CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

In order to perform research on traditional drum, it was necessary to know which mechanical and acoustic properties of a particular wood lead to a fine drum shell and the composite materials that were investigated in the past as wood alternatives. Furthermore, in order to design and manufacture drum shell, it was required to know the important attributes of drum shell and fundamental acoustics of drums. As a result, the main literature that was reviewed can be divided into four categories

1) Acoustic properties of wood used in musical instruments
2) Application of fibre-reinforced composites to musical instruments
3) Attributes of drum shell
4) Musical acoustics

2.2 WOOD IN MUSICAL INSTRUMENTS

Musical instruments can be classified into four main categories: (1) idiophones: instruments that produce sound by vibrating themselves, e.g. xylophones (2) membranophones: instruments that use stretched vibrating membrane to produce sound, e.g. drums (3) chordophones: instruments that relay on a stretched vibrating string e.g. violins, guitars (4) aerophones:
instruments that use vibrating air column for producing sound e.g., flutes, bagpipes (Hornbostel & Sachs 1961). The major structural part of many musical instruments is made from wood due to their unique range and combination of mechanical and acoustical properties (Wegst 2008; Fletcher 2012). In drums with membranes the supporting structure should be sufficiently strong and rigid. Jackfruit wood is most preferred for the popular Indian Tabla and Mridangam and a wide variety of stringed instruments like Veena and Tampura, due its fine grain structure, aesthetics (golden yellow colour) and termite resistance (protection from insects). In general, the best musical instruments are still made from wood species, (Wegst 2006).

Traditionally, the suitability of the wood is evaluated by tapping with the hand and the radiated sound is judged by ear by the luthier. Further the selection of a particular wood for a specific musical instrument depends upon the experience and skill of the craftsman. The construction of musical instruments starts with the selection of materials. There has been already a vast research in order to characterize the acoustically important properties of wood for musical instruments (Haines 1979). For example, a violin top plate is made out of spruce wood due to its high specific stiffness (i.e., stiffness relative to density) and lower internal friction in the longitudinal direction (Ono & Norimoto 1983), whereas the back plate is made with curly maple. Curly maple is used for its specific mechanical properties: it act as very elastic spring, especially due its curly texture. However, limited work has been reported for the woods used as materials for traditional drum shells, (Yoshikawa & Waltham 2014).

2.2.1 The Need for Wood Alternatives

Despite the unique mechanical and acoustic properties of wood, it suffers the disadvantages of drying, cracking and inconsistent quality. Wood is natural, aesthetically good; however, for the instrument builders it is
difficult to know the inner quality of the wood. Figure 2.1 shows a typical crack inside the wooden trunk.

![Inner crack in drum shell](image)

**Figure 2.1 Inner crack in drum shell**

The current supply of wood cannot meet the significant demand for quality musical instruments; hence an alternative material for musical instrument applications, to reduce manufacturing time and overcome problems encountered using traditional wood, is both desirable and necessary. In the near future musical instrument manufacturers will likely switch to non-traditional materials like plantation timbers, polymers or composites (Barlow 1997). In addition, there is intensified pressure to limit the use of endangered wood species. Brazilian rosewood used for guitars, African blackwood used for making western clarinets have already been added to the protected species list by the Convention for International Trade in Endangered Species (CITES). Further, in Tamilnadu, India the cutting of jackfruit wood is banned due to environmental reasons. These problems have resulted in that many researchers search for alternative materials (Yano et al 1997; Sharma et al 2011). Much of the work is reported in development of alternatives for soundboard applications. The selection criteria for soundboards are reviewed briefly in the following section.
2.2.2 Selection Criteria for Soundboard Applications

With the development of many characterisation techniques, researchers have quantified the criteria for choosing alternatives for soundboards. The important mechanical properties which governed the selection of soundboards are low density, high specific modulus and low internal friction (along the grain direction). Soundboard quality criteria can be defined as the ratio of damping ($Q^{-1}$) to that of specific modulus ($E/\rho$), where $E$ is the Young’s modulus, $\rho$ is the density and $Q^{-1}$ is the loss factor (detailed in section 3.2). A material with a low value of $Q^{-1}/(E/\rho)$ is best suited for soundboards (Ono & Norimoto 1983). A combination of elastic constants and their anisotropy together with the aesthetics are the most important factors for selecting alternative materials.

