Indonesian Wood as Material for Acoustic Guitars and Violins

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Abstract

Traditionally, acoustic guitars and violins are made from European woods. Spruce is most preferred for the top plate (soundboard), whereas maple, sycamore and rosewood are often used for the back plate. However, these woods are not easily available in Indonesia. In this paper, we present a study on the suitability of a selection of Indonesian woods, namely acacia, mahogany, pine, sengon and sonokembang, as materials for acoustic guitars and violins. The most important acoustical properties for selecting materials for musical instruments, i.e. the speed of sound, the sound radiation coefficient and the damping factor, were investigated. Furthermore, the performance of pine and mahogany were tested by making them into a violin and a guitar. The vibration frequency spectrum and the damping factor of the top plate were measured. The results show that the acoustical characteristics of mahogany are very close to those of maple and still quite close to those of Indian rosewood, which makes it a very suitable local material for back plates. Pine has quite similar acoustical characteristics to spruce. Although its sound radiation coefficient is slightly lower, its aesthetic appeal and workability makes pine a suitable alternative for top plates. However, instruments with pine top plates exhibit different tonal colour compared to instruments with spruce top plates, due to some differences in the vibration frequency spectrum. Furthermore, the generally higher damping factors of pine and mahogany compared to those of the European woods should be taken into account, because they affect the sustain-time of the generated sound.

Keywords: Indonesian wood, sound radiation coefficient, damping factor, frequency spectrum.

Introduction

Despite the significant increase in the range and sophistication of musical instruments nowadays, the range of material from which the instruments are manufactured has changed remarkably little. The arrival of alloys, polymers and composites do not change the fact that vital parts in most musical instruments are still made of natural materials, primarily from wood (Wegst 2006). In the class of chordophones, i.e. instruments that rely on stretched strings to make sound, e.g. violins, guitars, and pianos, wood-based instruments are still preferred.

Acoustic guitars and violins produce sound due to the interaction between the vibrating strings and the wooden plates that form a hollow space underneath. The quality of the sound, among others, depends on the acoustical properties of the woods being used. Therefore, the choice of wood for the top plate (soundboard) and the back plate is an important factor. Because acoustic guitars and violins were developed and perfected in Europe, it is understandable that the traditional materials for these musical instruments are European woods. Based on centuries of experience, spruce (*Picea* sp.) is the most preferred choice for top plates, whereas maple and sycamore (both *Acer* sp.), as well as rosewood (*Dalbergia* sp.) are often used for back plates (Yano *et al*. 1997; Wegst 2006).

The aforementioned woods are not easily available in Indonesia. However, Indonesia has vast area of forests with around 4000 types of wood (Martawijaya *et al*. 1986). A number of local craftsmen have used local woods to make acoustic guitars and violins, but the choice of wood is mainly based on trial and the wood's aesthetic appeal. At the moment, data on the types of Indonesian wood that can be used as material for musical instruments, as well as their acoustical properties, is not yet available.

The most important acoustical properties for selecting materials for musical instruments are the speed of sound, the sound radiation coefficient and the damping factor. The speed of sound, which is directly related to the modulus of elasticity and density, shows how fast sound travels through the material. The sound radiation coefficient, sometimes referred to as the acoustical admittance, describes the ability of the material to radiate sound. The higher the sound radiation coefficient, the louder the sound it produces. This factor is also dependent on the material's modulus of elasticity and density. The damping factor measures the degree to which a material dissipates vibration energy by internal friction. It is independent of the material's modulus of elasticity and density. A lower damping factor will give a longer vibration and, thus, a more sustaining sound.

Following the method of Yano *et al*. (1997), Rines (2001) carried out measurements on the dynamic Young's modulus (E/γ, ratio of stiffness to specific gravity) and damping of a number of Indonesian woods. He concluded that sonokeling (*Dalbergia latifolia* Roxb.) has adequate acoustical properties to be used as material for guitar and violin back plates. Ikhfan (2004) studied the influence of wood processing, i.e. drying in a 100°C oven, boiling in water and boiling in alcohol-benzene, towards the vibration and acoustical properties of some Indonesian woods. He found that pine (*Pinus merkusii* Jungh et De Vr.), which has been boiled in alcohol-benzene, has suitable properties as material for guitar and violin top plates.

