Chapter 8

Conclusions and Recommendations

8.1 Conclusions

Several experiments have been conducted which will permit an understanding of the properties and behavior of Calcutta bamboo. A great deal of valuable information has been obtained through the determination of Calcutta bamboo physical and mechanical properties, surface properties and the penetration of adhesive. A prototype bamboo parallel strip lumber (BPSL) was produced in the laboratory to demonstrate the suitability of Calcutta bamboo as the raw material for structural composite products. Methods of analyzing materials for specific application, especially materials other that wood, are not entirely standardized. Experiments employed in this dissertation could be utilized in the future as a preliminary method to assess the suitability of non-wood materials for composite applications.

The relative density of Calcutta bamboo is comparatively high and is limited for higher density and laminated-type composite products. Calcutta bamboo is dimensionally less stable due to its higher swelling. However it is a very strong and stiff material, which makes it suitable for structural application. Calcutta bamboo showed good wettability, and its surface tension is very close to the common timber species used in producing composite products. The general trend found in the adhesive penetration study was similar to wood. Consequently, from the analysis, Calcutta bamboo is suitable as a replacement material for various kinds of products, including structural composite products.

In addition to the facts above, the variability in properties of the bamboo culm were also investigated. Variability may originate from different orthogonal directions, the location along the culm length, and the culm section (nodes and internodes). Some statistically significant differences were found, but in some cases the variability was small, and perhaps of no practical importance. Thus, the entire Calcutta bamboo culm can be used to produce composite materials. However, the location along the culm length demonstrated a statistically significant variability in dimensional stability as well as tensile bending strength and stiffness. The location along the culm length also showed variability in wettability. The bottom parts and top parts of the culm should be evenly distributed in the products. This will create a more homogeneous material. Generally, the radial and tangential direction does not exhibit significant variability. Shrinkage, bending strength and stiffness, wettability and adhesive penetration between radial and tangential directions are not significant different from one another. From this finding, it can be concluded that in cutting or chipping Calcutta bamboo for composite products the directional orientation of the culm need not be considered. The complexity of producing composite material is thus minimized and simplified. In addition to this, the culm's outer skin contains high silica content. It does not interact well with adhesive. Thus, it should be discarded in the production of any composite materials.

The investigation has shown that nodes have higher relative density and shrinkage compared to the internodes. Nodes also demonstrated a higher contact angle and lower adhesive penetration compared to internodes. The experiments have shown that generally nodes are lower in tensile and bending strength compared to internodes. From this information, it was concluded that nodes possess inferior properties. In a production process nodes could be separated from internodes. From an economic point of view, it is a waste to discard nodes, because they can be used for other products or placed in a composite, such as the core, where their presence would not be detrimental. A general rule of thumb is to distribute nodes evenly throughout the products. In this regard, nodes would be no different than the knots found in wood.

Bamboo parallel strip lumber (BPSL) produced in the laboratory has shown properties in regard to strength and durability comparable to wood composites. BPSL has shown comparable bending and compression strength, but lower stiffness values than equivalent wood-based products. When it was exposed to the accelerated aging process, the mechanical properties were not reduced significantly, except for MOR and MOE. BPSL also showed good dimension stability.

Information on the variability of different properties along the culm length, as well as the nodes and the orthogonal directions, were important in assessing the usefulness of bamboo. Calcutta bamboo exhibits orthogonal variability. However, wood also exhibits variability in the form of knots, earlywood and latewood, juvenile wood and density variation. This does not deter wood from being used in various applications found today. Many composite products from Calcutta bamboo could be designed and engineered in the future to minimize its variability. New products from Calcutta bamboo, as well as other bamboo species, can be produced over a wide range of specifications conforming to international standards. However, the major benefit of using this material is that it is a fast-growing, natural plant fiber. This material is renewable and available in abundant volumes in many regions of the world. Consequently, the use of bamboo will provide other opportunities for developing sustainable resources for the manufacture of building products. This study of bamboo has shown that existing technology may be applied to the manufacture of bamboo-based composite products.

8.2 Recommendations

The study conducted showed a promising future for Calcutta bamboo. Although there are limitations, Calcutta bamboo offers a potential alternative to the existing building materials. The investigations performed in this dissertation covered only one bamboo species and only one prototype composite. Thus, future research is needed to understand and expand the knowledge of bamboo as a building material.

Study of other bamboo species is recommended, since bamboo offers a broad range of relative density and physical dimensions, and each of them is characterized by properties exceptional to itself. This may expand the applications of bamboo for composite materials.

The large percentage of moisture-induced dimensional changes, in comparison to timber, could pose certain problems in utilizing bamboo for building materials. Thus, the study on this behavior is vital. The relation of dimensional stability to anatomical structure, chemical and other physical properties should be investigated, which may allow bamboo to be classified into species groups.

The equilibrium moisture content behavior is closely related to shrinkage and swelling, and therefore, should be studied. Drying and preservative treatment, especially that which relates to composite materials, should be studied. Due to the large number of bamboo species, classification into groups according to natural durability would be essential information.

The mechanical properties of bamboos depend on the botanical species itself. The age, moisture content, the position along the culm (top or bottom), and the present of nodes are all the factors that influence the strength of bamboo. These factors need to be clarified and studied. Future research is recommended for other strength properties, such as tension parallel to grain, compression parallel and perpendicular to grain, nail withdrawal, toughness and others. The influence of bamboo anatomical features to its mechanical properties, especially the absence of rays should be investigated. Although many studies have been conducted on the mechanical properties of specific bamboo species, next step is to consolidate the data into species groups according to their mechanical properties. This should be done because there are large number of bamboo species, which may posses close strength properties.

The prototype bamboo parallel strip lumber (BPSL) produced in the laboratory was found to be similar in its selected physical and mechanical properties to structural wood-based composite products. The study could be extended in the future to further define the factors that influence physical and mechanical properties. Resin content, moisture content, pressure, density, temperature and bamboo particle geometry are parameters that may be manipulated to improve product performance. Due to the large number of bamboo species, perhaps a study on a mixture of bamboo species for composite manufacture would be practical.

Lastly, the economic feasibility of using bamboo, as a structural composite material should also be investigated. An important consideration for most applications is weather bamboos is cheaper than timber or not. Comparison of the price of composite products from bamboo should be made to composite timber. In the future bamboo could be an important option for structural and non-structural materials. However, before this will materialize, further study will be required.