Prerequisites for alternative materials are (1) to match the vibrational behaviour of the target wood, and (2) to obtain good mechanical strength and workability to match that of the existing wood. A scheme to classify the selection for non-traditional materials for making string instruments was developed by (Yoshikawa 2007). In that study, selection criteria were proposed by plotting transmission parameter $cQ$ to antivibration parameter $\rho/c$, where $c$ denotes the propagation of speed of the longitudinal wave along the wood grain, the $Q$ value is the reciprocal of the loss factor and $\rho$ is the density of the material. These regression lines, defined by the classical wood materials, establish criteria to select FRC (Fibre Reinforced Composite) for musical instrument applications. Figure 2.2 shows material property charts that plot mechanical properties such as Young’s modulus and the density against one another will help to analyze material performance and develop selection criteria for soundboards, (Wegst 2008; Woodhouse 2014; Yoshikawa & Waltham 2014)
2.2.3 Application of Composites for Soundboards

The research interest to find wood alternatives in string instruments was initiated by researchers long ago. McIntyre & Woodhouse (1988) investigated corrugated sheet, plywood and other reinforced composites for stringed instruments. (Ono et al 2002; Ono & Isomura 2004; Ono & Okuda 2007) have performed significant work to develop alternative materials for violins and guitars. The anisotropic nature of the soundboards can be mimicked by proper orientation of particular fibre layers in the matrix structure. For the development of fibre reinforced soundboards, the four key properties, namely bending stiffness, areal density (mass per unit area), internal friction and degree of anisotropy, have to be compared with that of the traditional wood.

Subsequent to the previous studies, to mimic the microstructure of wood, a flax fibre composite sandwich structure for stringed musical instruments was developed by (Philips 2009; Philips & Lessard 2012). A
prototype Ukulele (string instrument) was manufactured by a novel manufacturing technique. The monocoque instrument developed from that study does not require bracing and the use of animal glue is not required compared to the wooden instrument. This kind of design offers more uniform stiffness across the entire surface and requires less maintenance. It was concluded that “the sound output level and low frequency response problems need to be addressed before it can match the sound of a wooden soundboard”.

Recently, (Mehdi Jalili et al 2014) investigated the acoustic properties of carbon fibre, glass fibre and hemp fibre reinforced polyester composites for music instrument sound boards. The results showed that carbon fibre reinforced composites exhibited less damping which could be desirable for soundboards. Further, water absorption studies also revealed that the performance of composites will be less affected by humidity. Composites offer a choice for instrument makers that use no endangered species of wood (Yano et al 1997). It can be noted that a combination of elastic constants and their anisotropy together with the aesthetics are the most important factors for selecting alternative materials.

### 2.3 ADVANCED COMPOSITE MATERIALS

Advanced composite materials offer the unique possibility of designing the material, the manufacturing methods and the structure in one combined process (Daniel & Ishai 2005; Decker 1995). As a result, the majority of the alternative materials investigated for musical instrument applications are fibre reinforced composites (Besnainou 2000). Composite materials are good replacement for wood due to their inherent orthotropic properties and superior stability.

Composite materials typically consist of strong fibres (eg. carbon, glass) embedded within a light polymer (eg. polyester, epoxy) matrix.
Composite material can be defined as two or more materials combined together to form a new material with superior mechanical properties. Many of the material developments have been based on stiffness criterion rather than the strength of the material. An example of efficient utilisation of composite structure is sandwich construction. The main advantage of sandwich construction is its high bending stiffness and strength to weight ratio (Mallick 2010).

