

ASSESSING THE VIBROACOUSTIC PROPERTIES OF BAMBOO BASED COMPOSITE SOUNDBOARDS IN VIOLIN

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Abstract:

In this research, the application of the method in microphone array to the sound quality of the violin soundboard will be evaluated by the vibro-acoustic properties of the bamboo. The appropriate methods in corresponding process are composed of bamboo physical properties, texture, soundboard processing, surface geometry procedures and soundboard thickness which further establish the sound characteristics of handmade violin. To create the best sound quality of violin, the properties of Taiwan Moso bamboo species, sound quality and processes have to be combined. The acoustic features, fine aesthetics and sound quality of violin will be highlighted. Furthermore, this research will predict the performance of sound quality by integrated the factors as the vibro-acoustic of the bamboo soundboard, processes and the sub-assembly structure etc. However, the entire evaluation of violin sound quality will be recorded via the analysis, vibro-acoustic characteristics, bamboo histological, processing technology and matched combination. Therefore, the sound characteristics and current status of violin (such as moisture content, dimensional stability) are monitored by the microphone array measurement to establish the reference of handmade violin quality by bamboo. The bamboo violin tones are periodic which the harmonics are more consist and coupling to correlate the bright and clear sound performances. The wooden violin acoustic has richer anharmonic and overtones which the peaks and overtones are correlated to create the better loudness and thickness sound performances. Further study about the sound performance of violin which is made by the combination of bamboo and wood for more advanced explanations about timbre characteristics.

Key words: soundboard; bamboo; vibroacoustic; microphone array; violin.

INTRODUCTION

Bamboo is an anisotropic, heterogeneous and viscoelastic material. Due to its excellent physical and mechanical properties, bamboo is extensively used as the construction and building materials. It is a plant of rapid growth hence its use will contribute to the reduction of the use of non-renewable and polluting materials such as steel and concrete (Aditanoyo et al. 2017). Considering these characteristics, bamboo can be created as diversity functional materials. In addition, increased the various applications of bamboo will reduce the global warming caused by the indiscriminate use of industrialized materials. However, few studies have been carried out to establish the physical and mechanical properties of bamboo with the objective of optimizing its use as music instrument applications.

The properties of bamboo are always varying in the directions of parallel and perpendicular to the grain. Therefore, traditional modal frequencies and damping constants would not satisfy into the particular soundboard with the characteristic performing sound, which is dependent of the shape and the boundary conditions. Detections of violin's sound characters are hierarchically depended on the vibration and acoustic properties of soundboards (Schwarze et al. 2008; Tsai et al. 2005). According to the previous research was widely used the accelerometer to measure the instruments vibration property (Guan et al. 2015). However, the transducer mass effects are significant impact factor and mathematic model theory could affect the accuracy of the measurement and results which would be to practical estimate the vibro-acoustic properties and sound performance of the violin objectivity (Yoshikawa 2007). Each instrument is a unique product of plant genetics, the terrain and climate that grew the tree, and the skill of the maker (Obataya et al. 2000; Ono 1996). As the most string instruments, the researches were studying about the vibration and acoustic of violin soundboard which relevant evaluation indexes from the vibration's traits of efficiency, tone, the diffusivity of sound and so on. (Zhou et al. 2014).

The vibro-acoustic behavior of the violin's structure is often quite complicated. (Suzuki 2007). The physical properties, texture, process, surface geometry procedures and thickness (or depth of figure) of violin soundboards obtained significant influences on the quality and character of its sound (Tandona and Choudhury 1999; Yost and Zhong 2014). The acoustic properties of soundboard are influence on the factors, as (1) dynamic specific modulus, (2) acoustic impedance, (3) radiation ratio, (4) damping ratio, and (5) acoustic conversion efficiency (Ouis 2002; Rossing 2010). By the way, only few researches specific focus on the process technology of the boards with the geometry of board, thickness, surface characters, combinative methods and punching conditions.

