

Analysis of Methods of Development, Structure, and Properties of Engineered Bamboo Materials

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Abstract

Engineered bamboo materials have received much attention in recent years due to their sustainable nature and potential as an alternative to traditional building materials. This article provides a comprehensive analysis of the development methods, structural features, and properties of engineered bamboo materials. The introduction sets the stage by explaining the importance of such materials in relation to sustainability and environmental protection. The later analysis presents important research works and classifies them into four main areas: development methods, properties of manufactured bamboo products, composite bamboo products, and quality control measures. These classes discuss different methods of handling and processing bamboo to improve its mechanical and physical properties, as well as analyze the resulting structural properties. Quality control measures are also checked to ensure the reliability and consistency of the bamboo materials produced. The analysis culminates in a discussion of current challenges and future directions for the industry, which highlights the need for continued research and innovation to fully exploit the potential of engineered bamboo materials in sustainable construction.

Keywords: Engineered bamboo, development methods, structural attribute properties, quality control

Introduction

North-East India is rich in natural resources. Bamboo is abundantly found in the forest of this landmass. Around 60% of the total Indian bamboo resources are found in this region of the country. Among various species, Bhaluka bamboo [Bambusa balcooa], Jati bamboo [Bambusa tulda], Muli [Melocanna bambusoides], Dalu [Teinostachyum dalloa], Khang [Dendrocalmus longispatus], Kaligoda [Oxytenanthera nigrociliata], and Pecha [Dendrocalamus Hamilton-ii] are the economically important species found across the region.

Bamboo, as a natural green plant, has a tremendous role in carbon sinking. Thus, the planned cultivation of this plant will further enhance its contribution towards the mitigation of climate change [2]. However, due to a lack of a proper market and sustained demand, the inhabitants of North-East India hardly show any interest in growing or managing the forest of bamboo plants.

Traditionally, bamboo is used for fencing, handicrafts, roofing, and so on [2]. A few species are also sometimes used for consumption [3]. However, this resource has the great potential to contribute to the livelihood of the rural masses [4]. The conversion of this resource into high-value products and their acceptance in the market will enhance its contribution to livelihood. The quantum

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of use of bamboo in the near future depends upon the availability of information about the behavior of bamboo extracted through research and innovative product development [5]. The standardization of testing and structure also has an impact on the acceptance of bamboo commercially.

Engineered materials using bamboo as the raw material have emerged as a popular option for harnessing this renewable resource in recent times [6]. In this product line, bamboos are processed to get a straight edge and consistent structure [7]. The properties of the engineered bamboo change from its original form and show excellent mechanical properties [8, 9]. The final properties of an engineered bamboo vary depending upon the raw materials used, the shape and size of the cross-section, the columns slenderness ratio, density, the arrangement of the strips, applied processes, and so forth [10–12]. Some interrelated issues associated with bamboo are presented in Figure 1.

IMPORTANT RESEARCH WORKS ON ENGINEERED BAMBOO

Methods of Development

Diverse methods are used to develop bamboo-based engineered materials. The methods are different in terms of the process involved (applied adhesive, selection of raw materials, etc.) [7]. Depending upon the applied method, various types of engineered bamboo materials with varying properties are grown [13]. For example, for treatment purposes, both caramelizing and bleaching methods are used. But if bamboo strips are used to make the final product, the chemical bleaching provides better surface characteristics for the bonding [14]. Furthermore, the type and concentration of the chemical used for the bleaching affects the mechanical properties of the engineered bamboo, in addition to its resistance to termite [15]. The treatment processes also play a role in the durability of the material [16]. Figure 2 depicts the important steps of a typical process to develop the laminated engineered bamboo product.

