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Engineered bamboo for structural applications

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HIGHLIGHTS

- Relevance of engineered bamboo products to construction and industry.
- Mechanical characterisation of bamboo scrimber and laminated bamboo is presented.
- Bamboo scrimber is shown to have similar strength to laminated bamboo.
- Engineered bamboo products have properties that are equal to or surpass that of timber.

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ABSTRACT

Bamboo is a rapidly renewable material that has many applications in construction. Engineered bamboo products result from processing the raw bamboo culm into a laminated composite, similar to glue-laminated timber products. These products allow the material to be used in standardised sections and have less inherent variability than the natural material. The present work investigates the mechanical properties of two types of commercially available products – bamboo scrimber and laminated bamboo sheets – and compares these to timber and engineered timber products. It is shown that engineered bamboo products have properties that are comparable to or surpass that of timber and timber-based products. Potential limitations to use in structural design are also discussed. The study contributes to a growing body of research on engineered bamboo and presents areas in which further investigation is needed.

1. Introduction

Bamboo has many advantages as a construction material: it is a rapidly renewable sustainable resource and has mechanical properties similar to timber. Worldwide, there is a growing interest in the development of bamboo products as a sustainable, cost-effective and ecologically responsible alternative construction material [1]. Partially due to the faster growth rate, and therefore harvest cycle, bamboo forests have up to four times the carbon density per hectare of spruce forests over the long term [2]. Bamboo is found in rapidly developing areas of the world where often timber resources are limited [2]. While the potential of bamboo is promising, more widespread development and use of bamboo is hampered by the lack of engineering data for mechanical properties and appropriate building codes [3,4].

Bamboo is an anisotropic material, having mechanical properties that vary in the longitudinal, radial and transverse directions. The raw material is a giant grass consisting of a hollow culm having longitudinal fibres aligned within a lignin matrix, divided by nodes (solid diaphragms) along the culm length (Fig. 1). The thickness of the culm wall tapers from the base of the culm to the top. As a functionally graded material, the bamboo fibres also vary within the culm wall decreasing in density from the exterior to the interior (Fig. 1).

While there are more than 1200 species worldwide, full culm bamboo construction is limited by the variation in geometric and mechanical properties. The difficulty in making connections and joints suitable for round (and variable) sections is also prohibitive for mainstream construction; however increasing research demonstrates a growing industry and demand for sustainable building products. Studies vary from the use of full culm bamboo in construction and scaffolding (e.g., [5–10] to engineered bamboo composites (e.g., [11–21]. Engineered bamboo composites are of particular interest due to the standardisation of shape and the relatively low variability in material properties [22].

Two examples of engineered bamboo are bamboo scrimber and laminated bamboo [22]. Bamboo scrimber, also referred to as strand woven or parallel strand bamboo, consists of crushed fibre bundles saturated in resin and compressed into a dense block (Fig. 2). The process is materially efficient, utilising approximately

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80% of raw inputs [23], and produces a product with a Janka hardness that is acceptable for external applications such as deck flooring. The process maintains the longitudinal direction of the bamboo fibres and utilises the resin matrix to connect the fibre bundles. In contrast, laminated bamboo maintains both the longitudinal fibres as well as a portion of the original culm matrix. The bamboo culm is split, planed, processed (bleached or caramelised), laminated and pressed to form the board product (Fig. 3). The orientation of the strip within the board, and therefore the direction of the radial fibre density, is randomly placed within in the board (Fig. 3). The final products use only approximately 30% of raw material input due to large losses of material when the strips are planed to form the rectangular section [23]. The sheet product is primarily used indoors for surface applications or furniture. While both materials are currently used for surface applications, both maintain the inherent strength of bamboo by maintaining the longitudinal fibre orientation and the engineered product creates a uniform section for connections and joints in structural applications.

The present work investigates the mechanical properties of bamboo scrimber and laminated bamboo to assess the potential for structural applications. A comparison with timber and engineered timber products is also presented.

2. Materials and methods

Two commercially produced products from China were used in the study. The bamboo scrimber product is comprised of *Phyllostachys pubescens* (Moso) with a phenol formaldehyde resin. The final product is a 140 × 140 mm section available in varying lengths. As shown in Fig. 2 and discussed in the previous section, the process of manufacturing bamboo scrimber uses the bamboo culm with minimal processing. The resulting commercial product is tested as a final product with no additional modifications. The average density of the bamboo scrimber is 1160 kg/m^3 with a moisture content of 7%. In comparison, Moso as a raw material has a relative density of approximately 0.5–1.0.