As a luthier engraves the soundboards which regards to depth of figure that is accurate to the tenth of a millimeter. Along with the sound post, bass bar and bridge, the thickness of the soundboard figure strongly correlates to the instrument's sound (Peeling et al. 2007). Varying wood soundboards bring considerable range of sound quality despite similar thicknesses and homogenous wood grain appearances (Legg and Bradley 2016; Ono and Isomura 2004). Especially, there are few reports which have studied the Taiwan bamboo vibroacoustic of the violin. The top of the soundboard was usually graduated to about 2.4~2.7mm except in the area around the sound post, which is usually thicker. The back's thickness was shaped differently: thicker towards the middle and thinner at the edges. There were several methods (such as caliper, vibrating mode shapes...etc.) used to determine the optimal thickness distribution on the soundboards (Noguchi et al. 2012; Schwarze et al. 2008).

The microphone array method is based on the acoustic mapping techniques which combined with near sound source method, supervised learning network, and blind source separation. In this method, according to the vibro-acoustic properties of the soundboards that can be modified on the region and indicated whether and where the shape and thickness of the soundboards need adjusting which would be defined though the acoustic mapping results (Liu et al. 2008; Long and Chien 2018).

In this experimental method, the microphone array measured the response of the violin soundboard above the surface points to construct acoustic response holographic mapping. This research was focused on the violin making procedures which related to the bamboo, shape and thickness of soundboard to its sound performance. Although, the regulation of the sound quality with modified the shape, thickness and various types of bamboo features was not an easy task. The results were obtained the acoustic parameters by using the microphone array method which could be provided to the luthier during the engraving soundboard process.

OBJECTIVE

The main objective of the present research was to evaluate the acoustic characteristics on Moso bamboo violin soundboard, not only the relations between the vibration and thickness, also a comparison with a spruce plate, to study the acoustic performance between both soundboards. In final expectations, we hope to see how the resonance appears on the board carved and the relations between how much it was carved, or how much should the thickness and the curve be to get a brighter sound, and developed templates and methods for bamboo violin. The final acoustic evaluation tests which will compare the sound performance of a wooden (as spruce-maple) and a bamboo made violin which be demonstrated by the professional violinist.

Spruce, traditional material for violin top plate, has low density and low characteristic impedance, which makes it classified as the best material for radiating sound. Please note that sound radiation coefficient is speed of sound divided by density. The traditional materials such as spruce and maple have similar characteristics which well sound radiator and has sufficiently high characteristic impedance to act as a reflector for air oscillations in the hollow body (Rujinirun et al. 2005). Some comparison of how bamboo performs well as soundboard material versus other common materials have been done (Widijaja 2000). It was found that bamboo has a high sound radiation coefficient, closes enough to that soundboard materials, back plate materials (Jun 2006; Wegst 2008). In addition, impedance matching of the strings and the soundboard which is proportional to the characteristic sound impedance and to the square of the soundboard's thickness.

In this research, vibro-acoustics characteristics of a bamboo-based violin are studied particularly related with the soundboard an acoustic analyzing. The spectrum consists of fundamental frequency along with overtones at integer multiples of the fundamental. The fundamental frequency defines the pitch while the overtones gives the sensation of timbre. A comparison of results to both bamboo and wooden violins are also provided. It is expected that the sound characteristic of bamboo violin can be described in more detail.

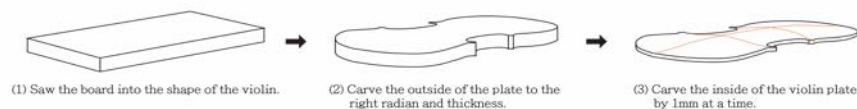
MATERIAL, METHOD, EQUIPMENT

Soundboard Specimens

This research used two types of soundboard samples; Moso bamboo (*Phyllostachys edulis*), Spruce (*Picea abies*) and Maple (*Acer opalus* ssp. *obtusatum*) panels were purchased from Taiwan and EU. The radial direction of wood panel was selected as the specimens. Laminate bamboo penal by used polyvinyl-

acetate adhesive (PVA). The soundboard specimens were cut into 410mm (length), 240mm (width), 18mm (thickness). There have been many attempts to modify the basic shape and geometry of violins by Guarneri 'del Gesù', whose models were used in this research (Fig. 1). The construction differences between bamboo and maple specimens were obtained carefully studied, including the geometry and physical properties (Zhou et al. 2014), depth of figure (6), varnishing methods (7), and so on. During the experiment, all the specimens were controlled under the same atmospheric environmental conditions at 24°C and 65% RH.