In this paper, we present a study on the suitability of a selection of Indonesian woods, namely acacia (*Acacia mangium*), mahogany (*Swietenia mahagoni* Jacq.), pine, sengon (*Paraserianthes falcataria*) and sonokembang (*Dalbergia latifolia*), as material for acoustic guitars and violins. Furthermore, the performance of pine and mahogany were tested by making them into a violin and a guitar. The goal is to obtain a comparison on the vibration and acoustical properties of these woods against those of European woods frequently used for violin and acoustical guitars, namely spruce, maple and rosewood.

Materials and Methods

In the first part of the study, the elasticity modulus, density and damping coefficient of the woods were investigated.

Modulus of Elasticity

A three-point bending test was carried out in accordance to the DIN 52186 standard (Deutsches Institut für Normung 1978) to find the modulus of elasticity of the woods. Each type of wood was made into five specimens of 30 mm width x 30 mm depth x 480 mm length, with the wood grain parallel to the length. The test was done using a Torsee Universal Testing Machine. A concentrated bending load was applied at the center with a span of 450 mm, see Figure 1. Data on the load were recorded for every 0.25 mm increase in deflection. The modulus of elasticity E (N/m^2) was then calculated by

$$E = \frac{PL^3}{48\Delta I} \tag{1}$$

where P is the proportional load (N), L is the length of the span (m), Δ is the deflection of the specimen corresponding to the applied load (m), and I is the moment of inertia of the specimen (m^4). Before and after testing, the moisture content of each specimen was also measured.

Density

The density ρ (kg/m^3) of the woods was determined from data of the mass m (kg) and volume V (m^3) of the specimens by the equation:

$$\rho = m/V \, . \tag{2}$$

A Mettler Toledo digital scale with a readability of 0.01 g was used to find the mass. The volume was calculated from the dimension of the specimens. The width, depth and length were each measured using a micrometer at three different points, two near the ends and one at the middle. All values were taken at air-dry condition with around 15% moisture content, based on the consideration that the wood will normally be at such condition when used as a violin or guitar top plate. Therefore, it is the density at this condition that will influence the acoustical properties.

Damping Factor of the Wood Specimen

For measurements of the damping factor, ten specimens of 34.8 mm width x 8 mm depth x 288 mm length was made from each type of wood, following the method of Noyce (2004). The test was carried out by clamping a specimen 20 mm on one of its end, and fixing an accelerometer on the other free end. The accelerometer (Bruel and Kjær type 4397) was connected to a charge amplifier (Bruel and Kjær type 2635) and a signal analyzer (Bruel and Kjær type 2035), see Figure 2. The free end of the specimen was given an initial displacement, after which the vibration was recorded. From the graph of amplitude versus time, we can determine the logarithmic decrement δ of the vibration, which is the natural logarithm of the ratio of any two successive vibration amplitudes. The damping factor ξ was then calculated by

$$\xi = \delta / 2\pi \, . \tag{3}$$

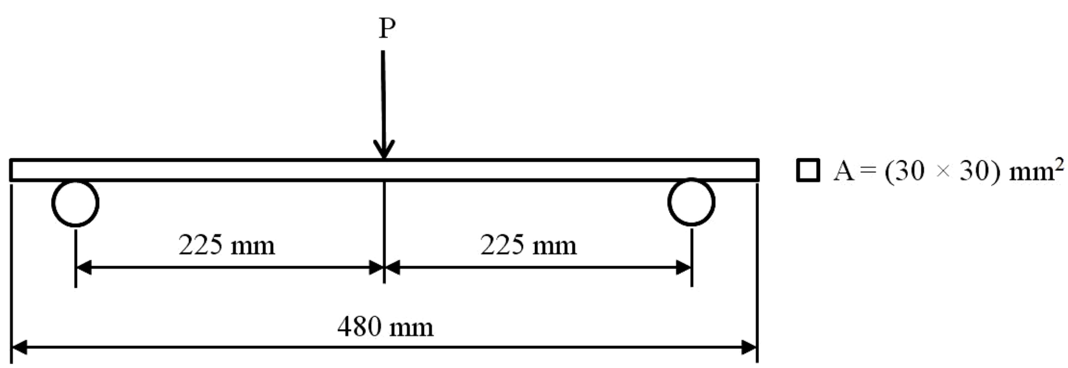

Figure 1. Three-point bending test in accordance to DIN 52186.

