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Study on Acoustic Characteristics of Carbon Lattice Bracing Classical Guitar

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Abstract- Generally, classical guitars have a wooden top and fan bracing as their basic structure, which allows for rich tonal expression, but structurally limits the volume they can produce. Carbon fiber has a higher specific strength compared to wood, thus reducing the mass required to withstand string tension. Therefore, this paper developed a guitar with a new structural that utilizes carbon fiber for the top and lattice bracing. The carbon lattice structure aims to improve vibration efficiency and increase sound volume. Carbon lattice guitar this paper made has successfully reduced the weight more than 0.1 kg lighter than the standard guitar used in this paper. As a result, measurements with an oscilloscope confirmed that the carbon lattice guitar produces a louder sound than a standard guitar on all strings. Furthermore, analysis of the overtone spectrum using FFT analysis indicated the increasing of 2nd overtone, which has an octave relationship to the fundamental tone and is particularly highly harmonious. Furthermore, an improvement in the consonant interval factor, an indicator of tonal harmony, was also confirmed. These results suggest that when designing a classical guitar, in addition to the top material, consider the structure and material of the bracing can adjust the volume and tone. The findings obtained in this paper are expected to contribute to the optimization of the acoustic characteristics of classical guitars by serving one indicator for designing guitars using new materials and new structure.

Keywords: Classical Guitar, Bracing, Tone, FFT Analysis, Overtone, Consonant Interval.

I. Introduction

Numerous studies have been conducted on the guitar (Cuzzucoli & Lombardo, 1999; Suzuki et al., 2017; Wrzeciono et al., 2018). Authors have also been engaged in work such as proposing evaluation methods for the tone of classical guitars (Tanaka & Itako, 2021, 2022), comparing tones using these methods (Yabuta & Itako, 2024), and developing tone evaluation devices (Yabuta & Itako,2025). The top of a classical guitar serves to amplify the vibration of the strings, and while woods such as spruce and cedar are commonly used, each has different acoustic properties. Given this role, it can be said that the top has a significant influence on the tone. Furthermore, wooden bracing is attached to the back of the guitar top. In addition to reinforcing the top to withstand the tension of the strings, the braces play a role in shaping the tone by controlling how vibrations are transmitted throughout the top. Generally, classical guitars have a wooden top and fan bracing as their basic structure, which allows for rich tonal expression, but structurally limits the volume they can produce. In today's world, as concert halls grow larger and performance environments become more diverse, there is an increasing demand for higher volume levels and clearer acoustic characteristics. In response to this, new guitar designs have been developed with the aim of increasing volume by altering the structure of the bracing, such as lattice bracing. Lattice bracing structure is an internal structure of a guitar that uses bracing arranged in a lattice pattern on the back of the top. The structure that supports the entire top allows for a thinner top to achieve a louder volume while maintaining sufficient strength to withstand the tension of the strings. However, most standard guitars and those with lattice bracing structure are made of wood, and the sensitivity of wood to temperature and humidity changes can lead to changes in its acoustic characteristics over time, as well as warping of wooden components, which can potentially affect sound. On the other hand, carbon fiber has strong resistance to temperature and humidity changes and has a higher specific strength compared to wood, thus reducing the mass required to withstand string tension. Therefore, this paper developed a guitar with a new structural that utilizes carbon fiber for the top and lattice bracing. The purpose of this structure is to improve vibration efficiency while solving the problems associated with wood. The standard thickness of a guitar top is about 2 to 3 millimeters. By leveraging the advantages of the lattice bracing structure, which allows for an extremely thin top due to its design that supports the entire top, and the superior durability of carbon fiber, this paper designed and made the top with a thickness thinner than the standard. This paper aimed to further increase the volume through this guitar design. However, due to the thinness of the top, some performers feel that lattice bracing guitar suppresses the expressive qualities of the sound such as the rich, varied tone characteristic of classical guitars. Therefore, this paper also examined the acoustic characteristics of carbon lattice bracing guitars.