(a). Arching the sound board construction



(b). Graduating the sound board thickness

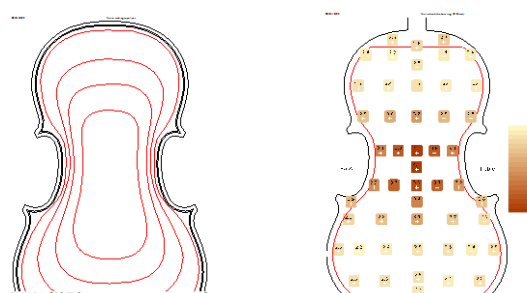


Fig. 1.

The arching and graduating are modified basic shape and geometry of violins by Guarneri 'del Gesù'.

Testing Apparatus and Vibroacoustic Measurement

The vibration test was used to first conducted on each full size of panel under free-free support condition. The vibration model shaker was located at the sound-post of the board to generate the vibration (Fig.2). The vibration response was detected by the laser vibrometer (PDV-100, Polytech). The measuring frequency varied from 0 to 3,200 Hz on the dimensions of the specimens which the experimental data were collected using FFT analyses (PULSE 3560C, B&K). The vibration properties were post-calculated by the frequency response function (FRF)(Brüel & Kjær,1999). Furthermore, the damping ratio ($\tan\delta$), acoustic impedance, radiation ratio, acoustical conversion efficient (AED) were calculated (Noguchi et al. 2012).

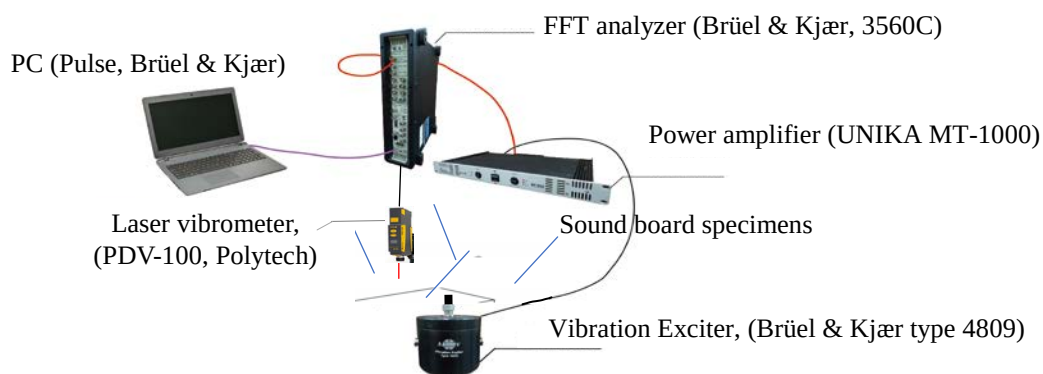


Fig. 2.

Free-free vibration method for uncontacted measuring the vibration properties of the soundboards.

Microphone Array Test

The research developed the microphone array method apparatus in the laboratory for evaluating the vibroacoustic properties with the depth of soundboard figure. The apparatus consisted of 12 free-field 1/4" microphones (44pp QC microphone, GRAS) showed as Fig.3. Then the conduct the comparison between the analysis of vibroacoustic, tone quality with the database which the estimate about the position of audio vibration and the quality. Then the soundboard specimens were arched and graduated from full size panel according to Guarneri's. It estimated the change of acoustic properties which was affected by the vibroacoustic which was acquired by the depth of soundboard figure that is accuracy as well as the significance influence with the sound quality. A LabView based software was written and used to collect and process both the acoustic signal and calculated the acoustic mapping program (Acoustic mapping, Xwin) which was integrated with near sound source method, supervised learning network and blind source separation method.