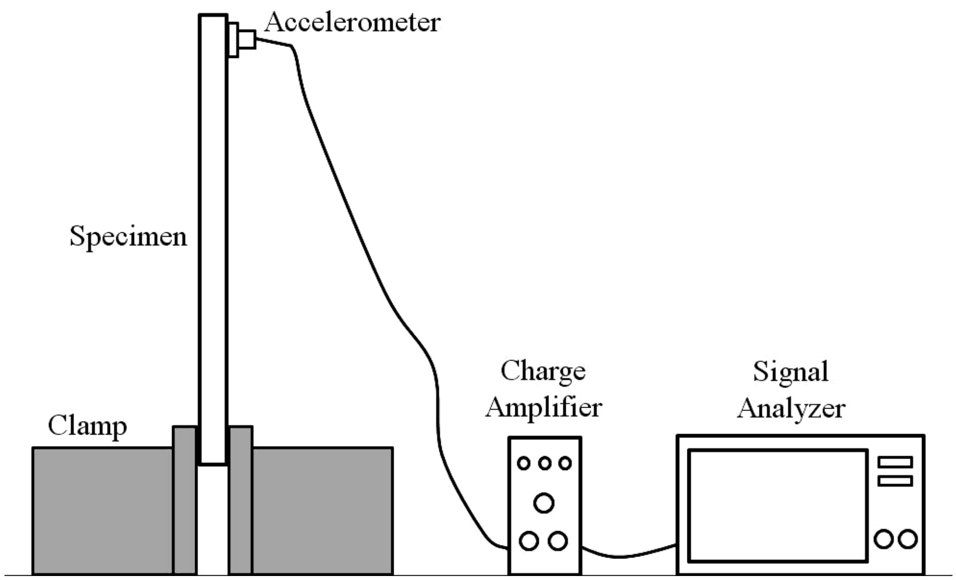

Figure 2. Set-up for measuring the damping factor of wood specimen.

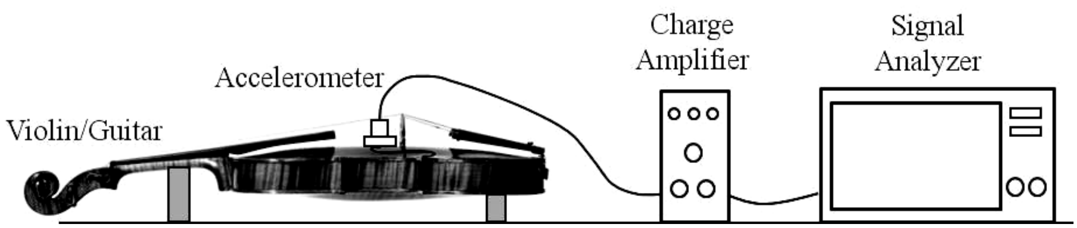

Figure 3. Set-up for measuring the vibration frequency spectrum and the damping factor of the guitar/violin top plate (drawing not to scale).

For the second part of this study, we ordered a violin and an acoustic guitar from local craftsmen using pine as the top plate and mahogany as the back plate. Then we carried out measurements to find the vibration frequency spectrum and the damping factor of the top plate.

Vibration Frequency Spectrum

This measurement was carried out using the experimental set-up depicted in Figure 3. The accelerometer was fixed at the top plate of the violin or the guitar, closely behind the bridge. The strings, which have been tuned to its standard frequency, were one-by-one plucked (for the guitar) or bowed (for the violin) in a free condition, i.e. not pressed anywhere along the fret-board. The vibration was then recorded using the signal analyzer, which was set to record amplitude versus frequency. From the graph, the frequency spectrum can be analyzed.

