CHAPTER EIGHT

CONCLUSIONS AND SCOPE FOR FUTURE WORK

Sandwich structures with natural fiber reinforced plastics and Polyurethane core were fabricated using a hydraulic process and the samples were placed under pressure in order to get high quality specimens. Ultrasonic inspection was conducted on the samples before and after testing to gauge the extent of damage caused by different tests. This thesis appears to be the first attempt to construct maps for sandwich beams with laminate skins and PU core. Since commercial panels are generally provided with standard skin thicknesses, but with differing core types and density, alternative maps with these core variables are presented. These will be more useful for a sandwich structure designer or manufacturer. Although the maps are generated for three point bending the method can also be applied to other loading geometries. Experimental results for failure under three point bending are summarized in three heading as follows

**PU Foam**

1. It can be seen that results from mechanical tests such as flat wise compression, edgewise compression and bending strength indicate, that among all the different densities of ratios studied, polyurethane foam with 50/50 proportion of MDI and PEP shows the best results in terms of peak load and modulus of elasticity in compression in both flat wise and edgewise orientations. It can also be seen for peak load and bending modulus, 50:50 ratio of PUF is again the best combination.

2. PUF with 50:50 proportion of foam exhibits better properties in tests conducted on the flammability. Results from tests conducted to determine the height of the flame, the time for flame to extinguish and the weight loss due to the flammability tests show that 50:50 combination of PUF is the best when compared with other proportions of PUF.
3. Studies on Scanning Electronic Microscope show that for 50/50 proportion of foam, the cell is uniformly distributed and equally spaced. This may be an important contributing factor for the good properties exhibited by this particular ratio.

4. It is also seen from the results from tests conducted for water absorption that the best properties are seen in the case of 50:50 ratio of PUF.

5. Flat wise Modulus of Elasticity in compression for 50/50 proportion of PUF is 1.75, 1.18 and 1.2 times higher than 60/40, 45/55 and 55/45 proportions respectively.

6. Edgewise Modulus of Elasticity in compression of 50/50 proportion is 1.6, 1.09 & 1.4 times higher than 60/40, 45/55, and 55/45 proportions respectively.

7. Hence, 50/50 combination of rigid PUF is selected for use as the core material in the sandwich structure.

**Natural fiber reinforced laminates**

1. Tensile tests on the various laminates indicated that the maximum strength was seen in Jute. The tensile strength of jute 0/90° composites is 3.4, 5.66, and 17 times higher than jute 0/45°, bamboo 0/90°, and bamboo 0/45° composites respectively.

2. Fibres in the 0/90° orientation showed better results than the 0/45° orientation.

3. The series of flexural tests conducted to determine the bending stress and indicated that 0/90° jute was the better among all the combinations selected. This was also true for the inter-laminar shear strength. The inter-laminar shear strength of jute 0/90° laminate is 1.66, 1.42, and 5 times higher than jute 0/45°, bamboo 0/90°, and bamboo 0/45° respectively.

4. Time for the flame to extinguish is the lowest for glass, followed by bamboo and then jute. Jute composites in the vertical direction are 2.42 and 1.3 times higher than glass and bamboo composites respectively. Therefore, where fire is a real time and constant threat, bamboo based laminates might be the better alternative.

5. In case of horizontal direction, time for flame to extinguish in case of jute composites is 1.529 and 1.3 times higher than that of glass and bamboo composites respectively.
6. Jute based laminates shows better mechanical properties such as tensile, three point bending and ILSS when compared with other skin materials.

7. Therefore where fire is not a serious threat and constant threat, jute in the 0/90 orientation is the better candidate for the laminate in the sandwich structure.

**Sandwich structure**

1. Results from tests conducted for flat wise compression test of different combinations of sandwich structures indicate that glass/jute hybrid sandwich structures possess higher value of peak load carrying capacity and also flat wise compressive strength compared to other types of sandwich structure.

2. Results from tests conducted for edgewise compression test of different sandwich structures indicate that glass/jute hybrid sandwich structure possess higher value of peak load carrying capacity and facing compressive stress when compared with other types of sandwich structure.

3. Results obtained from the tests on three-point bending test for various sandwich structures, bamboo/glass hybrid structure show almost the same values of peak load and core shear stress, when compared with the other sandwich structure. However, the value of face bending stress is the same for both glass/glass and bamboo/glass combination.

4. Results from the graphs of effect of number of cycles on deflection for various sandwich structures at 1450 N force indicate that various combinations of sandwich structure show different behaviour in terms of deflections in case of cyclic compression. The least deflection after 10 cycles of compression is exhibited by pure glass sandwich structure followed by the glass/jute and jute/jute combinations. Maximum deflection is seen in the case of bamboo/bamboo sandwich structure.

5. Studies on water absorption test for sandwich structure indicate that the value of the percentage of water absorption is found to be maximum in case of jute/bamboo hybrid sandwich structures. This is higher than pure jute or pure bamboo sandwich structures. The percentage of water absorbed is lowest in the case of pure glass and
among the bio-fibre sandwich structures, glass/jute and bamboo/bamboo show minimum values.

6. This study characterizes some important strength, environmental and hazardous properties of various foams, laminates and their combinations of sandwich structures. The potential use of these in could range from simple building structures to temporary structures during emergency disaster management. The use of these hybrid structures leaves a smaller carbon foot print and is also environmentally sustainable, since these are mostly organic in nature. It could also potentially, create an impetus to commercial agriculture. Thus, from hybridization concept of bio-fibers, we can save resource, money, and environment and also directly contribute to the economic benefits of their growers.
SCOPE FOR FUTURE WORK

Although a fair amount of work is completed, more testing is still necessary to fully define the failure characteristics of the chosen system sandwich system. Due to time and work volume constraints, only one cyclic-mode of test was conducted. Also, flexural issues were discovered regarding various natural fiber specimens. As a result of these issues, more tests may need to be conducted, with a possible correlation from closed form solutions, if available.

1. In this work only natural fiber was used for sandwich structure. The same work can be extended for all natural composite materials (resin and fiber) sandwich structure.

2. The present work was conducted at the laboratory scale. This can be extended to monolithic structural panels that can be suitable for use as loading bearing structural member such as beam, wall etc.

3. In the present work the effect of water absorption was studied. This study can be extended to investigate the effect of environmental actual aging on the performance of natural fiber based sandwich structure.

4. In the present work all type of mechanical properties were studied, except impact and fatigue. There is a scope for extending this work to study the effect of both low velocity impact and fatigue on natural fiber based sandwich structures.