The wood alternatives should have strength and performance characteristics similar to that of traditional wooden instruments. Fibre composites are appropriate as this material can be engineered based on the acoustically related mechanical properties, namely, stiffness and vibration damping. The anisotropic nature of the soundboards can be mimicked by correctly orienting fibre layers in the matrix (Decker et al 1990). Fibre reinforced composites are very stiff and the performance will not vary with the humidity. Being light weight, they offer ease of handling and are easy to transport. Furthermore, they offer better resistance to environmental changes, less material variability and lower manufacturing time. Fibre reinforced composites could be an ideal material for the development of drum shells. A more rigorous design process may be necessary in order to design with composites efficiently. It is anticipated that with optimum arrangement of fibre materials, the final drum shell would achieve sufficient strength and shear rigidity with minimal deflection under the tension of the ropes.

2.3.1 Previous Work at McGill

In order to develop better musical instruments from composite material, many instruments like violin, guitar, and snare drum were studied at Structures and Composites Laboratory at McGill University, Canada. Much of the research in composite instruments carried out at McGill over past 8 years forms an important foundation for the work presented in this thesis.
Figure 2.3 shows a violin top plate made from carbon fibre composite. Experimental modal analysis and finite element method was used to test the suitability of the carbon fibre soundboards. The results showed that the damping ratio of the composite top plate is comparable to that of spruce wood (Lu 2013).

A composite snare drum was developed using Carbon/Kevlar hybrid composite. The snare drum with an innovative shell material and employing the existing tensioning hardware is shown in Figure 2.4. The stiff structure of the shell resulted in higher resonant frequency and higher pitch is observed. The inherent elasticity of the shell also assisted in maintaining uniform tuning.

Figure 2.3 Carbon fibre violin

Figure 2.4 Carbon/Kevlar hybrid snare drum
In the last two decades the development of natural fibre reinforced composite have also gained lot of interest (Phillips & Lessard 2012). A prototype ukulele (stringed instrument) made from flax fibre composite is shown in Figure 2.5. Natural fibre composites not only mimic the vibrational characteristics but also improve the aesthetics of the instrument. The high availability of these fibres also reduces the cost of the instrument substantially. It is evident that the search for wood substitutes for musical instruments has a tremendous interest worldwide. Table 2.1 shows the recent developments in composite instruments. However, limited work has reported for the traditional drums application.

![Figure 2.5 Flax fibre composite ukulele](image)

**Table 2.1 Recent developments on fibre reinforced composites**

<table>
<thead>
<tr>
<th>Country</th>
<th>Description</th>
<th>Type of Application</th>
<th>Level of Development (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>Carbon fibre reinforced plastic, and flax fibres</td>
<td>Violin, Ukulele,</td>
<td>Actual application (33,52,53)</td>
</tr>
<tr>
<td>U.S.</td>
<td>Carbon fibre composite</td>
<td>Guitar, Cello</td>
<td>Actual application(14,15)</td>
</tr>
<tr>
<td>Japan</td>
<td>Wood plastic Composite</td>
<td>Traditional Drum</td>
<td>R &amp; D (51)</td>
</tr>
<tr>
<td>India</td>
<td>Carbon fibre/balsa sandwich</td>
<td>Traditional Drum</td>
<td>Trial application</td>
</tr>
<tr>
<td>U.K.</td>
<td>Carbon fibre composite</td>
<td>Violin</td>
<td>R &amp; D (72)</td>
</tr>
</tbody>
</table>
2.3.2 Composite Materials in Drum Shells

The science of string vibration has allowed scientists and engineers to determine the required resonant frequencies to develop composite resonating structures. Compared to the literature available for stringed instruments, very few studies have been reported on percussion drums. However, recently the research interest in drums has gained attention (Rossing 2001; Richardson 2010).

Synthetic drum shells for various drum shapes were reported earlier by (Appolonia 1994). An innovative method by using carbon fibre and epoxy resin to make consistent quality drum shells was presented. Careful selection of fibre, resin, manufacturing process will lead to a drum shell which produces longer sustain, sound pressure, consistent sound quality as well as durability against environmental conditions. Composites shells were fabricated by filament winding technique. However, the above method is expensive and is not viable for traditional drums in developing countries.

