

Review Article

Progress of Bamboo Recombination Technology in China

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At present, China is the world's largest producer of bamboo resource possessor and bamboo processing. The main processing method of bamboo recombination technology is rolling and compaction, by which a reconstituted material with bamboo fibrotic veneer as matrix and phenolic resin as reinforcement is prepared. It has excellent physical and mechanical properties and can replace high-quality wood to manufacture various engineering structural materials and building decoration materials. This paper reviewed the research process and progress of bamboo recombination technology, the existing technical problems and prospects, in order to provide references for future research on bamboo recombination theory and production practice. In recent years, as a new material with controllable properties, designable structures, and adjustable dimensions, bamboo reconstituted materials have been comprehensively studied from the aspects of pressing process parameters, physicochemical mechanical properties evaluation system, and microstructure characterization, but the research is not comprehensive and has not in-depth view. In the future, the relationship between microstructure and performance should be emphatically studied to clarify the law of mechanical performance change and ultimate mechanical performance under synergistic enhancement effect, as well as the performance change and interface formation of the resin during the entire molding process. Meanwhile, the reliability and relevance of applied research should be further expanded, and the integration of natural and artificial aging environment, process and performance, and macro- and microscales should be strengthened.

1. Introduction

Bamboo, as an important ecological, industrial, and cultural resource, has become the green and sunrise industry of modern forestry in China. At present, the output value of China's bamboo industry is 200 billion yuan, with more than 10 000 kinds of products. It plays a major role in developing green low-carbon economy, coping with climate change, achieving precise poverty alleviation, and promoting employment and income increase for farmers. With the increase of the demand for ecological products in China, the comprehensive stop of commercial logging in natural forests, and the enhancement of environmental awareness, the forestry industry will face the contradiction between the increase in market demand and the shortage of resource supply. How to fully exploit the abundant bamboo resources and make up for the shortage of high-quality timber resources has become the focus of forestry industry development and research in China.

Bamboo wood-based panel is one of the effective ways to realize the industrialization, scale, and high value utilization of bamboo. The main products include bamboo plywood [1–3], bamboo particleboard [4], bamboo fiberboard [5], bamboo glulam [6], and laminated bamboo lumber [7]. The above-mentioned boards are mainly made of bamboo strips and other basic units by planning, cutting, milling, etc. and there are a series of problems such as low utilization rate of bamboo resources, low production efficiency, and low added value. The recombination technology is mainly based on roller compaction and defibering, by which bamboo bundles or bamboo fiber mats are obtained. After the resin impregnation, parallel lay-up, the mats are hot pressed into boards or cold pressed (hot curing) into square-edged timber. This has greatly improved the utilization of raw materials and realized the structural designability and the controllability of the board properties, making the bamboo-based panels leap from the application fields of indoor floor, furniture, and cement to wind power blades with higher strength,