Laminated bamboo sheets are also manufactured from Moso bamboo strips using a soy-based resin as shown in Fig. 3 and discussed in the previous section. The structural specimens are built up from a commercial sheet (2440 × 1220 × 19 mm). The sheet was cut and the section laminated into the desired dimensions using polyurethane adhesive (Purbond HB S309). The adhesive was applied manually with a glue proportion of approximately 180 g/m^2 (final product) and the lamina pressed using manual clamps to apply the required pressure of 0.6 MPa for 4 hours (Fig. 4). Two orientations were tested: radial horizontal and radial vertical, which refer to the orientation of the original strip within the beam,

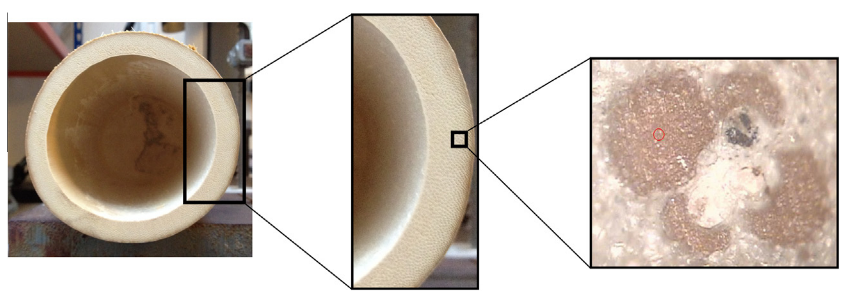

Fig. 1. Details of a bamboo culm.

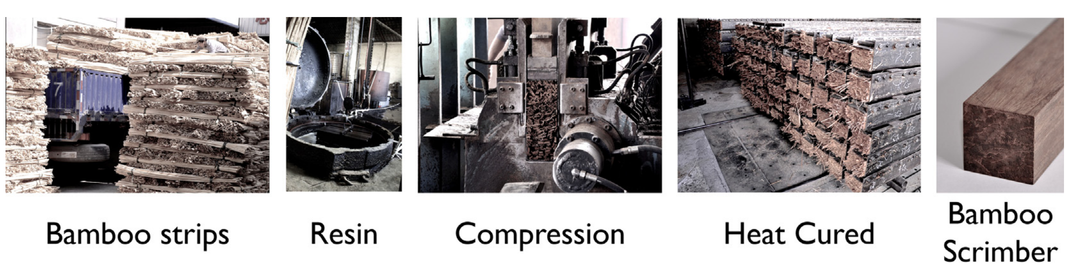

Fig. 2. Bamboo scrimber general manufacturing process in China.

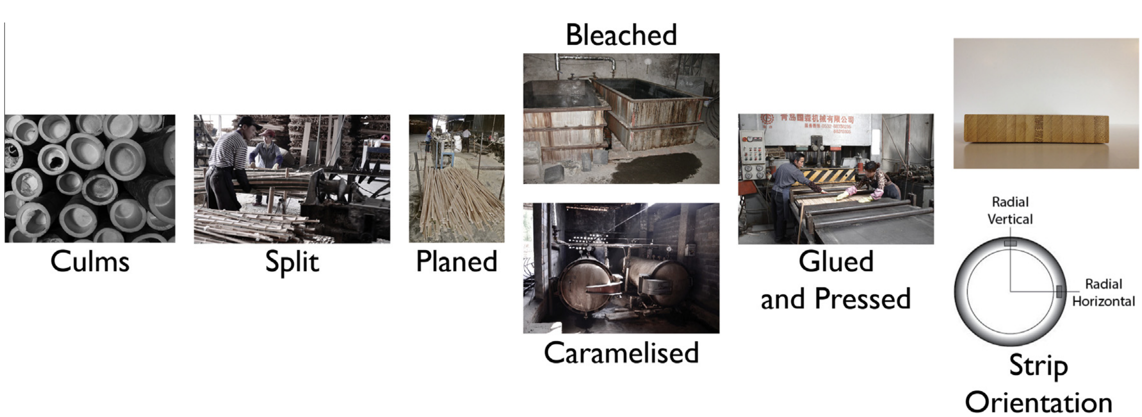

Fig. 3. Laminated bamboo general manufacturing process in China.