Ono et al (2009) investigated the use of a wood plastic shell for the traditional Japanese drum Wadaiko Figure 2.6. Drum shells were fabricated by compression moulding technique. Their approach provided a baseline reference to assess the performance of alternative materials for drum shell applications in traditional instruments. In their study, the vibrational characteristics and the frequency domain spectra were analysed systematically and compared with that of a traditional wooden drum. Their study concluded that the mechanical properties of the shell material are more important than that of vibrational aspects. A material with high specific modulus, good toughness was shown to be desirable. Furthermore, the shell structure should be stiff enough to withstand the tension in the ropes. However, the resulted wood plastic shell has density of 1.44 g/cm$^3$, which means, the weight of the shell increases by almost 3 times than that of the wooden shell. In Chenda,
weight is a major concern and hence the use of wood plastic is not further investigated. The present thesis focuses on developing alternative methods to manufacture drum shells which are light weight, stiff and durable. The important attributes and relevant acoustic parameters of the drum shell are also reviewed in the following section.

![Figure 2.6 Wood plastic composite drum (Ono et al. 2009)](image)

2.4 ATTRIBUTES OF DRUM SHELL

Previous research suggests that various physical and geometric properties of drum shell have impact on the sound produced by the drum. The present thesis aims to add new knowledge in how the drum behaves by changing the material of the shell. This will help both the musicians, music instrument builders and researchers for further understanding of acoustics of the traditional drums.

2.4.1 Shape of the Shell

“Drum” in true terminology, means an instrument in which the sound is produced by striking (either by hand or stick) a membrane stretched over the opening of either a frame or hollow body of any shape. The hollow
structure which supports the membrane is called drum shell. The shell is the most fundamental part of the drum. The different types of the shell which are widely used around the globe are shown in Figure 2.7.

![Types of drum shells: a) Cylindrical, b) Barrel, c) Hour glass, d) Chalice, e) Bowl](image)

As vibrating systems, drums can be divided into three categories based on the shape of the shell (Blades 1992). Those consisting of a single membrane coupled to an enclosed air cavity (e.g. Tabla, Timpani) Figure 2.7 (e); those consisting of a single membrane stretched over an open shell (e.g. Congo drum) Figure 2.7 (d) and those consisting of two membranes coupled by an enclosed air cavity (e.g. Chenda, snare drum, Tom drum) Figure 2.7 (a), (b), (c). Previous studies showed that the way in which the shell was designed for timpani has made it more harmonious, (Rossing 1992). Research carried out by (Richardson 2010), shows that cylindrical drums could also be considered a perfectly tuned by carefully manipulating the tension on drumheads. Therefore a change in shape has significant effect on the perceived sound of the drum.

Generally, the diameter of the shell determines the pitch of the drum and the depth influences articulation (clarity in production of successive notes) and resonance, with longer the drum the shorter sustain (Mynett et al
2011). During the manufacturing of composite shell, dimensions are tried kept same as that of the wooden shell. The effect of change in shape of the drum shell is not investigated in the present study.

2.4.2 Bearing Edge

The bearing edge is the either end of the cylindrical drum shell, the only point at which the drumhead touches the shell. Research has been carried out on the efficiency of different types of bearing edges (Macaulay 2003). The importance of bearing edge is that the edge is primary outlet for energy to transfer between the drum head and the drum. There exist many different designs for this edge like an equilateral triangle, a rounded edge and 30°, 60°, 90° triangle to name a few, and are in wide use, (Argo 2002). Figure 2.8 shows the different types of bearing edges.