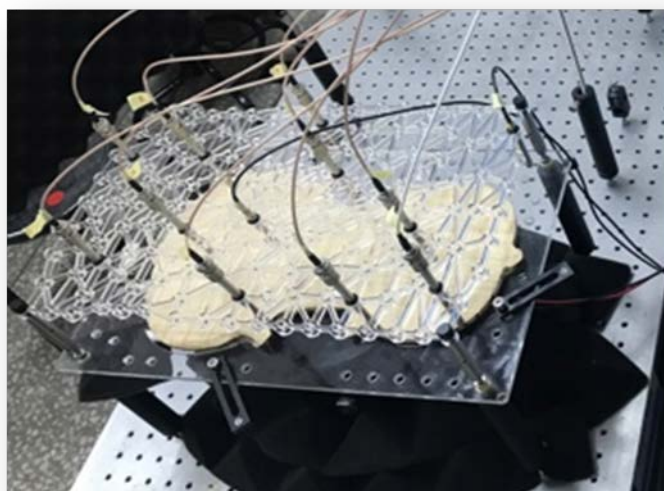


Fig. 3.

The microphone array measuring setup for the acoustic mapping of violin soundboards.

The Evaluation Test of the Violin Sound Performances

In this research, the figure of bamboo violin has been modified for creating the acoustic characteristics as Guarneri's. A wooden (spruce-maple) violin which made by Fei Shen 1989, is used for comparison. The evaluator, who is a professional performer, the tested both the spruce and bamboo violins which were used same strings set and bow. Each of four strings played the note at G3 (196Hz), D4 (293Hz), A4 (440Hz), and E5 (660Hz). The radiated sound of violin was recorded by an omnidirectional acoustic digital recorder which placed at a distance 120 cm and a high 120cm. All of the measurement was done in the hemi-anechoic chamber that could avoid undesired environmental noise. The set of measurement can be seen in Fig. 4.



Fig. 4.

The violin performing measurement was done in the hemi-anechoic chamber that could avoid undesired environmental noise.

RESULTS AND DISCUSSION

Vibrational Properties of Bamboo Soundboard

Table 1 lists the characteristics of the tested soundboard specimens. The spruce samples showed lower MOE_d , lower $\tan\delta_L$, and slightly higher R than the bamboo samples. As the MOE_d and R of bamboo strongly depend on its density (ρ), the higher MOE_d and R values of the spruce which may be attributed to their high ρ values. However, the high ρ values do not account for the high sound velocity ($V_L = (E_L / \rho)^{1/2}$) and low $\tan\delta_L$ of the aged wood because V_L and $\tan\delta_L$ do not depend on ρ , but on the viscoelastic properties of the wood cell wall [10]. Because the microfibril angle (MFA) of the bamboo was almost the same. However, the MFA was not a major reason for the high V_L and low $\tan\delta_L$ of the bamboo.

Table 1

The acoustic properties of various specimens for the violin soundboards

Wood Species	Density (ρ) (kg/m ³)	Sound velocity (V_L) (km/s)	MOE_d ¹⁾ (GPa)	Acoustic radiation ²⁾ (R) (m ⁴ /s.kg)	Damping coefficient ³⁾ ($\tan\delta_L$) x10 ⁻³	ACE ⁴⁾ (km/s)
Moso Bamboo	0.8(0.1)	5.2(0.2)	21.3(1.0)	6.5(1.2)	3.1(1.7)	2096(99)
Spruce	0.4(0.1)	5.1(0.3)	10.2(1.3)	12.6(1.5)	4.7(1.3)	2686(202)
Maple	0.6(0.1)	4.3(0.4)	11.1(1.2)	7.2(1.8)	5.7(1.9)	1257(142)

