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Effect of processing methods on the mechanical properties of engineered bamboo

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HIGHLIGHTS

- Mechanical characterisation of bleached and semi-caramelised laminated bamboo.
- Thermal treatment processing methods have an effect on the mechanical properties.
- Engineered bamboo has mechanical properties comparable to timber.

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ABSTRACT

Engineered bamboo is increasingly explored as a material with significant potential for structural applications. The material is comprised of raw bamboo processed into a laminated composite. Commercial methods vary due to the current primary use as an architectural surface material, with processing used to achieve different colours in the material. The present work investigates the effect of two types of processing methods, bleaching and caramelisation, to determine the effect on the mechanical properties. A comparison to other engineered bamboo and timber products is also presented. The results of the study indicate that processing does affect the mechanical properties of engineered bamboo products. Areas in need of further research are also identified for thermally treated bamboo to be used in structural applications.

1. Introduction

Research and development of engineered bamboo products is increasingly explored to design sustainable building materials for the built environment. Bamboo is recognised as a material that can serve as a competitive and environmentally friendly alternative to conventional construction materials [1]. Bamboo grows rapidly and matures to structural strength within 3–5 years, which allows the material to be harvested more quickly than conventional materials such as timber [2]. With over 1200 species worldwide, bamboo has the potential to serve as an alternative construction material, however the use of bamboo in construction is currently limited to cultural traditions and marginally engineered applications due to the lack of standardisation and inherent variability of the material within and between species [3,4].

As an anisotropic material with mechanical properties that vary in the longitudinal, radial and transverse directions, the raw bamboo 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 to the top of the culm. As a functionally graded material, the fibres also vary within the culm wall, decreasing in density from the exterior to the interior (Fig. 1). Although the raw material has excellent strength properties, the circular section and inherent variability limits its widespread use in structural applications. To increase utilisation, engineered bamboo was developed as a laminated composite, which maintains the inherent strength of the raw material to form with a uniform section, thus reducing the variability in properties [5].

The composite maintains the strength of the longitudinal fibres and creates a uniform section for connections and joints. A relatively new product, laminated bamboo is progressively marketed for construction. The material is being researched and developed globally with varying manufacturing methods and technologies. Lack of standardisation within the industry also creates variability in the production process and therefore in the materials themselves.

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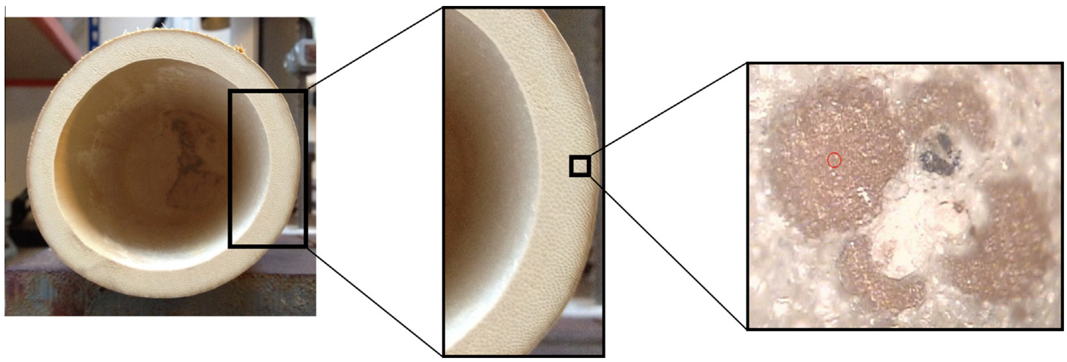

Fig. 1. Details of a bamboo culm.

An example of an engineered material is laminated bamboo sheet, a board product that is primarily used indoors for flooring or surface applications. The board consists of a bamboo culm, which is split, planed and laminated (Fig. 2). The raw bamboo material undergoes one of two processes for treatment: bleaching or caramelisation. The split and planed bamboo strips which are bleached in a hydrogen peroxide bath at 70–80 °C form the basis for the material commercially referred to as natural bamboo [6]. In contrast, the carmelisation process uses pressurised steam at approximately 120–130 °C [6] to caramelise the sugars in the bamboo to obtain the deeper brown colour referred to as caramelised or carbonised bamboo. The depth of the colour of the material differs based on the duration of treatment, which can vary from 4 to 8 h [6]. Commercially, the caramelised colour is preferred for surface applications, however the effects of processing on the mechanical properties is unknown.