![Figure 2.8 Bearing edge cross sections](image)

**Figure 2.8** Bearing edge cross sections: (a) single 45°, (b) Single 45° with round-over (c) double 45°

The head must evenly meet the shell all the way around in order to distribute the tension of the head. A great deal of precision is involved in creating the bearing edge so the head can sit perfectly (Modern Drummer 2014). In order to make the drumhead correctly resonate, there should not be
any irregularities on the bearing edge. The shell symmetry and flatness of the bearing edge describes the timbre of the drum. Good symmetry to a drum shell will ensure that a drum head can be put on to a shell and rotated freely. If the shell is slightly oval, out of round, then it is difficult to tune. If there is any significant gap between the drum head and the bearing edge, then it cannot be considered as flat and is very difficult to tune and hold a particular tuning. This phenomenon is due to the air leakage from the drum shell. This is a big concern in wooden drum shells as its stability is often affected by humidity and temperature.

Macaulay (2003) suggests that when the point of contact is a double 45°, which is in the middle of the drum shell, the energy will remain within the drum shell, rather than leaking outside the drum shell. It is expected that different bearing edges will behave differently and will have significant effect on the sound quality of the drum. A stronger coupling between the shell and more shell vibration is the result of a rounded bearing edge due to the more contact area. For the traditional Chenda, a rounded bearing edge is used.

2.4.3 Thickness of the Shell

Shell thickness is important and it describes the timbre of the drum. Thinner shells vibrate more and shells which vibrate less are above 8mm (Mynett et al 2011). Thicker shells vibrate less freely, primarily supports the massive drum head and therefore their tone is more dependent on the heads than that of a shell. The Chenda uses jackfruit wood and the shell thickness is 15 mm at the main hollow section and 20 mm at bearing edges shown in Figure 1.3.
The perceived volume and drum projection is proportional to the thickness of the shell. According to (Rossing et al 1992) the potential energy due to the change in shape of the shell and the kinetic energy present are proportional to the thickness. Due to this reason, wooden Chenda is very loud and the sound can be heard even at 3 km radius. Further, the drum shell could be analysed as a series of ring shaped elements. The selection of the head type determines the thickness of the shell. For a massive drum head, thicker shells are preferred (Hopkin & Scoville 1996). A thicker shell ensures more sustain than a thinner shell. In the present study all the prototypes developed is of the same shell thickness.

2.4.4 Shell Materials

A vast majority of Western drum shells are made of birch or maple wood due to their specific mechanical properties (Mynett et al 2011). Selection of particular wood type depends on the style of music. Each wood type conveys its own unique sound when hollowed in. Other non-traditional materials like steel, copper, aluminium, acrylic are also widely used by the Western drum manufacturers. Compared to metals, the use of synthetics like carbon fibre, acrylic, and glass fibre are not explored thoroughly (Modern Drummer 2015). Synthetics are generally harder and less damped hence gives a more sustained and wiry character to the sound (which suites that genre pretty well). They are more durable and less fragile. Synthetic materials are widely used in drums since the taste of people in rock and jazz is more liberal compared to that in classical genre.

For a double headed membrane drum the mechanical coupling between the batter head and the resonant head is through the drum shell and the air cavity inside. However, the effect of change in the shell material on
the sound characteristics of the drum is not yet investigated. The sound quality of a particular instrument depends on the shape of the shell, tension on the drum head quality of the raw materials used for the manufacturing (Ono et al 2009). To what extent the response of a drum sound affects with the change of material is not yet quantified. The present thesis is to investigate systematically the acoustic effects on the shell material in a traditional Indian drum. Table 2.2 summarises important attributes of drum shells.