¹⁾ MOE_d (GPa) = $V_L^2 \rho$

²⁾ Acoustic impedance (R) = $(MOE_d / \rho^3)^{1/2}$

³⁾ Damping coefficient ($\tan\delta_L$) = $1/Q$, $Q_{factor} = f_{center}/\Delta f$, f = frequency (Hz)

⁴⁾ Acoustic conversion efficiency (ACE) = $R / \tan\delta_L$

The obtained results show that the density of the bamboo was higher values than spruce and maple soundboards. By comparing the sound velocity obtained for the bamboo is between spruce and maple. There is significant relationship between sound velocity and MOE_d . Furthermore, acoustic radiation (R) is extractives effect the acoustical properties of resonance soundboards. The effectiveness of sound radiation is evaluated by the acoustic conversion efficiency (ACE) defined as $R/\tan\delta_L$. Therefore, theoretical calculation has shown that low ρ , high MOE_d / ρ ($= V_L^2$), and low $\tan\delta_L$ result in increased sound radiation from spruce soundboards. ACE is an important factor in the evaluation of the "loudness" of a soundboard; however, it is not a direct indication of the viscoelastic properties of the wood cell wall because it strongly depends on ρ . Therefore, ACE is proportional of ρ and it can be directly correlated with the viscoelastic properties of the wood cell wall [13]. The ACE values of the wood samples are listed in Table 1. The higher ACE values of the wood soundboards are indicative of their superior acoustic quality. The results show ACE value of maple is lower than bamboo. Therefore, the bamboo is higher V_L and lower $\tan\delta_L$ than maple indicate that the effectiveness of sound radiation from the wood was better than that from the wood.

Acoustic Mapping of Soundboard

The sound quality of a soundboard mainly depends on its frequency response. The quality of the soundboard is not only determined by the loudness of the sound but also by the quality of the tone. In other words, the sound quality factor that represents the anisotropic nature of the wood or bamboo cell wall. This research obtained the soundboard vibroacoustic features of violin and its shape and depth of figure which will be applied to conduct the assessment and improvement the loudness and sound quality of the soundboards. As shown in Fig. 5, that obtained a more uniform distribution of sound field with the thickness disparity under the tenth of a millimeter. Furthermore, increased the curvature thickness of the middle, and reduced the arch of the belly, and modified the depth of figure could modified the sound quality of the soundboard. The above-mentioned results indicate that microphone array method is an effective way to improve the acoustic quality of soundboards. It enhances the loudness without degrading the tone quality. This fact coincides with luthier' empirical observation that the quality of the soundboards improves with the figure and thickness.

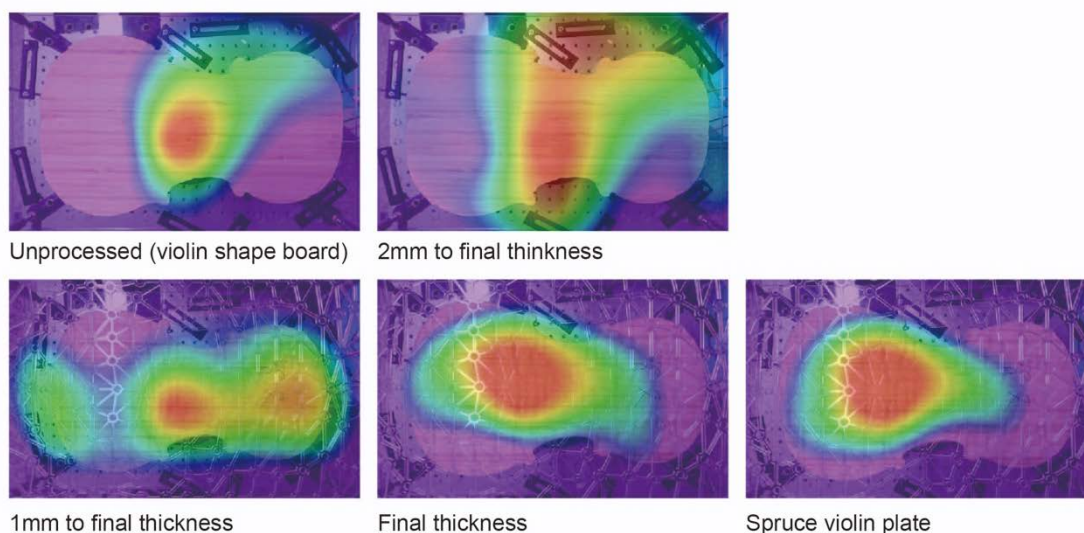


Fig. 6.
The acoustic images on different thickness on Moso bamboo and Spruce soundboards.

