STUDIES ON MECHANICAL PROPERTIES OF LAMINATED BAMBOO COMPOSITES

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to

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CERTIFICATE

This is to certify that "*Studies on Mechanical Properties of Laminated Bamboo Composites*" being submitted by Mr Chandra Shekhar Verma to the Indian Institute of Technology, Delhi for the award of **Doctor of Philosophy** is a record of original bonafide research work carried out by him under my guidance and supervision. In my opinion, the thesis has reached the standard of fulfilling the requirements of all the regulations related to the degree. The research report and results presented in this thesis have not been submitted, in part or in full, to any other university or institution for the award of any degree or diploma.

I certify that he has pursued the prescribed course of research.

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"Studies on Mechanical Properties of Laminated Bamboo Composites"

ABSTRACT

With the continued rapid development of the global economy and constant increase in population, the overall demand for timber and timber based products will likely continue to increase in the future. The available supply of quality timber in the world is reducing rapidly. In India, as in other parts of the world, the trend is toward lower quality and more expensive timber for the manufacture of wood products. In several European markets as well as in other parts of the world, many tropical wood-based products have been either banned or discouraged. End-users of wood-based products have realized the serious danger to the environment if certain natural forest stands are depleted. Since the demand for these products will continue, an alternative or substitute for timber is desirable.

A suitable substitute for timber should possess properties comparable to and be compatible with existing processing technology. A fast growing and abundant species would be preferable. Bamboo is such a material which has excellent growth rate, with some species growing at a rate of 15 to 18 cm daily and maximum height achieved in just four to six months. Over 1,200 bamboo species have been identified globally of which some bamboo species grow to over 30 m high and have a diameter of 40 to 60 cm.

Natural fibre based composites are mixtures of natural fibres such as bamboo, sisal, coir, jute (in fibre, mat or slat form) with polymeric materials, processed under controlled temperature and pressure to obtain a class of products having superior properties than the individual components (Thea, 2003, Mathur, 2006, Lakkad, 1980). These composites have high strength to weight ratio, durability, and dimensional stability, amenability to be engineered to any complex shape or size and above all lower the cost of production. Among the various biomass sources, bamboo is one of the most rapidly generating resources. Bamboo has been processed into composites as a wood substitute and replaced timber in many applications such as doors & windows and their frames, partitions, wardrobes, cabinets, flooring, furniture etc.

Over the last two decades bamboo-resin composites have been increasingly explored as a material in the construction industry because the tensile, compressive and bending strength of the composites is superior to that of both the natural material as well as resin component in the composite. Use of resin prevents cracking and deformation under relative humidity.

Also, bamboo-resin composites show higher resistance to insect pest bio-erosion. Detailed research studies on mechanical properties of bamboo polymer laminates are few. Therefore, there is need to characterize bamboo based laminates for mechanical properties including tensile strength, compressive strength and flexural strength, so that the full potential of bamboo as an engineering material could be realized. One of the objectives of this research is to explore the mechanical properties of bamboo-polymer laminates to be used as an environment friendly material in the construction sector.

The objectives of this research are :

- Study of mechanical properties of bamboo laminae from different regions of culm of *Dendrocalamus strictus*.
- Study of compression, tension and flexural properties of Laminated Bamboo Composites incorporating *Dendrocalamus strictus* and Epoxy with different lamina angles.
- Validation of mechanical properties of Laminated Bamboo Composites using rule of mixtures and with other similar materials.

The above research objectives have been investigated through an array of tensile, flexural and compressive testing in addition to failure testing and validation through rule of mixtures and constituting equations. The summary of results from this research could be listed as follows :

The results of experimental evaluation of mechanical properties of bamboo laminae, prepared from bamboo slivers of 4 year old bamboo culms of *Dendrocalamus strictus* species show that mechanical properties such as tensile, compressive and flexural strength and their modulus of bamboo increases from inner to outer regions and with height of bamboo culms. The strength of the culms increases with height to compensate for the deterioration of rigidity due to the culms geometry. Bi-linear stress-strain response was observed in lamina under tensile loading. First change of slope took place at about 45% of ultimate stress. Nonlinear stress-strain response was observed in laminae under both compressive and flesural loading for which bifurcation points are difficult to identify. Mechanical properties of laminas selected from outer regions were found to be superior to other regions due to availability of higher volume fraction of bamboo fibres. Nodes were found to be the weakest portion of the culm when it comes to tensile loads. Comparative study with hard wood indicates that mechanical properties of bamboo culms were suitable for utilization in Laminated Bamboo Composite (LBCs).

Tensile and compressive properties of laminated bamboo composites (LBCs) decreases with increase in lamina angle. A combination of different factors could be used to decide the application of bamboo laminates because mechanical properties were affected by the lamina configuration. Mechanical properties such as tensile strength, compressive strength, flexural strength and screw holding capability and cost per cubic foot are resembling with the properties of the other similar type of materials. A comparative cost and mechanical properties of LBCs with other materials indicates that LBCs could be used as building and general purposes material like furniture, beam and column etc because there is possibility to increase the volume in any shape and in any direction by increasing number of layers where the thickness and shape of composite can be tailored during fabrication to meet specific requirement. Similarly, surface of LBCs could be as smooth as hard wood for aesthetic purposes by surface sanding, policing and finally by ultraviolet finishing. Furthermore use of more bamboo and technology for fabrication of LBCs could help to improve economy of rural people. An empirical expression has been derived which is useful for determining amount of adhesive required.

Studies for stiffness and strength of LBCs at macroscopic studies have been reported. Under tensile loading, bi-linear stress-strain curves were observed for all internodal laminae of Dendrocalamus strictus bamboo culm. Bi-linear stress-strain response upto 90% of ultimate stress were also observed for all LBCs. The first matrix failure occurs followed by fibres failure with metallic sound of any one layer and subsequently other layers in LBCs. The study indicates god agreement between the estimated and predicted values for stiffness and strength of LBCs which are satisfactory agreement for initial design purposes. The first chord modulus for almost all LBCs is close to the theoretical prediction using rule-of-mixture. Using elastic constants of top middle region lamina, stresses and strains obtained of Hypothetical Laminated Bamboo Composite (HLBC) are lower than experimental failure limit of said lamina. This indicates that proposed LBC behaves like a fibrous composite which are presently in use for a variety of structural applications. Strength of LBCs were compared with other similar composite materials.

Some recommendations from this research are as follows :

In view of global scarcity of timber, incentives need to be provided to small and marginal farmers to cultivate bamboo and also an attempt should be made to set up small cluster-based training cum production centres so that bamboo could be harvested locally and

converted into value-added products. This would give a boost to the rural economy and create livelihoods. This would also lead to utilization of greater proportion of green materials in product design, building construction and in many other sectors where the functionally graded composite that is bamboo can deliver based on its inherent strength.

Research and Development into innovative product design of bamboo composites needs to be initiated by agencies promoting bamboo cultivation and product development in mission mode. An exhaustive mission mode study of bamboo species of India with respect to their utilization as a material for vehicle bodies, roofing material, flooring solution and furniture applications needs to be urgently undertaken. Codes for various products need to be developed so that architects and product designers could incorporate bamboo composites much more in their practice.

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