Table 2.2 Drum shell attributes

<table>
<thead>
<tr>
<th>Description</th>
<th>Drum shell attributes</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch, volume, sustain</td>
<td>Shape</td>
<td>Increases with reduction in diameter Increase with depth</td>
</tr>
<tr>
<td>Projection</td>
<td>Thickness</td>
<td>Increases</td>
</tr>
<tr>
<td>Overtone</td>
<td>Bearing edge</td>
<td>Increase with sharpness (45° or Rounded)</td>
</tr>
<tr>
<td>Resonance</td>
<td>Inside surface finish</td>
<td>Increases</td>
</tr>
</tbody>
</table>

2.5 MUSICAL ACOUSTICS

Research in musical acoustics is interdisciplinary and has been approached by people working in physics, engineering, mathematics, computer science and psychology. Recent developments in digital signal analysis and fast computing techniques have aided the research in musical acoustics. The key research areas regarding various aspects of the instruments cover physical properties of materials used for making the instrument to the psychoacoustic analysis of the radiated sound. Experimental modal analysis and numerical methods have been increasingly used to understand the
functionality of a particular component in the instrument and interaction with other parts (Wright 1996). The present thesis focuses on the acoustic behaviour of the traditional drum while changing the material of construction of the shell.

2.5.1 Modal Analysis

Modal analysis refers to a process of characterising the dynamic response of a structure by describing its vibrational motion by means of a set of mathematical relationship (Ewins 2000). Modal analysis has been extensively used in the past for the study of acoustic behaviour of percussion drums. Analysis on vibrational or sound pressure response over a specific range of frequency yield valuable information about the instrument. For example, Figure 2.9 shows the Frequency Response Functions (FRF) of a kettle drum. (Tronchin 2005) have studied the acoustical features of two kettle drums with different features by modal analysis.

A new parameter called Intensity of Acoustic Radiation (IAR), which is defined as the product of sound pressure and velocity of the membrane was also investigated. According to him similar FRF obtained for both drums irrespective of the make and model and the modal shapes were found better by the impact hammer technique. Further, the results showed a close correlation between the FRF and IAR. Peaks in the response curves are associated with the instrument’s normal modes. Many of the important properties of the modes can be determined by measuring the amplitudes, frequencies and damping values of the peaks. Earlier studies performed on drums have focussed on the frequencies of the drum head vibrations.
2.5.2 Vibrational Characteristics of Drums

The physics of drums can be described using circular membrane theory based on Bessel functions (Rossing & Fletcher 2004). In a percussion drum each mode represents a resonant frequency based on the displacement of the skin and can easily be defined by the pattern of nodes and antinodes. A graphical representation of basic nodes and antinodes are given by (Russell 1998). A node is a point or a line on the drum head which does not move while the rest of the structure is vibrating. The basic terminology for specifying vibrational modes is (mn) where the vibrational mode has \( m \) nodal diameters and \( n \) nodal circles. The (01) mode is the fundamental mode. The (11) mode has a smaller displacement and is 1.59 times the frequency of the fundamental. As per (Rossing 1992a), the semi harmonic series resulted in Timpani (1: 1.50: 1.97:2.44.) is due to air loading inside the kettle drum.

Acoustics of Indian drums (Mridangam and Tabla) were studied by Nobel laureate (Raman 1934). It was showed that the first five modes of vibration of the drum are integer multiples of the fundamental frequency. The peculiar way in which these drum heads are fabricated makes it analogues to a
fine tuned stringed instrument. Figure 2.10 shows Indian Tabla. The drum heads are centrally loaded with a paste in diminishing diameter. The sustained character of the vibration of the drum and pure tonal characteristics made it widely popular.

![Image of Tabla](image.png)

Figure 2.10  The Tabla (Sathej 2008)

Harvey & Whiteley (2014) have studied the effect on the striking location on the sound characteristics of a Congo drum. A difference in the amplitude of the frequencies was observed when changing the strike position from the centre of the drum head towards the rim. Deviation from the ideal membrane theory was also observed in the case of Congo drum. It was concluded that higher pitch is obtained by striking near the rim.

2.5.3  Vibrations of Coupled Membranes

Most of the percussion drummers in Kerala use drums with double headed membranes. By adding a second head to the system doubles the vibrating mass and the radiated sound sustains longer after being hit. For a double headed drum, the coupling of the air between the drumheads can even enable the player to change the pitch and sound of the given note by applying
tension to the drumhead not being struck. Hence the present research will be very valuable with respect to percussion performance.