II. Standard Guitar and Made Carbon Lattice Guitar

In this paper, a guitar with a carbon lattice structure was made for the experiment. To obtain the characteristics of only the top and bracing, the top and bracing were removed from a standard shown in Figure 1(a), and a carbon material shaped like the lattice bracing and guitar top shown in Figure 1(b) was newly attached. The specifications for each guitar are shown in Table 1. The standard guitar used in this paper features fan bracing, and the top is made of spruce. The top is 3 mm thick, and the total weight of the guitar is 1.84 kg. The carbon lattice guitar this paper made uses carbon for the lattice bracing, and carbon was also used for the top. By reducing the top thickness to 0.5 mm, the total weight of the guitar was reduced to 1.71 kg.

(a) Standard guitar

(b) The carbon lattice guitar this paper made

Figure 1. The guitar used in the experiment.

Table 1. Guitar specifications.

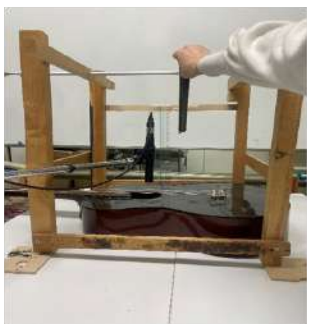
	Standard Guitar	Carbon Lattice Guitar
Top	Spruce	Carbon
Top Thickness	3mm	0.5 mm
Bracing	Fan Bracing	Carbon Lattice Bracing
Back & Side	Agathis	Agathis
Scale	650 mm	650 mm
String	AUGUSTINE RED	AUGUSTINE RED

III. Comparison of the Acoustic Characteristics of Standard Guitar and Carbon Lattice Guitar

3.1. Experimental Conditions:

AUGUSTINE RED strings were used. String measurements were taken with the strings in open strings. To ensure a consistent amount of energy was applied to the strings, the pendulum experimental system shown in Figure 2 was used, and all strings other than the one being measured were removed. Since the mass of the pendulum weight is 0.36 kg, the acceleration due to gravity is 9.8 m/s², and the pendulum is dropped from a height of 0.085 m above the string, so the energy imparted to the string is 0.30 J. Additionally, the plucking position was set 10 cm from the bridge. The microphone was placed in a straight line with the sound hole, 5 cm away from the guitar top.

(a) Potential energy 0J



(b) Potential energy 0.30J

Figure 2. Experimental system.

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3.2. Volume Comparison

A microphone (Audio-Technica AT4049a) and an oscilloscope (YOKOGAWA DL350) were used to measure the volume. The guitar sound was converted into an electrical signal by the microphone, and the peak-to-peak value was determined from the waveform of the signal output to the oscilloscope.

Figure 3 shows the results of the volume measurements. Carbon lattice guitar has been confirmed to produce a louder volume than the standard guitar across all strings. This is thought to be due to improved vibration efficiency resulting from the carbon lattice bracing structure. The increase in volume is particularly noticeable in the 4th to 6th string of lower strings. As shown in Figure 3, even on a standard guitar, the lower strings tend to produce more volume than the higher strings and cause the top to vibrate more strongly. Therefore, it is thought that the lightweight and high stiffness structural characteristics of the carbon lattice bracing structure were more effectively realized in the lower strings.

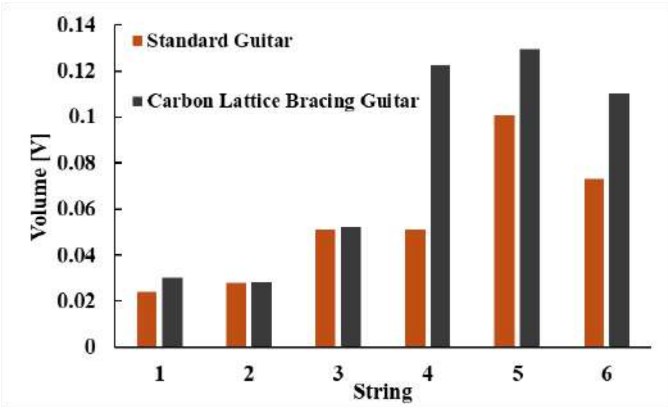


Figure 3. Volume measurement results.