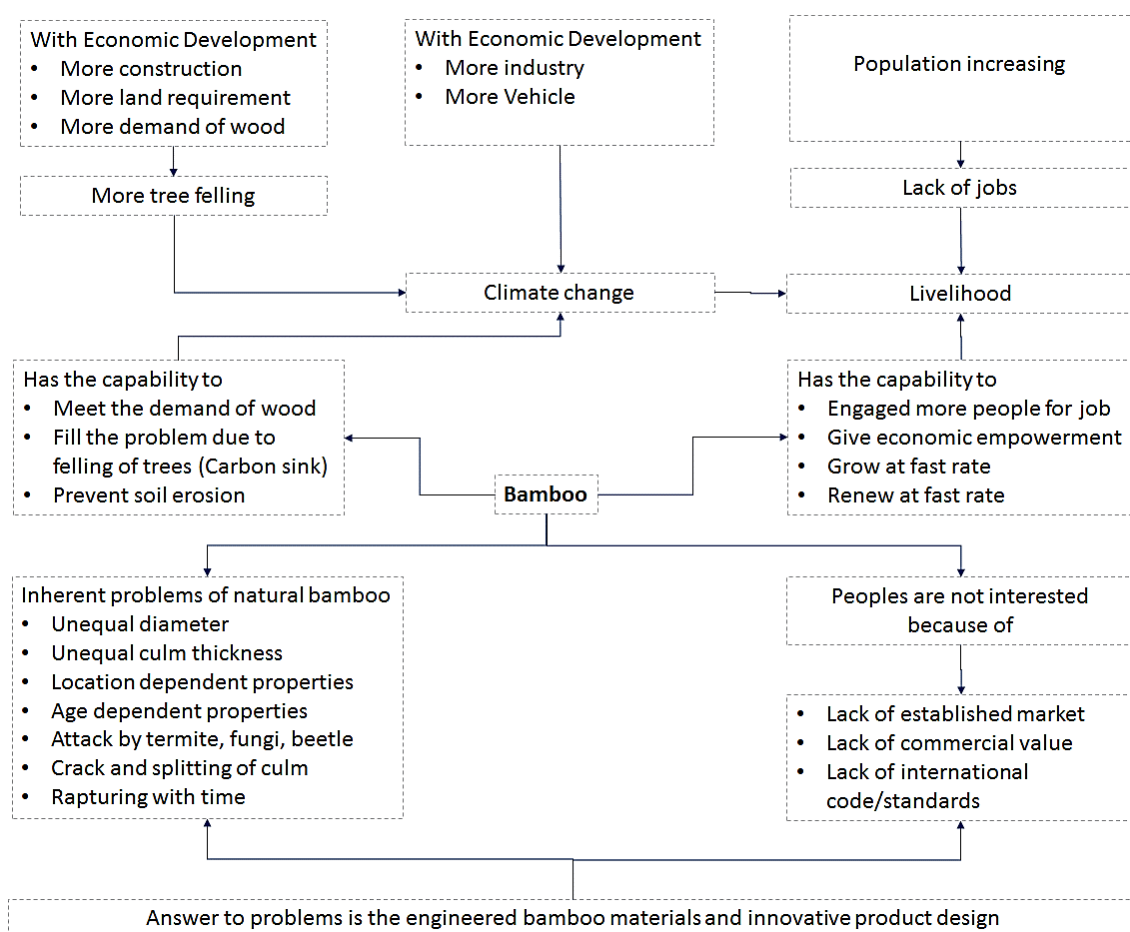


Figure 1. Some interrelated issues with bamboo.