Rossing et al (1992) studied the vibrational and sound radiation behaviour for a Western snare drum. Mode shapes and modal frequencies were determined for the drum by impact modal testing, holographic interferometry and scanning the near field sound. Mode shapes and the ratio of $f_{01}/ f_{mn}$ are identified. The shell movement is approximately 1% of that of batter head in the (01) mode. A weak coupling is obtained in (02) mode. The study concluded that each mode of vibration has its own characteristic radiation pattern, and the timbre of the drum is different in different directions. The mass of the shell has significance in the modal decay rates.

The modes of vibration of the snare drum are shown in Figure 2.11. For each of the modes of vibration shown below, the description on the upper side, for ex. (01), (11), (21) etc., describes the mode in terms of nodal diameters and circles respectively. The description on the lower side denotes the frequency of vibration of mode with respect to the fundamental frequency. The first mode of vibration 01 denotes the fundamental mode with 0 nodal diameters and 1 nodal circle with frequency considered to be the reference one. This mode of vibration occurs when the drum head is struck at the centre. In this case all the drum head vibrations are quickly transferred into sound. Hence this mode does not contribute to the tone of the drum. The second mode (11), with one nodal diameter and circle has frequency 1.59 times to that of the fundamental. This mode occurs when the drum head is struck between the centre and outer edge. The decay rate of drum head vibration is lesser in this case, thereby contributing to the character of the drum. Likewise all possible modes of vibration produced in a drum head are shown with the corresponding frequencies.
In line with Rossing, (Skrodzka et al 2006) performed the modal analysis of the batter head of a snare drum and also measured the instrument’s sound spectrum. The drum was excited by an impact hammer and the response signal was measured by an accelerometer. Modal parameters like modal damping, frequencies etc. were compared for the various modes. The results showed that the batter head vibrating in its lowest mode (01) is highly damped and acts as the ideal membrane. The antisymmetric mode (11) is much less damped and is not a strongly radiated mode (contrary to Kettle drums). The modes with higher frequencies are slightly damped as the coupling between the two heads is much smaller. Thus, the total impression generated from the sound of snare drum results from the radiation of the whole system of the drum. This is similar to the conclusions of (Rossing 1992a; Rossing et al 1992). Another important finding is the non-harmonic relation between the sound spectra maxima and also between modal frequencies. This clearly explains the indefinite pitch of the snare drum sound.
In Japan, the coupling between two membranes in a traditional Wadaiko drum (barrel shaped shell with circular cow hide membranes) was analysed using an analytical model (Suzuki & Hwang 2008). The frequency and amplitude ratios of the coupled membranes are affected by the tension ratio of the membranes. He extended the analytical study in coupling of the membranes in Nagado-diako drum also. The effect of stiffness on the drum head was analysed by measuring the resonance frequencies.

Ono et al (2009) performed the acoustic investigation of Japanese Wadaiko drum with wood plastic shell. The frequency response of the wood plastic shell showed more peaks and resulted in complex sound characteristics. The membranes on the wooden Wadaiko are fixed exactly to the bearing edge of the shell and clear peaks are exhibited. However, with the synthetic material due to the high modulus of the shell, under the tension of the drum head shell is not elastically deformed which resulted in improper assembly. Among other causes is the change in the boundary condition of support, which resulted in change in the effective radius of the membrane for vibration.

