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Development of layered laminate bamboo composite and their mechanical properties

C.S. Verma *, V.M. Chariar

AICTE, Chanderlok Building, Janpath, New Delhi, India

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ABSTRACT

Dry bamboo culms of *Dendrocalamus strictus* were processed into thin laminas and cold pressed using epoxy resin to produce layered bamboo epoxy composite laminates. Mechanical properties of layered bamboo–epoxy composite laminates including tensile strength, compressive strength, flexural strength and screw holding capability have been evaluated. Mode of failure were identified at macroscopic level as suggested in ASTM standard and their mechanism were examined at microscopic level using SEM analysis of fractured surfaces under different type of tests.

1. Introduction

Bamboo is fast becoming a promising wood substitute and one of the chief reasons for this is that as usable bamboo can be harvested in 3–4 years from the time of plantation as opposed to timber which takes decades [1,2]. While there are several publications on characterization of bamboo composites based on bamboo fibers in polymeric matrix [3–10] very few reports on evaluation of bamboo composites based on laminas exist in the literature [11,12]. The tensile and compressive properties such as strength and modulus of fibrous composites decreases with increase of angle of fibers from 0° [13]. The modified epoxy was prepared to get improved impact and adhesive properties by different techniques [14,15]. Conventional screw yielded the maximum screw withdrawal resistance in Oak, followed by stone pine, black pine and fir [16,17]. Mechanical and physical properties of woods such as teak, deodar, and kail are good for structural purposes [18–24]. Mechanical properties of bamboo based laminates need to be investigated thoroughly so that the full potential of bamboo as a functionally graded composite could be utilized. This publication reports the mechanical properties evaluation of 5-layered bamboo epoxy laminates.

2. Materials and methods

2.1. Fabrication of LLBCs

Four year old green bamboo (*Dendrocalamus strictus* species) culms were obtained from TERI Gram (Tata Energy and Research Institute), District Gurgaon (Haryana), India. Moisture content of green bamboo collected were 37% at the time of felling (Digital moisture meter model MD-4G). Moisture content is then reduced to 10–12% by sundry. This was done to ensure better adhesion between bamboo laminae and the epoxy resin. A full length bamboo culms were labeled at nodes and internodes as shown in Fig. 1. Bamboo culm was cut length-wise into six slats using radial hydraulic splitting machine. Each slat was sliced using sliver cutting machine for getting slivers from outer, middle and inner regions as shown in Fig. 1. Slivers prepared from outer regions were processed on two side planning machine to remove some amount of outer skin which is weak in adhesion. Lamina specimens were prepared from outer slivers only for fabricating layered laminate bamboo composites (LLBCs). It is noted that width of laminas comes out from bamboo culms were generally less due to circular cross section. Therefore laminas were butt joined using adhesive to make laminates/plies with larger width. The liquid diglycidyl ether of bisphenol–A type (Araldite LY 556) with curing agent/hardener triethylene tetramine (TETA, HY 951) was used as adhesive. Density and curing time at room temperature of adhesive are 1.3 g/cm^3 and 24 h respectively. The suggested ratio of araldite and hardener used are 100:23 by weight. The said adhesive will provide a low-viscosity, solvent free room temperature curing laminating system. Due to the very low cure shrinkage, Araldite LY 556 with hardener HY 951 based laminates will be dimensionally stable, free from internal stresses and excellent water resistance [14,15]. Tensile, compressive and flexural strength of Araldite given in Huntsman parts manufacturing selector guide are 30–35 MPa, 110–120 MPa and 85–90 MPa respectively and their modulus are 3–10 GPa, 2.5–2.8 GPa and 3 GPa respectively. The laminae were butt joined using said adhesive to make one laminate

* Corresponding author. Fax: +91 11 2324193.
E-mail address: csvnsitd@yahoo.co.in (C.S. Verma).

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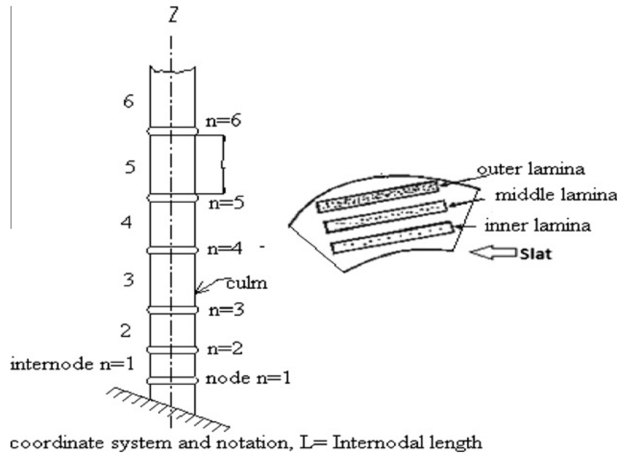

Fig. 1. Bamboo culms and location of laminas on slats.