3.3. Spectral Analysis

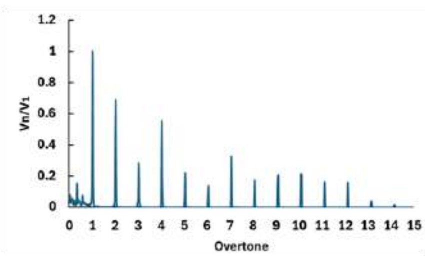
A microphone (Audio-Technica AT4049a) and an FFT analyzer (ONOSOKKI CF-3600) were used to measure the frequency spectrum. The measurement range was set to 0–5 kHz. Sound consists of a fundamental tone that determines the pitch, and overtones that determine the tone. As shown in Table 2, a classical guitar has six strings, with the 1st to 3rd strings are higher strings (nylon strings) and the 4th to 6th strings are lower strings (metal wound strings). The fundamental frequencies of each string are as follows: 1st string 330 Hz, 2nd string 247 Hz, 3rd string 196 Hz, 4th string 147 Hz, 5th string 110 Hz, and 6th string 82 Hz. Overtones have frequencies that are integer multiples of the fundamental tone, and the type of overtone is determined by the frequency ratio with the fundamental tone. Overtone has consonant intervals that are harmonic with the fundamental tone and dissonant intervals that are non-harmonic with fundamental tone. As characteristic features of each interval, consonant intervals are often perceived as clear sound, while dissonant intervals are often perceived as muddy sound. Table 3 (Tanaka & Itako, 2022) shows the classification of overtones into consonant intervals and dissonant intervals. As shown in the table, many of the higher overtones beyond the 7th are dissonant intervals. Therefore, in this paper, the range up to the 6th overtone is referred to as the consonant interval domain, and the range from the 7th overtone onward is referred to as the dissonant interval domain. Based on Table 2, the frequency spectrum obtained from the FFT analyzer was converted to an overtone axis. For each guitar, the spectra for each overtone component were compared.

Table 2. The fundamental tone of the guitar. **Table 3**. Classification of overtones.

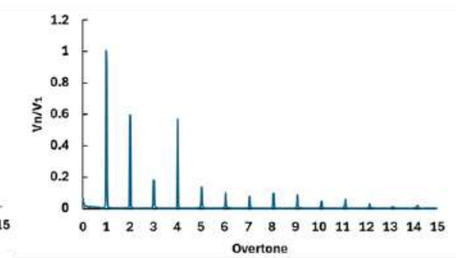
String	Fundamental Tone	Overtone	Type of Overtone
1	330	1	Fundamental Tone
2	247	2	Octave
3	196	3	Consonant interval
4	147	4	Octave
5	110	5	Consonant interval

6	82	6	Consonant interval
		7	Dissonant interval
		8	Octave
		9	Dissonant interval
		10	Consonant interval
		11	Dissonant interval
		12	Consonant interval
		13	Dissonant interval
		14	Dissonant interval
		15	Dissonant interval

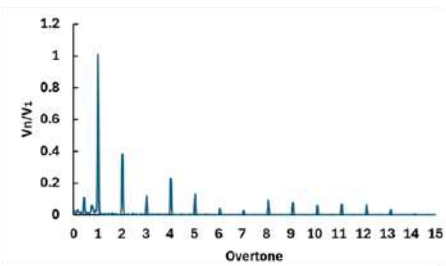
The results of the spectral analysis are shown in Figure 4. For the 1st and 2nd strings, the standard guitar showed a wide spectral distribution, with overtone spectrum visible even in the dissonant interval domain, whereas the carbon lattice guitar showed spectral concentration in the consonant interval domain. For the 3rd string, the standard guitar showed reduced spectral intensity for frequencies other than the fundamental tone. Similar to the 1st and 2nd strings, the spectrum of the carbon lattice guitar is concentrated in the consonant interval domain, but the results showed a particularly rich content of 2nd overtone. On the 4th string, the standard guitar contained more 2nd and 4th overtones, but no significant differences were observed between the two guitars regarding other overtone spectrum. On the 5th and 6th strings, the carbon lattice guitar produced a wide overtone spectral distribution compared to the standard guitar. Furthermore, on the 5th string, the 2nd overtone exceeded the fundamental tone. Unlike the higher strings, spectrum was obtained even in the dissonant interval domain. As shown in Figure 3, the volume of the 5th and 6th strings is particularly high, it is thought that their higher vibration efficiency compared to the higher strings resulted in a wider spectral distribution. Furthermore, while the 2nd overtone exceeded the fundamental tone spectrum only on the 6th string in the standard guitar, in the carbon lattice guitar, this occurred on the 3rd, 5th, and 6th strings—more than in the standard guitar. These results suggest that the carbon lattice bracing structure has the effect of producing a relatively more content of 2nd overtone. This is likely due to the use of carbon for both the top and the bracing, combined with the lattice structure of the bracing, which increased the overall stiffness of the top.
As a result, deformation of top during vibration is suppressed, and vibrations are transmitted more stably, which is thought to have resulted in an increase in 2nd overtone component that is octave related to the fundamental tone.