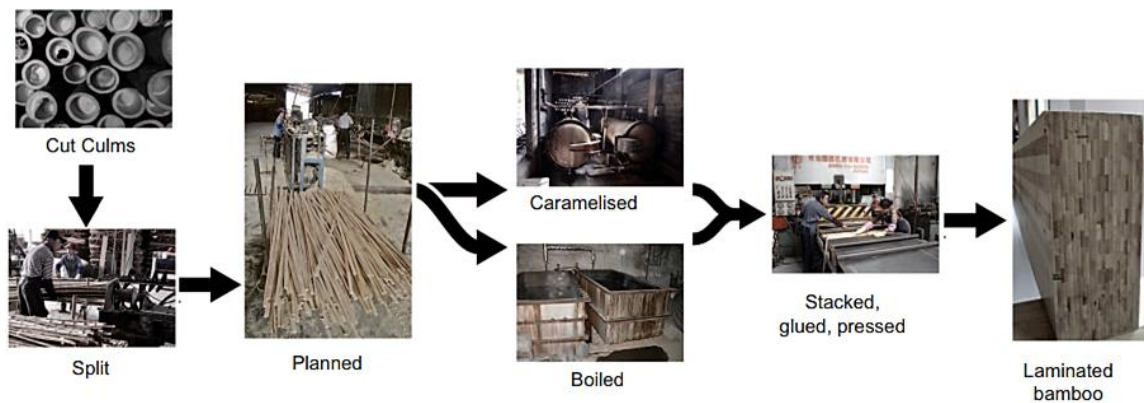


Figure 2. Manufacturing process of laminated engineered bamboo [17].

The applied method also leads to variability in the amount of required resin per unit area, which is one of the prime factors in the engineered bamboo [18]. For example, with an increase in density and quantity of resin, almost all the physical and mechanical properties of engineered bamboo get improved except the bending property [19].

Properties of Engineered Bamboo Products

Many researchers have investigated the mechanical properties of the engineered bamboo developed under varying conditions. Among the various parameters of mechanical properties, some of the factors studied are stiffness, bending behavior, compressive nature, tensile strength, flexural performance, mode of failure, effects of joints on the failure, modulus of elasticity, modulus of rupture, absorption capacity, and so on [12, 20–24].

Once the material is developed, it is cut according to the targeted application. At this stage, the physical and mechanical properties of the developed materials are altered. Sun et al. [20] found that the stiffness and ultimate load capacity increase with the cross-sectional size of the product.

Joints are an important aspect of using bamboo for all practical purposes. It is important in both the pole and the engineered bamboo. In the case of engineered bamboo, the joints among the strips determine the possible length and bending strength of the material. They also determine the failure nature of the material. In their experimental study, X. Guan et al. [11] found joints to be the second-most source of failure next to the nodes of bamboo.

Furthermore, different means, such as nut-bolts, nails, adhesive, clamps, and so on, are applied to connect the materials with one another to get the required structures. In this process, the material is physically treated with force. This leads to changes in mechanical strength and, hence, the lifetime of the material. J. Zhao et al. [25] found that when holes are drilled in the engineered bamboo material, the bending properties of the material decrease. Also, the decrease in bending properties was enhanced with an increase in hole size. The bending properties also change with a change in position of the whole.

In the case of pole bamboo, the joints are needed to get the required strength and structure. Depending upon the ways and means of joints, the life of the pole bamboo structure also varies. B. Lefevre et al. [26] propose a culm-to-culm joint using a wooden block and metal hose clamp. The joint was found to have a bending strength of 70% of the maximum possible value.

The hydrothermal properties, such as heat capacity and moisture-dependent thermal conductivity, along with the density ratio of a structural material, determine its effectiveness. As far as the thermal conductivity of bamboo scrimber is concerned, it is higher than that of timber. With temperature, it initially increases, but after a certain temperature, it starts to decrease. Also, the thermal conductivity

shows directional behavior. For example, it is higher in parallel to the grain direction compared with the perpendicular direction [27]. Furthermore, the hydrothermal properties of bamboo show that bamboo-based materials are more effective in temperate and hot regions compared with cold climatic conditions [28]. Moreover, the better thermal properties of the bamboo-based composite wall have great potential for energy saving of a building. Li et al. [29] found that a composite wall made of bamboo and steel can improve the building's energy performance by 27.1% to 40.9% in a given climatic condition.

Composite Engineered Bamboo Products

Many researchers have also worked on the composite materials of bamboo fibers with other natural or synthetic fibers. For example, P. Lokesh et al. [30] experimentally studied the effect of bamboo fiber length and its content on the mechanical strength of composite material made with epoxy resin. The tensile and flexural strengths also change with the fiber volume fraction in the bamboo epoxy resin composite [31]. The strength and stiffness of bamboo composite materials are comparable to those of wood. The behavior of bamboo composite materials reinforced with steel, concrete, coir, and jute fibers, simple FRP, and basalt fiber reinforced polymer [BFRP] has been reported in ref. [11, 32–37]. Figure 3 shows the bamboo-reinforced concrete beams in different steps.