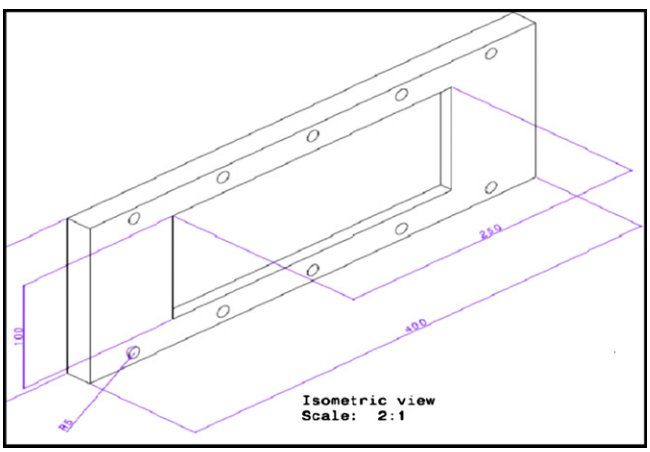

Fig. 2. Die from M.S. plate.

of larger width. To make first layer of laminate, laminae were arranged systematically and placed over on die cavity of 250 mm × 100 mm × 15 mm (Fig. 2) using adhesive for butt joined. One piece of lamina (rectangular light thick surface shown in Fig. 5, which is microscopic image) is butted against another and affixed with adhesive (rectangular dark thin surface shown in Fig. 5, which is microscopic image). To avoid adhesion between epoxy and die, polyesters sheet were used. Top surface of first layer of laminate was then coated with adhesive for interfacial bonding. Then other laminas were placed over on first laminate to make another layer of laminate. In this manner five layers of laminate/ply were stacked together to form one sample of unidirectional LLBCs. This laminate was then sandwiched between the plates of die set by applying pressure of 10 kg/cm^2 (2.5 T) using UTM (100 T). This ensured that the slivers were straight during solidification of adhesive and the excess adhesive was squeezed out. The sample was left for 24 h at room temperature for cross linking of epoxy. Surfaces of specimens were cleaned with acetone. The sample obtained was subjected to sand grinding from all sides so as to obtain smooth surfaces as shown in Fig. 3. Using said suggested methods, following types of samples with different lamina configurations/angles have also been prepared.

1. Sample A [0°/0°/0°/0°/0°]. 2. Sample B [0°/45°/0°/45°/0°].
3. Sample C [0°/90°/0°/90°/0°].

Five test specimens were prepared from each type of LLBCs samples respectively using cross cutting and grinding as per ASTM

Fig. 3. The bamboo epoxy laminated composite (LLBC).

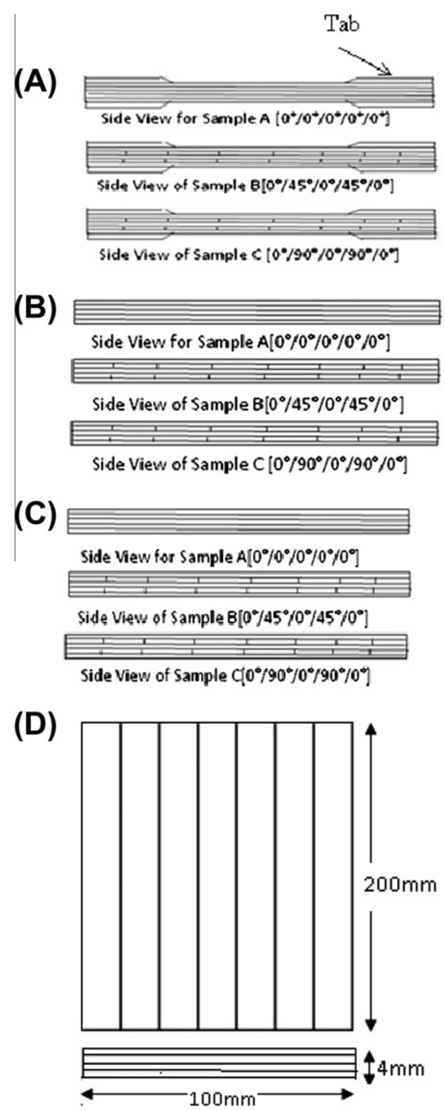

Fig. 4. (A) Sketch of LLBCs specimens with different lamina configuration for tensile testing, (B) sketch of LLBCs specimens with different lamina configuration for compressive testing, (C) sketch of LLBCs specimens with different lamina configuration for flexural testing, (D) sketch of LLBCs specimens with different lamina configuration for screw withdrawal testing.

standards D3039M and D7264 for tensile and flexural testing respectively where specimens were in the form of constant rectangular cross section of 250 mm overall length, 16 mm wide with a