water soaking.
2. Several soaking cycles were not necessary for mulberry. Two soaking cycles made it possible to reach the lower damping coefficient value for walnut.
3. No significant relationships were found for the damping coefficient before and after soaking. However significant links were found between the first and the other steps of soaking.
4. There were no significant velocity shifts for the first mode of longitudinal vibration due to soaking in distilled water. The dynamic modulus of elasticity also did not vary.

5. The process of soaking in Iranian musical instrument manufacture decreased the damping.
6. Mulberry and walnut woods are used traditionally as the top plate of setar and santoor. Based on this study, these species must be replaced (even the soaked pieces) with a more suitable species that could meet the qualifications of the sound boards, introduced in the literature (e.g. Wegst 2006). Some outstanding pieces of these woods might occasionally be qualified.

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