CHAPTER 3

METHODOLOGY AND RESEARCH APPROACH

3.1 PLAN OF INVESTIGATION

Based on the objectives, the present research work was undertaken to study the suitability of composite manufacturing and acoustics of Chenda. The study was motivated by exploring the link between acoustic performances and manufacturing details of a traditional drum. This chapter discusses the methods and the sequence of investigations adopted in the investigation of Chenda. The various phases in the present thesis are given in the Figure 3.1.

![Plan of investigation diagram]

**Figure 3.1** Plan of investigation
3.1.1 **Structural Sandwich**

The application of sandwich composites is investigated for the Chenda. A sandwich structure consists of two relatively dense and stiff face sheets that are bonded to a low-density core. The face sheets resist all the applied edgewise loads, the core separates and stabilises the thin face sheets and provides shear rigidity to the sandwich construction. It also helps to resist buckling of the face sheets under axial compressive loading. The core usually has low in-plane and flexural stiffness compared to the face sheets, but it can have significant transverse stiffness and shear stiffness (Mallick 2010; Fleck & Sridhar 2002). In order to meet necessary design criteria to that of the existing wood, it was critical to select an appropriate fibre, matrix and core material. The schematic of sandwich structure is shown in Figure 3.2. By proper choice of materials for facings and core, the weight of a geometrically perfect shell with specified load carrying capacity can be designed (Hutchinson & He 2000; Ma et al 2008). Nonstructural advantages can also be incorporated in a sandwich construction by careful selection of facing and core materials. The facing sheet can act as moisture barrier for the shell and will improve the aesthetics the shell. Core material will provide the required damping and decay resistance (Forest products & Knovel 1999). For Chenda shell both the structural and nonstructural advantages of the material were considered.

![Figure 3.2 Sandwich structure](image)

**Figure 3.2 Sandwich structure**
3.1.1.1 Facing material

Facing material is the major load bearing element of the sandwich structure. Facing materials include fibre reinforced polymers or laminates such as glass fibre, Kevlar, carbon/graphite, and boron etc. The stiffness, stability of the sandwich structure is determined by the characteristics of the facings. After surveying several types of fibres, it was found that carbon fibre has the optimum properties for the light weight, high strength applications. Carbon fibre possesses high specific strength (strength relative to density), high stiffness (modulus relative to density) and are environmentally stable. The strength of the composite is due to the presence of very small diameter fibres (7-10 µm). Further, carbon fibre composites have already established in various high performance applications like air craft, sporting equipment and soundboards (Soutis 2005; Stewart 2010).

3.1.1.2 Core

The selection of core material is important. Figure 3.3 shows the various commercially available core materials. Many lightweight materials such as balsa wood, rubber foam, cork, expanded plastics, formed sheets etc. are widely used in sandwich construction. Typically, cores are used to increase the stiffness without added excessive weight to the composite structure. Compared to foam and honeycomb core materials balsa wood offers good compressive strength, shear strength and is relatively low cost. Further, balsa wood is a renewable source and can be harvested in about seven years (Sloan 2010). Apart from enhancing the bending stiffness and shear properties, core material also influences the damping of the final laminate. Further, for a given core material balsa wood has the highest density. In general, balsa wood can be considered as a natural composite material, with cellulose fibres surrounded by a lignin and hemicellulose matrix. It is more homogenous and possesses both structural and non-structural properties.
required for a drum shell. Hence balsa wood is selected for Chenda shell. Table 3.1 summarises the comparison of different core materials (Black 2003, Da Silva & Kyriakides 2007).

Figure 3.3 Various core materials

Table 3.1 Comparison of core materials

<table>
<thead>
<tr>
<th>Description</th>
<th>Balsawood</th>
<th>PVC foam</th>
<th>Honeycomb plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear strength</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Compression strength</td>
<td>Very high</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Moisture resistance</td>
<td>Low</td>
<td>Very high</td>
<td>Very high</td>
</tr>
<tr>
<td>Damping</td>
<td>Medium</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Density</td>
<td>High</td>
<td>Medium</td>
<td>Very low</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>
3.1.1.3 Manufacturing