Damping Factor of the Top Plate

This experiment used the same set-up as depicted in Figure 3. The strings were one-by-one plucked (for both the guitar and the violin) in a free condition and the vibration recorded. Here, the signal analyzer was set to record amplitude versus time. From the graph, the damping factor can be analyzed.

Results and Discussion

Results from the first part of the study consist of data on the modulus of elasticity *E*, density *ρ* and damping factor ξ of acacia, mahogany, pine, sengon and sonokembang. The first two parameters were used to calculate the speed of sound *c* (m/s) and the sound radiation coefficient *R* by the equations:

$$c = \sqrt{\frac{E}{\rho}} \tag{4}$$

and

$$R = \frac{c}{\rho} = \sqrt{\frac{E}{\rho^3}} \,. \tag{5}$$

The above acoustical properties were then compared to those of spruce for top plates, and Indian rosewood and maple for back plates, as given in Table 1 and Table 2.

It should be first noted that, while the measured densities of the other woods relatively matched those found in previous studies, the measured density of acacia was found to be quite high, i.e. 908.3 kg/m^3. As a comparison, the study by MacDicken and Brewbaker (1984) stated that the density of acacia ranges from 420~600 kg/m^3. Therefore, an adjustment was made for the calculation of

Table 1. Speed of sound and sound radiation coefficient of selected Indonesian woods.

Type of Wood	E (GN/m^2)	ρ (kg/m^3)	c (m/s)	R
Acacia	6.07	500[b]	3485	6.97
Mahogany	5.81	605.2	3105	5.19
Pine	7.37	442.5	4080	9.23
Sengon	4.69	285.2	4045	14.22
Sonokembang	6.74	742.6	3000	4.05
Spruce[a]	15	480	5590	11.64
Indian Rosewood[a]	17	790	4640	5.87
Maple[a]	11	750	3830	5.11

[a] As comparison, from Haines (1979); [b] Adjusted value, from MacDicken and Brewbaker (1984).

Table 2. Damping factor of selected Indonesian woods.

Type of Wood	Logarithmic decrement, δ	Damping factor, ξ
Acacia	0.353	0.056
Mahogany	0.491	0.078
Pine	0.263	0.041
Sengon	0.284	0.045
Sonokembang	0.436	0.069
Spruce[a]	0.138	0.022
Indian Rosewood[a]	0.119	0.019
Maple[a]	0.232	0.037

[a] As comparison, from Haines (1979).

Table 3. Damping factor of the violin top plate in response to the vibration of the strings.

String	ξ Pine-Mahogany	ξ Spruce-Maple
G	0.041	0.021
D	0.011	0.041
A	0.021	0.016
E	0.022	0.019

Table 4. Damping factor of the guitar top plate in response to the vibration of the strings.

String	ξ Pine-Mahogany	ξ Spruce-Mahogany
E	0.016	0.022
A	0.030	0.026
D	0.031	0.021
G	0.041	0.019
B	0.028	0.013
E’	0.036	0.021

the speed of sound and the sound radiation coefficient for the acacia, in which we used a density of 500 kg/m^3.

From Table 1, we can see that, amongst the investigated local woods, sengon gives the highest sound radiation coefficient, which is even higher than that of spruce. This initially indicates that sengon can be a good material for the top plate of a violin or a guitar. However, in practice, factors such as aesthetic appeal and workability are also of influence. The grain of sengon does not make an interesting or beautiful top plate. Furthermore, the wood is too soft and pliant, such that it is easily deformed and difficult to process.

The second highest sound radiation coefficient is given by pine, which is fairly close to that of spruce. Its parallel grain gives an interesting pattern. Also, the wood structure is not too soft and pliant, so it is very workable. Hence, pine can be an alternative material for the top plate. Based on its density, pine is quite close to spruce. Therefore, it can be categorized as softwood, which is suitable for violin and guitar top plates. Nevertheless, we should also consider that, from Table 2, the damping factor of pine is almost twice that of spruce. This means that the sustainability of sound produced by a pine violin will be shorter than that of a spruce violin. However, amongst the other local woods, the damping factor of pine is still the lowest.