Richardson (2010) evaluated the modal ratios of the Toms for both resonant and batter head separately. By adjusting the tension on drum heads a corresponding change in frequency ratios varying from 1.49 to 1.91 and 1.53 to 2.21 to that of batter head and resonant head respectively were obtained. Hence by manipulating the tension of the drum head, a semi harmonic relationship compared with that of Timpani in the first two modes was obtained. However, higher modes of vibration have to be investigated in order to claim that cylindrical drums are to be considered as perfectly pitched instrument. Their results hence deviated from the ideal membrane theory.
Another important factor to compare two instruments, particularly two percussion ones, is the damping factor for individual modes and its trend over the frequency range (Woodhouse & Langley 2012). Damping can be referred to as the rate at which vibrating systems dissipate energy. Fletcher & Rossing (1998) discuss three types of damping for strings: air damping, internal damping and transfer of energy to other vibrating systems. Damping measurements throughout this thesis are reported using the quality factor ‘Q’ which gives the measure of modal damping. Figure 2.12 illustrates the comparison of ‘Q’ factors between heavily and lightly damped structures (Maloney 2011). A high Q factor indicates a longer sustain of the vibration. Double headed membranes are coupled by a mass of air; the damping produced by air loading is appreciable. The internal damping would be the material properties of the membrane, independent of its thickness, diameter or tension. Comparison of damping behaviour for the wooden and composite Chenda were carried out in the present study.

![Decaying Response](image)

**Figure 2.12** Comparison of Q factor (Maloney 2011)
2.5.5 The Perceived Sound of Percussion

The American National Standards Institute (ANSI) has provided definitions of terms related to the perception of sound such as timbre, loudness, and pitch (Howard & Angus 2009). The tone quality/timbre of the drum primarily describes the shape of the shell and the type of drum head. Since the loudness response is related to the structural vibration characteristics, specific geometric designs will result in target sound spectrum content. Cylindrical drums are considered as untuned percussion instrument due to the non-harmonic relationship to the fundamental frequency.

In order to understand the difference in sound produced by an instrument both objective and subjective evaluations are necessary. Subjective listening tests will help to understand how the listeners experience the perceived sound. The effect on change in material on flute crown and the cello’s end pin on the timbre of musical instrument was investigated by (Yamauchi et al 2001). Recently the research interest in the study on music perception has gained attention (Saitis et al 2012; Fritz & Dubois 2015). A comprehensive study on the state of the art methods for perceptual evaluation of musical instruments was given by them. The link between subjective and objective analyses of musical instruments has gained lot of interest among researchers. However, a comprehensive psychoacoustic evaluation of the Chenda is not included in the present thesis.

It is worth mentioning that, in the past researchers were interested in the vibration characteristics of the drumhead which are more harmonious. However, recent research suggests that cylindrical double headed drums can be tuned to a perfect pitch or notes like the stringed instruments. Many variables used to create drum sounds are now controllable and tuneable with the help of modern techniques for the percussionists. However, the researches carried out on the traditional drums are limited and hence the instrument
manufacturers and the musicians still relay on age-old traditions. Any new knowledge in production techniques of the drum shells will benefit both musicians, instrument builders and also promote the use of drums.

2.6 SUMMARY OF LITERATURE REVIEW

As a result of the interdisciplinary nature of the study, extensive literature review was carried out on application of composite materials to musical instruments, attributes of drum shell and previous studies on acoustics of drums. The widespread decline in availability of most traditional wood combined with intensified pressure to limit its use as a result of environmental reasons are the main drive for research throughout the world aimed at finding a suitable alternative for traditional wooden instruments. It was also shown that fibre reinforced composites have the ability to compete effectively with traditional wooden instruments. Composites can be engineered based on the required structural applications and has excellent durability requiring less maintenance.

The many advantages of fibre composite structure support the development of high strength, visually appealing and durable drum shells. However, little is known about the actual performance of the final instrument made from composites. A quantitative analysis, in order to understand the behaviour of composite material is necessary even though the structural benefit of the fibre composite have been highlighted in many applications. The overall sound characteristics of the Chenda should be determined and the validity of sandwich composite concept should be investigated thoroughly. These topics are systematically studied in the following chapters.

From the literature review of acoustics of drums it was found that many researchers have focused on the understanding of physics behind the instrument and/or the mathematical modelling. There is a wide gap in
communication between musicians, instrument builders and scientific community. Any improvement in the functionality, sound, ease of manufacturing of the instrument will benefit not only the musicians but also the instrument builders. The above aspect will be evaluated systematically for the Chenda in the present study. In chapter 3 the methodology and research approach are presented.