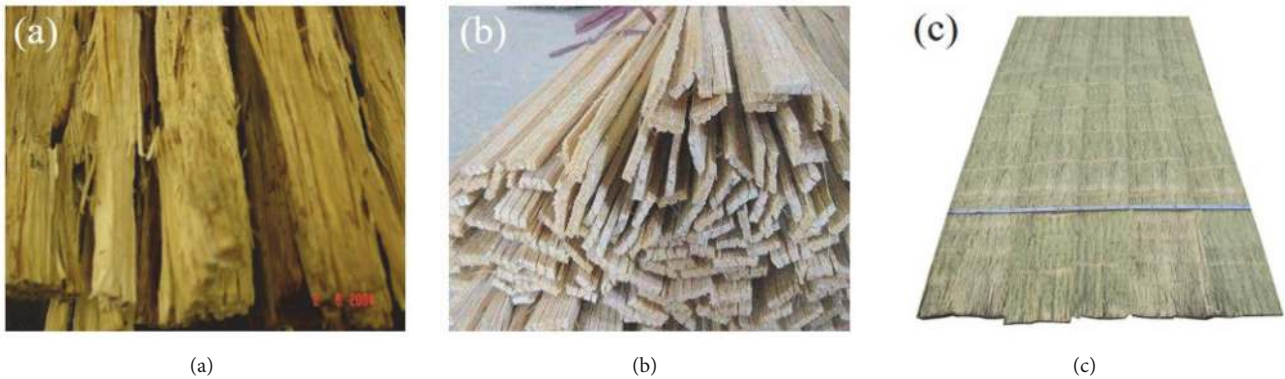


FIGURE 1: Research and development of bamboo scrimber unit. (a) Wood bundles for scrimber in Australia. (b) The first generation of bamboo recombination technology: bamboo bundles. (c) The second generation of bamboo recombination technology: bamboo fiber mats.

outdoor materials with high water resistance, and other high value-added fields [8]. This paper mainly introduced the research and development process of bamboo recombination technology in China, analyzed the current research status and main problems of key science and technology, and put forward some useful suggestions for the sustainable development of bamboo recombination industry and the improvement of product performance. Also, it hopes that it could serve as a reference for the theoretical research and practical application of bamboo recombination technology in the future.

2. Development Process and Research Progress of Bamboo Recombination Technology in China

2.1. Development Process of Bamboo Recombination Technology in China. The recombination technology originated in Australia. Low grade wood with small diameter, thinned wood, and brand wood were used as raw materials and processed into wood bundles by rolling. Then they were used as the basic units to develop a product similar to natural wood (Figure 1(a)). The development of recombinant technology had caused a great sensation in the world's wood-based panel industry. However, due to the inaccurate control of the recombination unit in the process of reorganization, it is difficult to effectively control the quality and realize large-scale industrialized production. The subsequent related personnel continued to study the technology of timber reorganization, but the breakthrough has not been made. Later, relevant personnel continued to study the wood recombination technology, but no breakthrough has been achieved.

At the end of 1980s, drawing on the manufacturing process and principle of wood scrimber, low quality bamboo with small diameter was used as raw materials and processed into strip-shaped bamboo bundles by rolling and flattening [9, 10]. Then they were compressed into bamboo scrimber after resin impregnation. Nevertheless, due to the tedious process, the relevant research was limited to the experimental stage. In the late 1990s, bamboo enterprises in Anji of Zhejiang first utilized waste bamboo silk from bamboo

curtain processing to produce bamboo scrimber through resin impregnation and mold pressing, and the products were favored by the market. Based on the above, the bamboo strips after removing the outer part and inner part were used as raw materials by related enterprises and researchers. Strips were machined into transverse, unbroken, and longitudinal unconsolidated bamboo bundles by means of mechanical rolling (Figure 1(b)). After carbonization, resin impregnation and drying, the recombined bamboos were prepared according to the CIS slabs, hot pressing (or cold pressing), and the first generation of bamboo recombination technology was developed. The first generation of bamboo scrimber products has the characteristics of large density and beautiful pattern and is widely used in furniture, interior decoration, architecture, etc. The production enterprises were mainly distributed in Zhejiang, Fujian, Sichuan, and Anhui province. However, as for the first generation of bamboo recombination technology, the outer part and inner part of bamboo could not be utilized and the utilization rate of bamboo was only 50-60%. In addition, the inhomogeneous resin impregnation and high unit pressure requirements caused by incomplete defibering of material unit ultimately led to high production costs and the performance of bamboo scrimber cannot meet the requirements of the outdoor products [8].

In recent years, on the basis of fully summarizing the characteristics of bamboo recombination technology mentioned above, Research Institute of Wood Industry, Chinese Academy of Forestry, has completed the development of rolling and defibering technology, which integrates controllable separation of bamboo, veneer flattening, and minimally invasive treatment of the outer part and inner part of bamboo. Using this technology, the basic unit of bamboo fibrotic veneer was formed (see Figure 1(c)), which was loose and was interlaced in the longitudinally and was not broken horizontally. The technology platform of bamboo recombination was constructed (see Figure 2), and the upgrading of bamboo recombination technology was realized. Compared with the traditional bamboo basic unit such as bamboo strips and bamboo bundles, the new recombination unit has solved the technical problem of the difficult gluing of the outer part and inner part of bamboo through the destruction of the bamboo