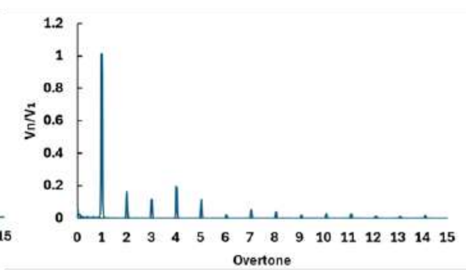
(a) Standard guitar 1st string



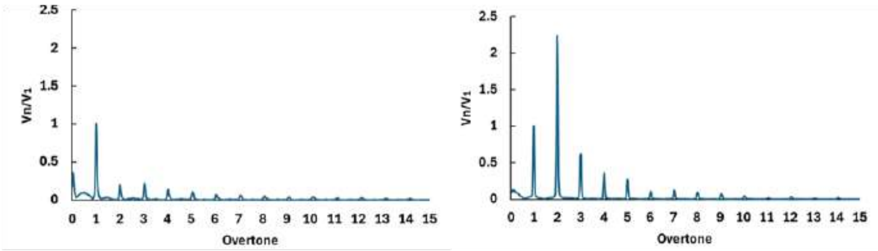
(b) Carbon lattice guitar 1st string



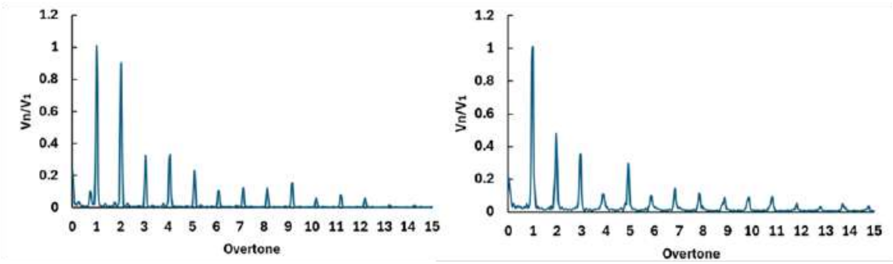
(c) Standard guitar 2nd string



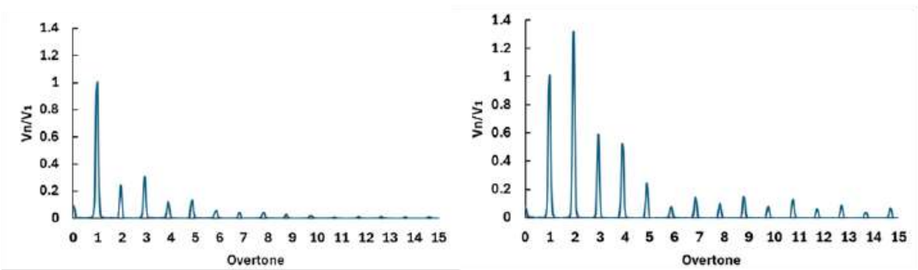
(d) Carbon lattice guitar 2nd string



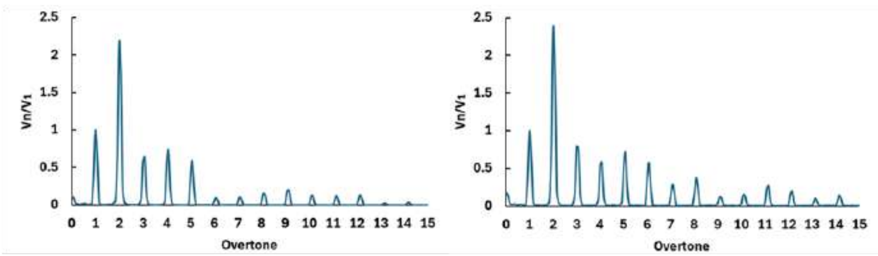
(e) Standard guitar 3rd string (f) Carbon lattice guitar 3rd string



(g) Standard guitar 4th string (h) Carbon lattice guitar 4th string



(i) Standard guitar 5th string (j) Carbon lattice guitar 5th string



(k) Standard guitar 6th string (l) Carbon lattice guitar 6th string

Figure 4. Spectral analysis results.