When comparing to maple and Indian rosewood, which both have sound radiation coefficients between 5 and 6, then mahogany gives the closest value amongst the other

(a)

(b)

(c)

(d)

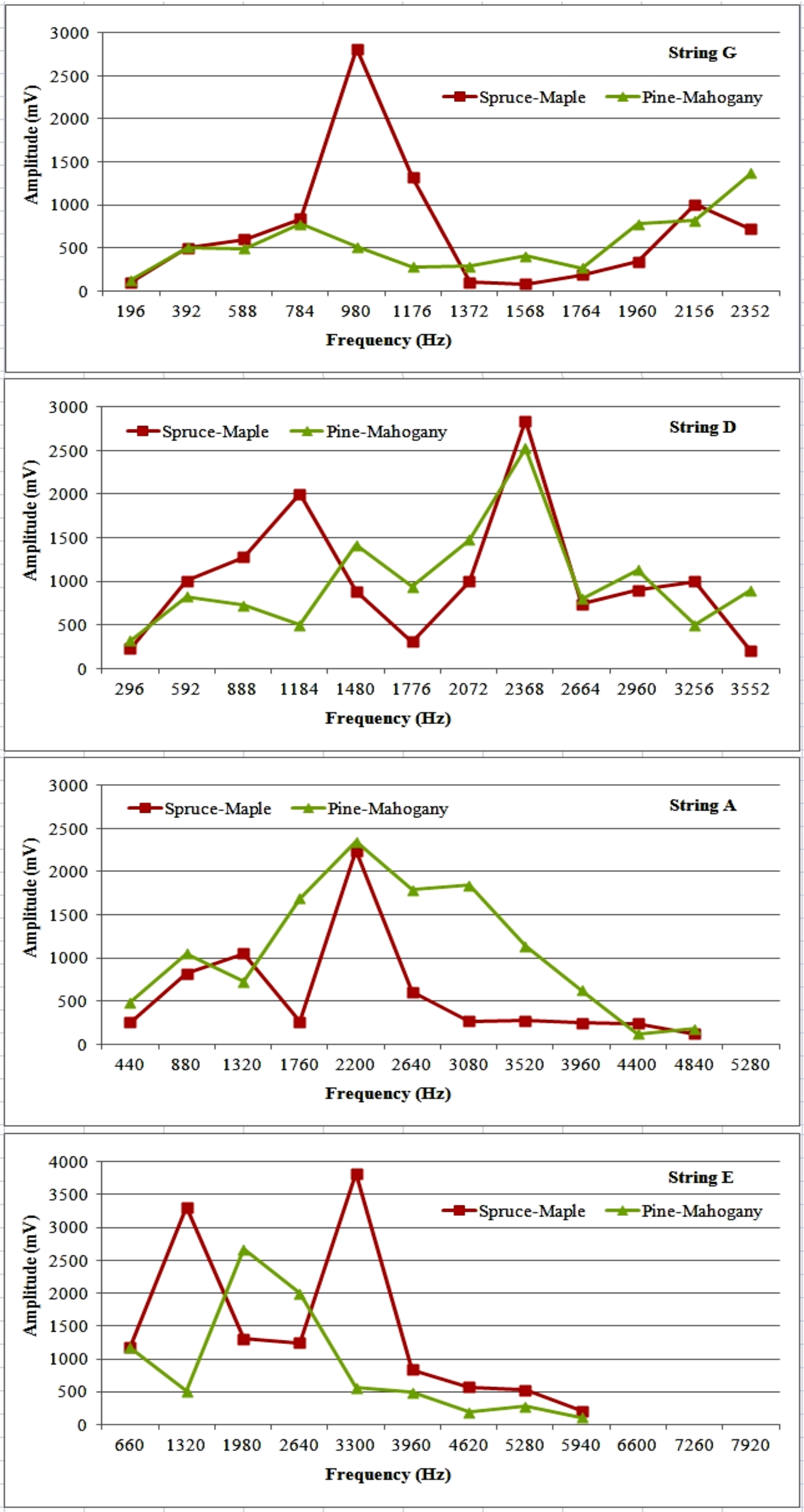

Figure 4. Vibration frequency spectrum of the violin top plate in response to the vibration of strings (a) G, (b) D, (c) A and (d) E.