The thickness effect on bamboo board, the contour map spreads out at the center of the plate which contacts the sound post, the amplitude at this stage is 98dB. Carved the outside of the plate and the inside of the plate leaving 2mm to the final thickness, the contour map has spread wider and the amplitude is 108 dB. At 1mm to the final thickness, in addition to the position of the sound post, the upper and lower ends of the plate also have a loud sound phenomenon, sound amplitude at 103 dB.

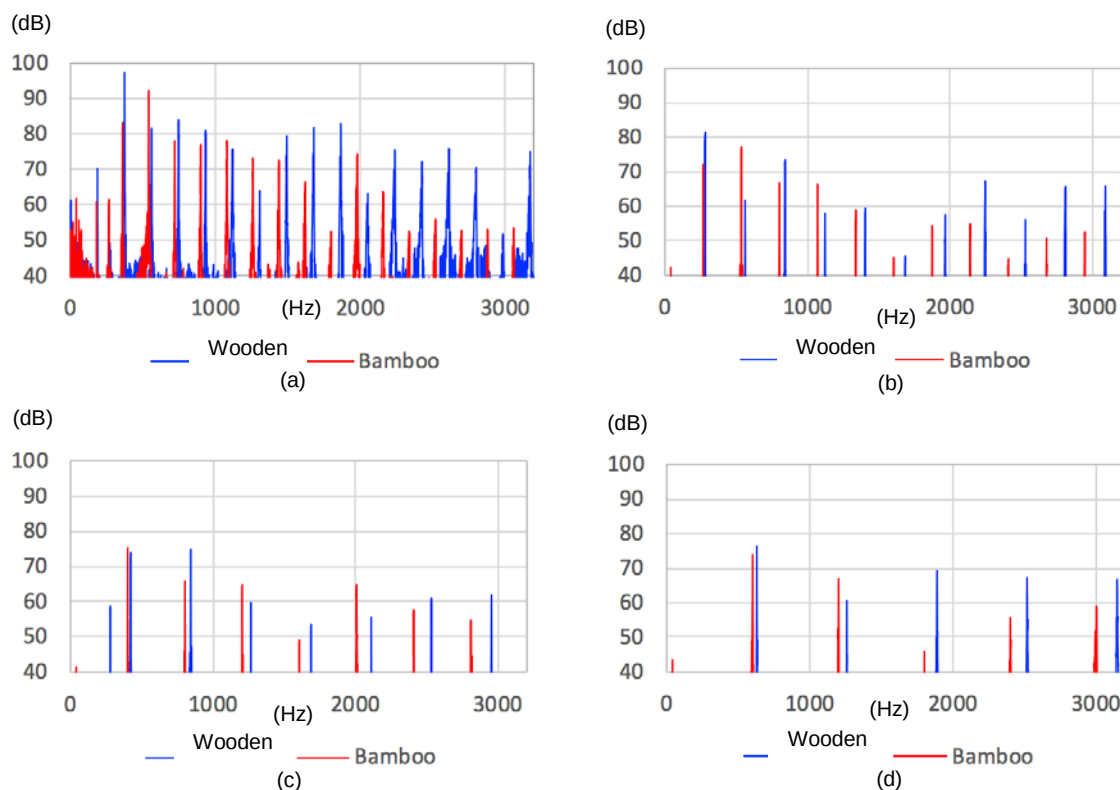


Fig. 7.
Comparison of acoustic spectrums on open string of wooden (spruce-maple) violin and bamboo violin (a) G3 (196 Hz); (b) D4 (293 Hz); (c) A4 (440 Hz); (d) E5 (660 Hz).