1.1. Processing effects in bamboo

Studies of the impact of processing on the properties of engineered bamboo are limited. The chemical composition of bamboo is known to consist of cellulose, hemicellulose, lignin, ash and other extractives [7]. The content varies between and within species and is dependent on the age of the culm, the location along the height and within the wall thickness [7]. Similar to timber, the chemical composition is altered when thermally treated. The effect of thermal treatment of bamboo is not yet established and most studies investigate the effects in connection with the potential for biomass, or explore non-structural applications of full culm bamboo, such as furniture.

Although biomass applications utilise temperatures above those used in the engineered bamboo processing, the effects on the properties are useful for understanding the changes in composition. Studies on bamboo charcoal have shown that the heat treatment of bamboo up to 200 °C degrades hemicellulose, and free water is generated due to the chemical breakdown [8]. The results support the typical reduced equilibrium moisture content of thermally treated bamboo. The changes in moisture content can also be related to the mechanical strength of the material. Zhang et al. [9] investigated the effect of thermal treatment on *Phyllostachys pubescens* (Moso) bamboo. The study used different temperatures and durations of treatment. The results indicated that the modulus of rupture increased up to treatment at 120 °C and then steadily decreased, while the modulus of elasticity showed a slight increase up to treatment at 140 °C. The authors also found that the modulus of rupture correlated with the mass loss due to thermal treatment, which occurred due to degradation of holo-cellulose and alpha-cellulose. Similar effects were noted in heated treated *Dendrocalamus barabtus* Hsueh *et* D.Z. Li and *Dendrocalamus asper* Backer *ex* Heyne, which indicated that slight modification of the material occurred at 130 °C with additional modification and degradation at increased temperatures, with treatment temperature found to be more significant than the duration [10]. The effects of treatment appear to vary by species. Colla et al. [11] explored the impact of heat treatment on *Dendrocalamus giganteus* Munro, also known as giant bamboo. The authors found that thermal treatment increased the dynamic modulus and modulus of rupture up to 140 °C, with additional increase in temperatures resulting in decreased strength and degradation at a micro-scale level. In contrast, the thermal treatment improved the dimensional stability of the samples.

The brief review of published studies indicates there is some degradation at the processing temperatures and durations that are used for laminated bamboo. The extent of the impact of changes to chemical composition on the mechanical properties of engineered bamboo is not fully understood. Similar effects have been observed in thermal treatment of timber.

1.2. Processing effects in timber

In timber, thermal treatment is used to increase dimensional stability, reduce moisture and improve durability. Modification results in changes to the chemical structure and the mechanical

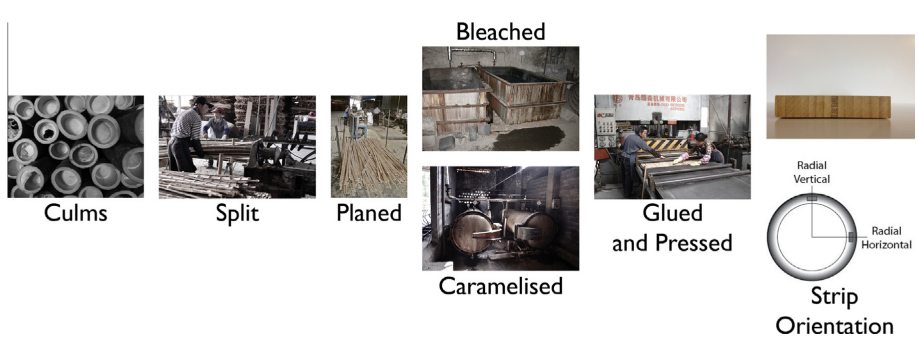

Fig. 2. Laminated bamboo general manufacturing process in China.