The main operation in the manufacture of sandwich shell/panels is bonding of the face sheet to the core. Polyester, vinyl ester, phenolic, epoxy, polyamides resins (polymer) are widely used in making structural composites. In general, the chemical composition, and physical properties of the resin affect the processing, fabrication and ultimate strength of the composite material. Thermosetting resins can easily moulded to any shapes, cure readily and are excellent adhesives and bonding agents. An epoxy resin system was selected due to its high strength and modulus, excellent adhesion to the skin and core materials and ease of processing (Decker et al 1990). Selection of resin also depends upon the manufacturing process. For Chenda the sandwich shell was developed by hand lay-up process in conjunction with vacuum bagging. The details are mentioned in section 5.3

3.1.2 Shell Design

Drum shell structures are designed for compressive loads due to the presence of the drum heads resting on them under high tension. For Chenda shell with radius R is considered subject to a uniform axial compressive force per unit length, N, such that the total force is \( P = 2\pi R N \). Laminate ply sequence were selected to meet the strength and damping properties comparable to that of jackfruit wood. 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 traditional wooden shell. The final shell ply sequence was \([0u] s \) (where u= unidirectional and s= symmetric) with a core thickness of 10 mm. This was achieved after careful design iterations.
3.1.2.1 Finite element modelling

The main purpose of the finite element model was to see if the shell structure could withstand the drum head tension and also to estimate the stability of the shell. The material properties that were input into an ANSYS finite element model is given in Table 3.2

### Table 3.2 Material properties (Daniel & Ishai 2005)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unidirectional Carbon/epoxy</th>
<th>Balsa wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, $\rho$, kg/m$^3$</td>
<td>1.57</td>
<td>0.15</td>
</tr>
<tr>
<td>Longitudinal modulus, $E_X$, GPa</td>
<td>138</td>
<td>0.065</td>
</tr>
<tr>
<td>Transverse in-plane modulus, $E_Y$, GPa</td>
<td>8.7</td>
<td>0.065</td>
</tr>
<tr>
<td>Transverse out-of-plane modulus, $E_Z$, GPa</td>
<td>8.7</td>
<td>0.065</td>
</tr>
<tr>
<td>In-plane shear modulus, $G_{XY}$, GPa</td>
<td>5</td>
<td>0.0587</td>
</tr>
<tr>
<td>Out-of-plane shear modulus, $G_{YZ}$, GPa</td>
<td>5</td>
<td>0.0587</td>
</tr>
<tr>
<td>Out-of-plane shear modulus, $G_{XZ}$, GPa</td>
<td>5</td>
<td>0.0587</td>
</tr>
<tr>
<td>Major in-plane Poisson ratio, $\nu_{XY}$</td>
<td>0.28</td>
<td>0.22</td>
</tr>
<tr>
<td>Out-of-plane Poisson ratio, $\nu_{XZ}$</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>Out-of-plane Poisson ratio, $\nu_{YZ}$</td>
<td>0.28</td>
<td>0.2</td>
</tr>
</tbody>
</table>

3.1.2.2 Meshing

The shell structure of the model was meshed using SHELL 181 elements. The laminate ply thickness for CFRP layer is 0.33 mm and total ply thickness is 15.6 mm. However, the core thickness is increased to 20 mm at the top and bottom bearing edges. This is to improve the bearing edge interaction between the skin and the shell. The composite shell modelled in ANSYS is shown in Figure 3.4
3.1.2.3 Stability analysis

Once the strength requirements are met for the shell, the sandwich shell is also checked for possible overall elastic buckling in compression.

Figure 3.4 Shell model

Figure 3.5 Boundary conditions and loading of the shell
Linear buckling analysis was carried out to predict the structural stability. The Lower end of the shell is fixed and the top was subjected to force of 5,500 N to stimulate the drum head tension, Figure 3.5. The first four buckling modes are captured and the analysis has predicted a very high safety factor, 106; Figure 3.6. Hence the shell structure is stable under the drum head tension.

![Linear buckling analysis showing first mode.](image)

**Figure 3.6** Linear buckling analysis showing first mode.

### 3.2 MATERIAL CHARACTERISATION

The first step in this study was to characterize jackfruit wood in order to understand the fundamental mechanical and acoustic behaviour. Despite the popularity of the jackfruit wood its mechanical and acoustic properties are not thoroughly studied. Chapter 4 presents the vibrational properties of specimens by using non-destructive testing using non-contact
forced released vibrations of free-free beams method developed by (Bremaud 2012; Brémaud et al 2012). Figure 3.5 shows the schematic test set up.