Quality Control

Quality control is a must for any product to be on the market. Also, the reduction in the loss of raw materials gives added advantages to the manufacturers of any material. In the case of engineered bamboo, much research is needed for modification and inclusion of modern manufacturing processes. For example, in the present manufacturing process, the outer culm of the bamboo, which has a high fiber concentration, is rarely used. But if the manufacturing process uses this layer, then engineered bamboo with a high bending modulus can be developed [38]. The inclusion of automation in the manufacturing process is another area to explore.



Figure 3. BRC beams with vertical strips [33].

Nodes are an integral part of bamboo. They give strength to the raw bamboo pole [39]. However, they act as a source of failure in the case of engineered bamboo. This issue needs to be addressed for the improvement of the performance of engineered bamboo.

The layout of strips, separation among them, size of the strips, their composition, and orientations determine the number of raw materials, density, and strength of the engineered bamboo [11, 38]. The nature of the strips is an important factor in the flexure characteristics of the engineered bamboo. More uniformity in the strip means less risk of flexure. Moreover, if the engineered materials are developed using mate instead of strips directly, the type of mate constructions becomes a significant factor in the strength of the engineered bamboo. Also, the joints among the strips dominate the allowable length of engineered bamboo. On the other hand, the present length of the engineered bamboo is lagging the conventional building materials. Thus, there remains a necessity for research and development in these regards.

Most of the drawbacks of natural bamboo, such as its non-uniform composition and strength, rapid degradation with time, and so on, are addressed in engineered bamboo. Furthermore, the strength of engineered bamboo is comparable to that of high-quality natural and engineered timbers. However, the lack of internationally accepted standards invites the perceived risk of using engineered bamboo, especially in the construction industry. The framing of some standards will boost the use of engineered bamboo commercially [40, 41]. Ample research on the engineered bamboo will lead to the accrual of a wide range of knowledge and data about this novel material and thereby help in formulating internationally accepted standards.

DISCUSSION AND CONCLUSION

Climate change is one of the most pressing issues that the world is facing today. The indiscriminate felling of trees further enhances this issue. In India alone, the number of trees felling has almost doubled between the years 2016–2019 [42]. With the growth of the economy, it can be envisaged that number of trees being felled is going to increase rapidly in the years to come. The illicit felling of trees impacted the microclimatic conditions in addition to biodiversity, soil quality, hydrological cycle, and so on [43]. All these negative happenings make the country more vulnerable towards the untoward incidents. Bamboo can help in replacing the demand for wood with a positive impact on the environment. Moreover, being one of the fastest-growing plants, which can grow 10 to 20 m tall [44, 45], bamboo can easily fill the vacuum developed due to the felling of trees.

However, due to a lack of an established market and commercial utilization of bamboo, this renewable resource is not getting its due in the current economy of the country. Further, bamboo has some inherent drawbacks associated with it in its natural form. Some of the problems associated with bamboo are non-uniform in their size and culm thickness, the development of cracks, and the splitting of the culm with time. Different species have different node structures. In the node, the fibers are discontinuous, so they have a different strength than the culm. Rupturing of culm tissues is another problem associated with natural bamboo. Another set of problems associated with untreated bamboo is its high vulnerability to the attack of fungi, termites, and beetles. To avoid the above problems, engineered bamboo materials and bamboo composite materials are developed.

However, the applicability and durability of these bamboo materials depend upon the source and age of raw materials, the processes used to develop them, and so on. The density and moisture content change from species to species with age as well as with the location of the bamboo [46]. These demand slightly different development conditions for different species, ages, or locations of the bamboo. Furthermore, the strength of the engineered bamboo materials varies with the type of joints used among the strips.

The process-dependent thermal characteristics, such as thermal conductivity, are another problem associated with the engineered bamboo materials. Absorption of moisture remains one of the major

problems associated with engineered bamboo products specifically for outdoor applications [47]. At last, but not least, attractive product design is one of the major areas to explore for the greater acceptance of bamboo as a mainstream product in the market.

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