DESIGN, MANUFACTURING AND TESTING OF A CYLINDRICAL DRUM-SHELL USING A SANDWICH STRUCTURE

A. Damodaran[1, 2], H. Mansour[3], L. Lessard[2*], G. Scavone[3], A. Suresh Babu[1]
[1] Department of Manufacturing Engineering, Anna University, Chennai, India, [2] Department of Mechanical Engineering,[3] Music Technology, McGill University, Montreal , Canada
* Corresponding author: (larry.lessard@mcgill.ca)
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Abstract

A composite drum shell using carbon fiber suitable for replacing hardwoods in traditional drums was developed. An Indian drum called a *Chenda* was investigated and the acoustic characteristics are reported. The mechanical properties of jackfruit wood were taken as benchmark for designing the sandwich structure. A prototype was developed by hand layup and vacuum bagging technique. An improved tuning system using turnbuckles and spectra fiber ropes was implemented. Acoustic tests were performed and the frequency spectra of the wooden and composite drums were compared. The tuning of the instrument was monitored at the 342 Hz for both the composite and wooden shell. The frequency response of the wooden shell was stronger than that of the composites shell. Damping trends for both the wooden and composite drum shells were also compared. This study indicated that in contrast to traditional drum shell manufacturing, standardization and uniformity could be achieved from the composite manufacturing.

1 Introduction

Drums are the oldest musical instruments [1]. The sound is produced by striking a stretched membrane over the opening of either a frame, or a hollow body of any shape. The hollow body is referred to as the drum shell. In the present work, a traditional south Indian drum called a chenda was investigated (Figure 1). The chenda consists of cylindrical shell covered with a cow hide membrane on either side.The drum body serves the purpose of holding the stretched membrane. It must be sturdy to withstand the tension of the membrane and light enough to resonate well.One end of the chenda drum possesses a relatively high pitched tonal drum head and the other end possesses a relatively low pitched bass drum head. Tension chords are passed over the hoops and the pitch is heightened or lowered by varying the tension on the chords. This drum is widely used in temple festivals and as an accompaniment in the dance called *kathakali*. Historically, the material of construction of a drum shell is limited to certain species of hardwoods, namely the Jackfruit (artocarpus). For instrument builders it is often difficult to find a suitable piece of wood for making quality instruments. Hardwoods possess high density, termite resistance (protection from insects) and good acoustic qualities.

Recently the availability of quality hard woods for making music instruments has decreased. Moreover the quality of the particular instrument depends on the skill of the craftsman. Dimensional stability is also a major reason why wood alternatives are attractive in musical instrument construction. Warpage is a big problem as it can cause the contact surface to deviate with the skin out-of-plane, or make it an oval, which has more audible consequences. Both of these situations can lead to cracking of the wood, which commonly occurs in drum shells. To overcome these issues, this study focused on replacing the hardwoods used in traditional instruments with composite structures to produce sustainable lightweight drum shells.

The aim of this paper is to investigate the suitability of sandwich structures for drum shell applications. Drum shell structures are designed for compressive loads due to the presence of the drum heads resting on them. Based on experience, a value of 9000N/m was chosen to represent the axial compressive load that is equal to the load carried by the tensioning ropes. This paper reports the manufacturing aspects of drum shells and the acoustic testing of the drum.

Fig. 1.Traditional Indian drum (*Chenda*)

2 Background

In order to develop a shell structure for a drum from composites, it was required to know which mechanical properties lead to a good drum body and which non-traditional materials have been investigated in the past. If a new material is to replicate resonant properties of wood it is likely that it should also have similar mechanical properties.
Phillips and Lessard presented a good approach for the design and manufacturing of a flax fiber composite for music instrument applications [2]. From the above work it is clear that the design and the manufacturing of structures from composite materials is a complex, but feasible process.