![Schematic of Experimental set-up for vibration test](image)

**Figure 3.7** Schematic of Experimental set-up for vibration test (Bremaud 2012) (a) supporting thread (b) vibration node location (c) thin steel plate (d) electromagnet (e) thin aluminum plate (f) eddy current sensor

### 3.2.1 Vibrations of Free-Free Beams

The wooden and composite specimens are made to vibrate through an electromagnet facing a thin steel piece glued to one end of the sample. Dynamic Young’s modulus of elasticity was calculated from the Euler-Bernoulli Equation (3.1).

\[
\frac{E'}{\rho} = \frac{48\pi^2 l^4}{m_n^4 h^2 f^2 R_n}
\]  

(3.1)

Where \( l \) is the length of the specimen and \( h \) is the thickness \( f_{R_n} \) is the resonance frequency of the mode \( n \) and \( m_n \) is the constant depending up on the mode order. The specific dynamic modulus as \( E'/\rho \) in MPa m\(^3\) kg\(^{-1}\). The damping coefficient is determined, in the frequency domain and \( \tan \delta \) is
determined by a frequency scan, through the bandwidth (Δf) at half power of the resonance curve, Figure 3.6, often called the quality factor given in the following Equation (3.2).

\[ Q^{-1} = \frac{(f_2 - f_1)}{f_R} = \tan \delta \]  

The frequency scan was imposed manually from a function generator. The frequency range of measurements was about 200 Hz to 1150 Hz. The resonance frequency and the decrement of amplitude were recorded with a fast Fourier transform (FFT) analyser. The recorded data files were analysed in MS Excel.

3.3 ACOUSTIC TESTING

In order to understand the effect of change in material of drum shell on Chenda, a set up was created to analyse the sound spectrum. All the experiments were carried out at the audio lab in the Centre for
Interdisciplinary Research in Music Media and Technology (CIRMMT) in McGill University. The following section describes the test setup.

### 3.3.1 Drum Setup for Experimentation

The drum was hung with free-free conditions to avoid any disturbance from boundaries. Any excitation method that allows free vibration to occur is sufficient, and in general the force of magnitude of excitation should not influence the frequencies and vibrational modes which are excited during free-free vibration. An impact hammer with plastic tip was used to excite the drum head. An impulse hammer consists of a head assembly containing a force sensor and a handle with rubber grip, interchangeable head extenders and several different impact tips (metal, plastic, rubber). Essentially the criteria is to use the tip that at least excites strongly up to the frequency of interest while does not cause other problems like double-hitting. As carefully as possible, the impact force is kept constant by maintaining a consistent stroke height throughout experiments. Figure 3.7 and 3.8 shows the schematic and actual test setup respectively.

![Figure 3.9 Schematic of experimental set up](image-url)
3.3.2 Data Capture and Analysis

An impulse hammer was used to apply the force (in the form of an impulse) while a microphone (Bruel & Kjaer Type 4228) was recording the resulting sounds. The microphone was placed at a distance of 120 cm from the drum head pointing normal toward the centre of the head. The two synchronous recordings were then used to calculate the Frequency Response Function (FRF).

Using custom built software developed in Matlab (daqplot by Gary Scavone), the hammer and microphone signals were acquired when the drum head was excited, from which the FRFs were computed (from the auto- and cross-correlation signals in the frequency domain). For each analysis (wooden and composite Chenda), a 2-second audio file (ie; 44100 samples at a sample rate of 22050 Hz) was captured. An average in the frequency domain of five measurements 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 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.
Other research methodologies like optical holography (Rossing et al 1992) and physical modelling are not investigated in the present research. Further, the method of measurement adopted in this study and its equivalency to the actual notes (played using wooden stick) was also evaluated. Extracting the mode shapes of Chenda was also the aim of this research, although they should not be far from the ones predicted by simple theoretical modes of an ideal membrane (Gough 2007), or the ones reported in the literature for other membrane-type percussion instruments. A typical frequency response of the composite Chenda by modal analysis is shown in Figure 3.9.

![Figure 3.11 Sample FRF of composite Chenda](image)

*Reference is arbitrary*
3.4 SUMMARY OF METHODOLOGY

The materials under study and the methodology followed in this current research are explained systematically. The vibrational test method for characterising acoustic properties of materials used in music instrument applications is described. Further the acoustic investigation method of percussion drum is also discussed. The digital signal analysis technique provides a quantifiable feedback for percussion drums.