3.4. Tone evaluation

For consonant interval components and dissonant interval components of the obtained spectrum, this paper calculated the consonant interval factor (C.F.), which represents the balance between the consonant interval components and dissonant interval components normalized to the fundamental tone using equation (1). A higher value indicates that the consonant interval components are relatively more included compared to the dissonant interval components. Furthermore, previous research has shown that the spectrum of overtones beyond the 16th overtone is less than 1% of the fundamental tone's spectrum. Because of this low ratio, this paper assumed 16th overtone onwards have little effect on the tone. Therefore, this paper set the overtone measurement range from the 2nd overtone to the 15th overtone.

$$C.F. = \frac{\sqrt{\sum_n {V_{cn}}^2} - \sqrt{\sum_n {V_{dn}}^2}}{V_1} \quad (1)$$

V_1 : Volume of the fundamental tone [V], n : Overtone order (n=2,3,4,…)
V_{cn} : Volume of the consonant interval (n=2-6,8,10,12) [V], V_{dn} : Volume of the dissonant interval (n=7,9,11,13-15) [V]

Figure 5 shows the results of calculating the consonant interval factor. For most strings other than the 2nd and 4th strings, the consonant interval factor was higher for the guitar with the carbon lattice bracing structure. This result indicates that the carbon lattice bracing structure increased the relative magnitude of the consonant interval components to the dissonant interval components. Therefore, it was shown that the guitar employing the carbon lattice bracing structure can also contribute to an improvement in tone. This is thought to be due to the material properties of carbon. This result suggests that the thinness of the top in lattice bracing guitar does not necessarily cause a deterioration in tone quality and depending on the materials used, it may be possible to improve the tone compared to a standard guitar.

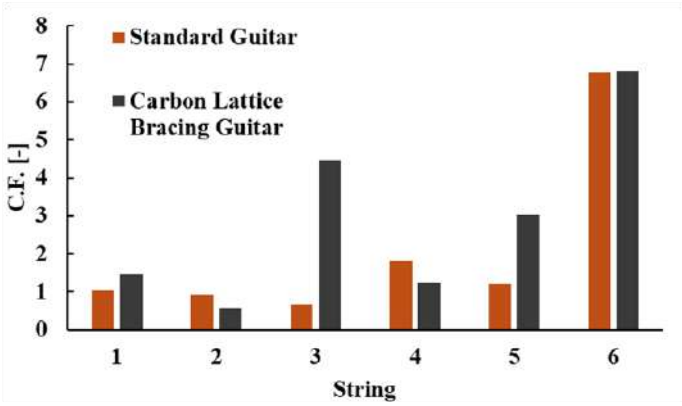


Figure 5. Analysis results of consonant interval factor

3.5 Sensory evaluation:

This paper conducted a questionnaire survey on perceived volume as a sensory evaluation. To evaluate the relative perception of the volume of the carbon lattice guitar compared to a standard guitar, subjects were asked to choose between “loud” and “quiet.” Figure 6 shows the results of the volume perception evaluation. The vertical axis indicates the number of subjects who reported that one of the two guitar types sounded louder. The carbon lattice guitar was perceived as louder than the standard guitar for all strings. Even with the higher strings shown in Figure 3, where the difference in sound volume as a physical quantity was small, the number of subjects who reported that the carbon lattice guitar sounded louder exceeded the number who reported that the standard guitar sounded louder. Furthermore, for the lower strings that exhibited a large difference in measured sound volume in Figure 3, most subjects reported that the carbon lattice guitar sounded louder, and the difference from the standard guitar was more pronounced on auditory perception. Therefore, it was confirmed that the measurement result of the physical quantity "The carbon lattice guitar has a louder volume than the standard guitar," as shown in Chapter 3.2, is also obtained in terms of auditory impression.