It was shown that the target values for material properties can be designed and achieved within a relatively good precision. Applying this kind of design considerations will be an important part of the evaluation process of composite materials for use in musical instruments structures. Ono *et al*. [3] investigated the use of a wood plastic shell for the traditional Japanese drum *Wadaiko*. Their approach provided a baseline reference to assess the performance of alternate materials for drum shell applications. In their study, the vibrational characteristics and the frequency domain spectra were analyzed. A material with high specific modulus was shown to be desirable so that the structure is stiff enough to withstand the tension in the chords as well as light enough to resonate well. Sandwich structures, due to their light weight and high specific flexural properties, are an interesting alternative to wooden drum shells. Moreover by using suitable core materials in music instrument applications, the damping properties could be mimicked. Hence, the focus of this study is to design, manufacture and test a drum shell with a sandwich structure.

3 Materials and design

The selection of fiber, matrix and core was important in the shell design. A fiber that possesses a high specific modulus and high density has more potential for use as reinforcement. For this reason, unidirectional carbon fiber was selected.

An epoxy resin system was selected in the present manufacturing process as it offered better adhesion to the core than polyester.Sikadur-300 epoxy supplied by Sika Corporation, which is a high strength, high modulus and room temperature curing resin system suitable for the wet lay-up process.
Among the various core materials available, balsa wood was selected for the drum shell application. Balsa wood provides better damping properties than honeycomb core and can lead to an appropriate sized structure for music instrument applications [4].A light weight drum body is not suitable for a massive drum head, because the drum body has to provide a stable anchor as it vibrates. Hence the use of honey comb and foam core is not investigated further.

Before designing the layup, preliminary static tensile tests were carried out on Jackfruit (*artocarpus*) specimens. The average Young's modulus in the axial direction and the density are shown in Table 1. Classical laminate theory was used to predict the in-plane and bending stiffness of the laminate so that it could be tailored to that of Jackfruit. The final shell ply sequence was $[0_u]_s$ (where u= unidirectional and s= symmetric) with a core thickness of 10mm. This was achieved after careful design iterations. The deflection of the shell under the axial compressive load was calculated as 0.03mm. The simulation was carried out by ANSYS software.

Table 1. Average values of density and static modulus of Artocarpus species

Name of the species	Density(g/cc)	Modulus of Elasticity, E (Gpa)	Tensile strength (Mpa)
Artocarpus	0.505	8.75	70±20

The acoustic properties of a drum are largely dependent on the design of the bearing edge, which acts as the contact surface between the drum shell and the drum head membrane. Circumferential hoops/stiffeners were added at both top and bottom of the shell in order to mimic the desired tonal qualities as in the wooden drum.

4 Manufacturing

In order to make a quality part, the design of a mold is significant. The two factors which were considered were cost and the ease of manufacturing of the mold. A two-part mold (Figure 2) was manufactured using GFRP. The dimensions of the shell were 280mm diameter and 500mm height, which was based on the traditional drum. After the two-part mold was built, it was treated with release agents (Chemlease), and a wet layup manufacturing process was developed.

Fig. 2. The two-part GFRP mold

The unidirectional carbon fabric was cut to the required size and epoxy resin was applied evenly by keeping the fabric on a flat aluminum plate. This ensured uniform and faster wetting of the fabric. Once the entire fabric was impregnated with the resin, carefully lifted and placed in to the treated GFRP mold and aligned properly. The core structure was prefabricated, (Figure 3.) which reduced the lay-up time considerably. Both the bearing edges were smoothened with the help of a sand paper.