selected local woods. These three woods are categorized as hardwood. This is a required property for back plates, as it functions as a reflector for the air oscillations within the body of the instrument (Wegst 2006). Thus, in terms of its sound radiation ability, mahogany is a very suitable wood for back plates of violin or acoustic guitars. However, once again we need to take into account that its damping factor is also around twice that of maple, and even much higher than that of Indian rosewood.

It is based on the above findings that we used pine for the top plate and mahogany for the back plate of the violin and acoustic guitars for the next part of the study.

Based on the second part of the study, we constructed graphs of the vibration frequency spectrums of the top plate of the pine-mahogany violin, in response to the vibration of strings G, D, A and E. These are presented in Figures 4 (a) to (d), respectively. Comparison was made against data from the top plate of a European-made spruce-maple violin, which we also measured. From these graphs, we see that the characteristics of the pine-mahogany violin are quite similar to those of the spruce-maple violin, particularly at the fundamental up to the third harmonic frequency. Exception applies for the response due to the vibration of string E, which is close to that of the spruce-maple violin only at the fundamental frequency.

It is also observed from the graphs that, at higher frequencies, the pine-mahogany violin generally exhibits stronger amplitudes. Since the vibration of the top plate acts as a resonator to amplify the vibration of the string, then the sound produced by the instrument will also be influenced. In this case, the pine-mahogany violin will give a more sonorous sound compared to the spruce-maple violin.

We have not yet measured the vibration frequency response of the top plate of the pine-mahogany guitar. However, based on the above results, we may expect that the characteristics of the pine-mahogany guitar at the fundamental and lower harmonics will also be somewhat similar to those of the spruce-mahogany guitar. A different tonal colour between the two guitars may be expected due to differences in the spectrum at higher frequencies.

The damping factors of the pine top plate in response to the vibration of the strings were measured for both the pine-mahogany violin as well as the pine-mahogany guitar. From Tables 3 and 4, it is shown that instruments with the pine top plates generally produce sound with somewhat shorter sustain-time, due to their slightly higher damping factors. The pine-mahogany violin, in particular, has a significantly shorter sustain-time for string G compared to the spruce-maple violin, but a significantly longer sustain-time for string D. The sustain-time for string G in the pine-mahogany guitar is also fairly shorter than that in the spruce-mahogany guitar. On the other hand, it is slightly longer for the lower string E.

Conclusions

This study was performed with the aim to investigate the suitability of a number of Indonesian woods, namely acacia, mahogany, pine, sengon and sonokembang, as material for acoustic guitars and violins. The most important acoustical properties for selecting materials for musical instruments, i.e. the speed of sound, the sound radiation coefficient and the damping factor, were investigated. Furthermore, the performance of pine and mahogany were tested by making them into a violin and a guitar. The vibration frequency spectrum and the damping factor of the top plate were measured.

The results show that the acoustical characteristics of mahogany are very close to those of maple and still quite close to those of Indian rosewood, which makes it a very suitable local material for back plates. Pine has quite similar acoustical characteristics to spruce. Although its sound radiation coefficient is slightly lower, its aesthetic appeal and workability makes pine a suitable alternative for top plates. However, instruments with pine top plates exhibit different tonal colour compared to instruments with spruce top plates, due to some differences in the vibration frequency spectrum at higher frequencies. Furthermore, the generally higher damping factors of pine and mahogany compared to those of the European woods should be taken into account, because they affect the sustain-time of the generated sound.

We finally add that the perception of instrument makers, musicians and audience toward the sound generated by the instruments, as well as the aesthetic appeal of the woods, may also influence whether or not pine and mahogany can really be acceptable alternatives for making violins and guitars.

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