The Evaluation Test of the Violin Sound Performances

The sound tone from a violin is complex, arising from the bow pulls at the violin string. It is well known that any periodic waveform can be built up from a number of waves each of whose frequencies is a multiple of a fundamental. The multiples are called harmonics or overtones. A note on the violin may have 12 or more harmonics. Fig.7 shows the spectrums of the open G3, D4, A4 and E5 string of the violins and under the frequency range from 0 to 3200 Hz. The bamboo and wooden violins create different harmonics or overtones. The figure is shown the partial frequencies of wooden violin are not simple integer multiples of a fundamental which are called anharmonic. The wooden violin in the fundamental G3(196Hz), the anharmonic frequencies obtain in Table 2 which is exactly the 1st to 17th harmonics of G3 (196 Hz – 3200Hz). For D4 the 11th partial frequency has been alternately raised by 7 Hz to (C7)2058Hz. There is a slight rise (sharpening) in pitch by about half a semitone (3%). For A4 the 7th harmonic frequency has been raised by 5 Hz to 2205Hz. And E5, the anharmonic frequencies are not obvious as many as above. Therefore, the spectrums of the harmonic or anharmonic tones are found from the both wooden and bamboo violins. The bamboo violin tones are periodic which the harmonics are more consist and coupling to correlate the bright and clear sound performances. Anyway, the wooden violin acoustic has richer anharmonic and overtones which the peaks and overtones are correlated to create the better loudness and thickness sound performances.

Table 2

The difference values between partial frequency and the integer multiple of a fundamental of wooden and bamboo violin

Frequency (Hz) G3(192Hz)			Frequency (Hz) D4(293Hz)			Frequency (Hz) A4(440Hz)			Frequency (Hz) E5(660Hz)		
Harmonic No.	Bamboo	Spruce	Harmonic No.	Bamboo	Spruce	Harmonic No.	Bamboo	Spruce	Harmonic No.	Bamboo	Spruce
1			1			1			1		
2	0		2	0		2	0		2	0	0
3	0		3	0		3	0		3	0	1
4	0		4	1		4	0		4	0	1
5	0		5	1		5	0		5	0	1
6	0		6	1		6	0		6		
7	0		7	2		7	0		7		
8	1		8	0		8			8		
9	0		9	4		9			9		
10	0		10	4		10			10		
11	1		11	5		11			11		
12	2										
13	1										
14	2										
15	2										
16	2										
17	2										

CONCLUSIONS

This research used the microphone array method to promote the acoustic characters of flow about producing violin's backboard. The vibroacoustic properties of Moso bamboo was compared with Spruce and Maple. The bamboo shows greater stiffness (MOE_d), higher sound velocity (V_L), and lower damping ($\tan\delta_L$) than wood. ACE is an important factor in the evaluation of the loudness of a soundboard. The ACE of bamboo is lower than Spruce but higher than Maple. However, ACE values were only sufficiently for the full size of soundboards. The acoustic properties of the soundboard were strongly depended on not only the ACE, but also the depth of soundboard figure. Anyway, ACE value was only sufficiently for the full size of soundboards. This research used the microphone array method to obtain the acoustic mapping characters accurately the soundboard producing. According to the unique combination of different structural can be adjusted the vibroacoustic response by the improved sound quality of the soundboard in an engraving stage. Both bamboo and wooden violin have different spectrum patterns at same tones. The differences can be occurred during the histological, physical and distinctive figure of the soundboard. The bamboo violin tones are periodic which the harmonics are more consist and coupling to correlate the bright and clear sound performances. The wooden violin acoustic has richer anharmonic and overtones which the peaks and overtones are correlated to create the better loudness and thickness sound performances. Further study about the sound performance of violin which is made by the combination of bamboo and wood for more advanced explanations about timbre characteristics.

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