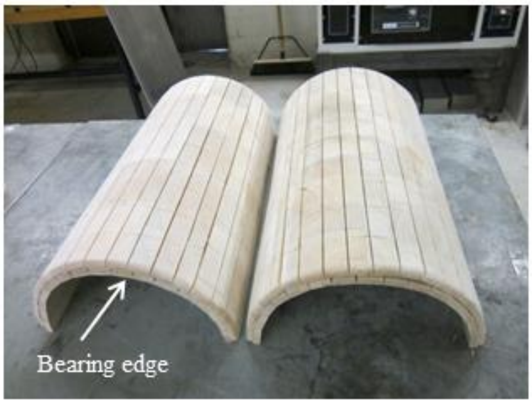

Fig. 3. Prefabricated balsa core

The above process was repeated for the second part of the mold. Tabs were provided for joining the two parts. The detailed procedure of the lay-up is illustrated in the Figure 4.The two parts of the mold were then joined with fasteners. Twelve M8 bolts were used to achieve proper sealing of the two parts of the mold.

Once the lay-up was completed, the vacuum bagging was carried out to consolidate the lay-up. The vacuum bag was made in the form of a straight tube. The nylon film material was supplied by Airtech, U.S.A. It was cut in to a rectangular shape and the tube shape was formed by joining the two longitudinal sides. The length of the tube is about 2.5 times longer than that of the mold and the diameter is 20% more than that of the outer diameter of the mold.

The tube was inserted to the inner part of the mold, folded and wrapped around the outer periphery of the mold. Further, the two sides of the tube were sealed concentrically with the help of a sealant tape (Figure 5.). This bagging technique could be adopted for making cylindrical parts with open type mold and can be easily reused. Once the bagging was completed the lay-up was consolidated under vacuum at room temperature for 24 hours.

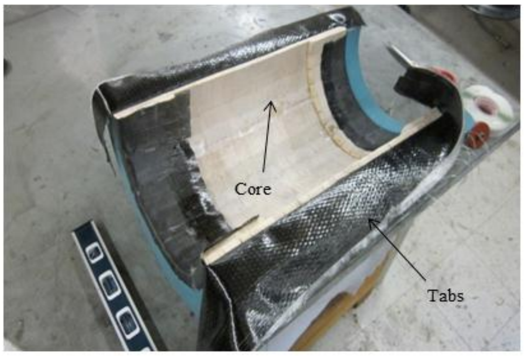

Fig. 4. Lay-up illustration

The finished chenda drum is shown in Figure 6. From the first prototype, a few surface defects were observed. These defects occurred due to the inability of the balsa core to follow the curvature of the mold. This presence of surface defects was also a result of uneven pressure application. Uneven edges were found at the bottom bearing edge of the shell, due to difficulty in placement of the core material. These surface defects were rectified by adopting a two stage hand lay-up procedure. The outer layer was cured first, and the core and the inner layer in the second stage. A shell with improved surface finish was obtained.

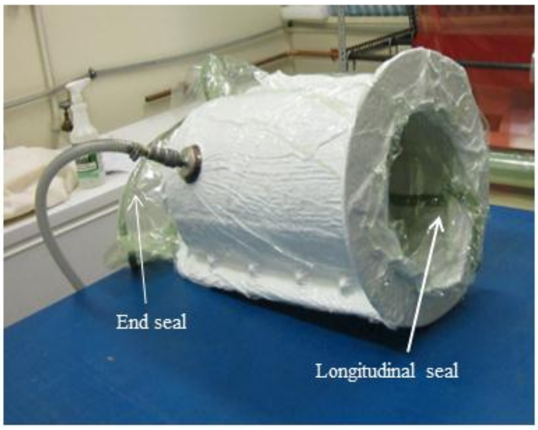

Fig. 5. Illustration of vacuum bagging

Once the drum shell was finished, the drum heads were attached to the shell with turnbuckles and spectra fiber ropes (8 mm. diameter).Twelve turnbuckles of jaw-jaw type stainless steel (AISI 316) were used for the assembly. Traditional cow hide membranes with circular hoops were used in the present study. Compared to the traditional assembly system, the improved materials provided an efficient tuning method which could be easily adapted to other drums as well.