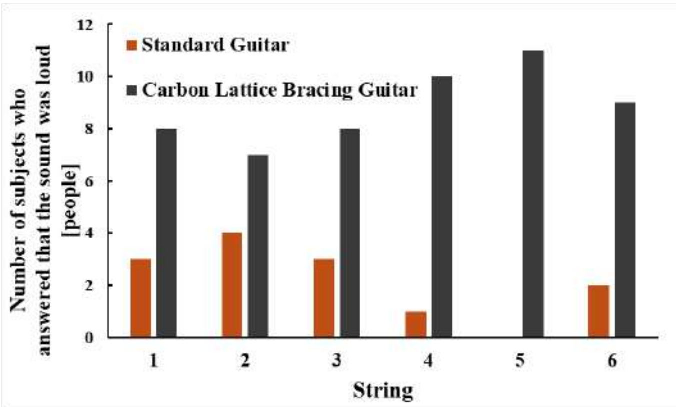


Figure 6. Evaluation of auditory perception of volume

IV. Conclusion

This paper proposes a new classical guitar that uses carbon fiber for the top and employs a carbon lattice bracing structure for the bracing, with the aim of increasing the volume of the classical guitar. The carbon lattice guitar successfully achieved a weight reduction of more than 0.1 kg and showed an increase in volume. The increase in volume was particularly pronounced in the low strings. It's thought that the lightweight yet highly stiffness structural characteristics improved the efficiency of vibration energy transmission. Furthermore, lattice bracing guitars are sometimes evaluated as lacking the rich overtone structure inherent to classical guitars due to the thinness of its top. The carbon lattice structure proposed in this paper improves the consonant interval factor for many strings, suggesting the potential to improve not only volume but also tone. This is thought to be due to the unique material properties of carbon. In addition, the carbon lattice guitar also tends to be perceived as louder than the standard guitar in terms of auditory perception, confirming the effectiveness of this structure as a method for obtaining a louder sound in classical guitars. These results show that, adjusting the volume and tone is possible by considering not only the material of the top but also the structure and material of the bracing when designing a classical guitar. The findings obtained in this paper are thought to contribute to the optimization of the acoustic characteristics of classical guitars by serving as one of the guidelines for guitar design using new materials and new structural designs. Furthermore, guitar bracing can be scalloped bracing, in which the surface of bracing bars are carved to create a curve, and non-scalloped bracing, in which the surface is left uncarved. The carbon lattice bracing structure proposed in this paper employs a non-scalloped bracing. In the future, investigating the acoustic properties of non-scalloped carbon lattice bracing structures with non-uniform lattice thickness is expected to lead to a further understanding of the effects of the bracing structure.

References

1. Giuseppe Cuzzucoli & Vincenzo Lombardo. (1999). *A Physical Model of the Classical Gui-tar, Including the Player's Touch*. Computer Music Journal, 23:2, pp. 52-69.
2. Akihiro Suzuki, Hisami Oishi, Hiroshi Hasegawa & Hiroshi Okamura. (2017). *The study of the aging effects for the classical guitar*. Dynamics & Design Conference 2017.
3. Piotr Wrzeciono, Wojciech Przybylski & Andrzej Ostrowski. (2018). *Guitar Sound Parameters to Assess the Impact of Atmospheric Conditions on the Acoustic Qualities of the Instrument*. 2018 Joint Conference - Acoustics.
4. Hagino Tanaka & Kazutaka Itako. (2021). *Investigation of a new evaluation method (Octave factor) for guitar tones using FFT analysis*. Journal of Advanced Science, Vol. 33, 33101.
5. Hagino Tanaka & Kazutaka Itako. (2022). *Investigation of a new evaluation method (Consonant interval factor) based on music theory for guitar timbre*. Journal of Advanced Science, Vol. 34, 34108.
6. Rio Yabuta & Kazutaka Itako. (2024). *Electrical Analysis of Classical Guitar for The Relation Between Plucked Position and Tone*. The International Council on Electrical Engineering Conference 2024.
7. Rio Yabuta & Kazutaka Itako. (2025). *Development of Tone Evaluation Device Using Electrical Methods*. The International Council on Electrical Engineering Conference 2025.