Fig.6. Finished sandwich drum shell and final assembly

5 Prototype evaluation

5.1 Test procedure

We compared the manufactured composite shell with a traditional wooden drum shell, when a common skin was used on the two bodies. The skin was first tested on the composite body and then on the wooden body. To avoid any bias in the results caused by different tensions applied to the skin, the tuning of the instrument was monitored when replacing the skin and it was carefully adjusted to create the same fundamental frequency on both shells (at 342 Hz). It is likely that the tension of the skin was slightly different for the two situations as the geometry of the wooden and the composite bodies were not quite the same. The wooden body had a slightly smaller diameter and was slightly oval due to very cold conditions. The same adjustable tension chord system was used on both shells.

The skin was tensioned on the composite body for more than a week so there were chances that the skin was deformed and adjusted itself with the exact profile of the edge of the composite body, with a more uniformly distributed tension (this is indeed desirable to happen before an instrument is ready to be played). The situation could however be different for the case of the wooden body in which the skin was assembled on the instrument during the test. To eliminate such biases and also to check the repeatability of the experiment, after the second set of measurements on the wooden body the skin was placed back on the composite body and was re-tested.

In each of the three cases the radiativity was measured. Radiativity is computed by dividing the radiated sound by the excitation force in the frequency domain [5]. An impulse hammer with a plastic tip (PCB Model 086C01) was used to apply the force (in the form of an impulse) while a microphone (Bruel&Kjaer Type 4228) was recording the hit sound. The two synchronous recordings were then used to calculate the Frequency Response Function (FRF).

All measurements were made in a semi-anechoic room and the microphone was placed at the distance of 120 cm from the skin pointing normal toward the center of the skin. The drum was hung with free-free conditions to avoid any disturbance from boundaries. An average of five measurements in frequency domain was applied to cancel the effect of random environmental noises. This procedure was repeated for 23 points marked concentrically on the skin. Multiple points were used to give us flexibility to later select any point that does not fall on the nodal line of any modes of the skin in the frequency range of interest. No effort was made in this study to extract the mode shapes, although they should not be far from the ones predicted by simple theoretical modes of an ideal membrane [6], or the ones reported in the literature of other membrane-type percussion instruments [7]. Figure 7 shows the experimental setup for the measurements.

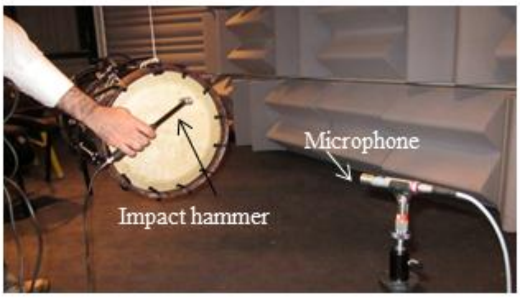

Fig. 7. Acoustic test setup

To summarize, the raw material to evaluate different cases were three radiativity plots for the same point selected on the skin when the skin was stretched on the composite shell, the wooden shell, and the composite again.

5.2 Discussion

The frequency spectra of the three above-mentioned cases were compared up to the frequency of 1800 Hz and are shown in Figure 8.

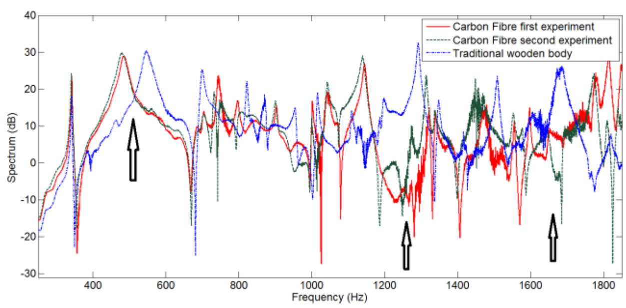

Fig. 8.Radiativity of the carbon fiber chenda, first repetition (Solid red line), the composite chenda, second repetition (dashed green line) and the traditional wooden chenda (dashed-dotted blue line). Black upward arrows show the areas of systematic dissimilarity between the wooden and carbon fiber bodies (discussed in text)

The general trend of all graphs is quite similar, and as was expected the frequency of the first mode perfectly matched for all three cases. The two repetitions of the same experiment on the composite shell showed a slight difference. The major source could be the fact that the edge of the body does not touch the exact same circle on the skin, which may lead (among other consequences) to a different position of the excitation point relative to the body edge. The composite body behaves slightly different than the traditional wooden body that we tested. The most significant differences are illustrated in Figure 8. The first and most obvious difference is the significantly higher frequency of the second mode for the wooden body (575 Hz vs. 480 Hz). The major reason for this disagreement might be the relatively smaller diameter of the wooden body and the fact that all mode frequencies of a stretched membrane do not scale proportionally when its tension changes.

Two other important differences of the wooden and the composite shells are relatively stronger frequency response of the wooden body as compared to both repetitions of the carbon fiber for the frequency ranges of 1200 Hz to 1400 Hz and again 1650 Hz to a 1750 Hz. The audible consequences of the dissimilarities mentioned in the two above-mentioned paragraphs would be a higher perceived pitch and a brighter tone for the wooden body respectively. This assumption was in agreement with our informal listening tests performed during the experiments. It is worth mentioning that the differences were still well within the range of variability of two traditionally-made instruments and the sound and feel of the composite chenda was indistinguishable from a regular one. Another important factor to compare two instruments, particularly two percussion ones, is the damping factor for individual modes and its trend over frequencies [8]. It was aimed to mimic the damping properties of the wooden body in our composite body so it was desired in our experiments to see a similar damping behavior for the common skin when placed on the two bodies.

Single mode fitting procedure was performed over the frequency range of our interest (below 1800 Hz) on the radiativity data illustrated in Figure 8. The quality factor (Q-factor) of each mode (its center frequency divided by the half-power bandwidth) can be seen in Figure 9. To make the cases easier to compare a linear trend line was fitted to each set of measurements, which is also shown in Figure 9. As was expected for a complex system with broadly different physics (rigid wood, flexible membrane, and the enclosed air), the Q-factors cover a wide range of values from 20 to 400. The very low values of the Q-factor are most likely corresponding to the longitudinal sloshing modes of the air within the enclosed cavity.

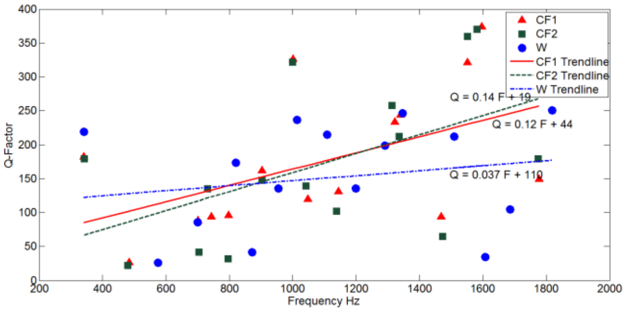

Fig. 9. Damping trend as a function of the frequency for composite chenda, first repetition (Solid red line, instances with red triangles), the composite chenda, second repetition (dashed green line, instances with green squares) and the traditional wooden chenda (dashed-dotted blue line, instances with blue circles).

In general, the damping trends for the two repetitions of the composite chenda were steeper than the trend for the traditional wooden instrument, with all damping trends rising with frequency. The average value of the damping, however, was relatively close for different cases with the average of around 150. This again confirms that the two bodies would make comparable instruments if a similar skin with a close tension is placed on them.

Conclusions

A hand lay-up manufacturing method was developed and prototypes of composite chenda were made and the sound characteristics were compared with wooden drum shell. A composite structure was developed to replace the traditional wooden drum shell.

The acoustic showed that the general behavior of the composite and wooden shells was relatively similar and the composite instrument fits well within the normal differences among two different wooden instruments. It is hoped that this study will help in the standardization and uniformity in manufacturing of the chenda.

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