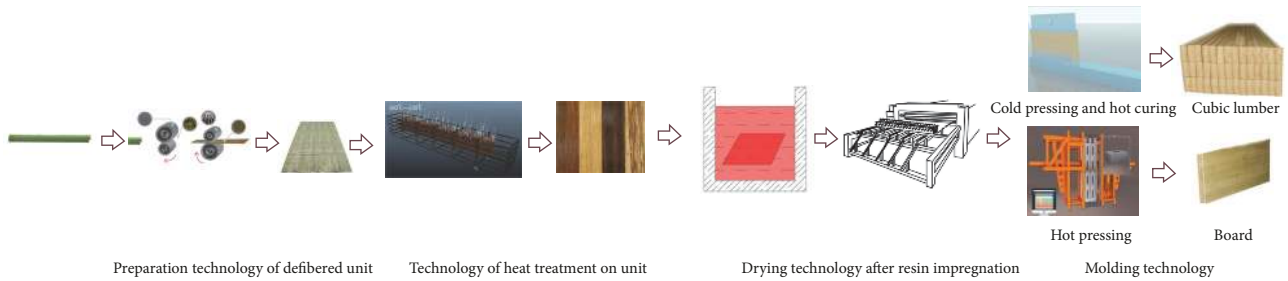


FIGURE 2: Process flowchart of production of bamboo scrimber.

cells and the opening of the dotted/linear crack channels. It also has broken through the problem of size limitation of bamboo processing and utilization and realized the utilization ratio of bamboo that increased from 50% to 90%. Currently, the innovative technology of bamboo recombination has been widely spread all over the country, and its products are widely used in the fields of wind power materials, outdoor materials, structural materials, and decoration materials. At present, the main market of reconstituted materials is aiming at outdoor areas, mainly for parks and nature reserves. The products include outdoor pavements, railings, and garden landscapes with market capacity ranging from 500 to 700 million m^3 . The technology of bamboo recombination abroad is mainly concentrated in India, Vietnam, and Myanmar in Southeast Asia, Brazil in America, and Ethiopia in Africa. Among them, India, Vietnam, and Ethiopia mainly imported the first generation of processing equipment for production of bamboo scrimber from China. In 2015, Brazil docked with the Ministry of Science and Technology of China to establish the Science and Technology Assistance Project for Developing Countries 'China Provides Bamboo Breeding and Efficient Utilization Technologies to Brazil.' Then second-generation recombination technology was introduced to Brazil for bamboo processing and utilization.

2.2. Research Progress of Bamboo Recombination Technology in China

2.2.1. Preparation Technology of Defibered Unit.

The preparation technology of defibered unit mainly focuses on the defibering process and its evaluation system as well as the adaptability of bamboo species. In recent years, new research contents have emerged, such as the mechanism of defibering and separation, the morphological characteristics of the defibered unit, and the continuous and efficient unit processing. The fibrotic bamboo veneer, as the basic unit for bamboo scrimber, is prepared through the tooth cutting and transmission friction of the roller in which the bamboo unit is extruded, rubbed, and cut. At the macrolevel, a deep and shallow fissure is formed along the radial direction of the outer part and inner part of bamboo. There is a certain angle between the cracking direction and the bamboo surface, and part of the siliceous and waxy layers on the surface falls off and forms dotted or linear cracks on the surface where the extramedullary tissues fall off and are destroyed [11]. At the

microlevel, the parenchyma cells fall off and are crushed and broken, the catheter wall is cut and broken, and the fiber cells are fractured and torn longitudinally and radially, of which the number of vascular bundles included in the unit sections is about 1 to 4 [12]. In terms of performance, the tensile strength of the unit decreased [13] and the surface area increased [14]. Through the preparation technology of defibered unit, the cortex that is difficult to glue falls off. The separation of fiber, vessel, and ground tissue maximally preserves the strength of bamboo fiber. The internal growth stress is released, and the permeation passage of the resin was greatly increased, which provides the foundation for the high-performance bamboo scrimber.

The morphological characteristics of the unit affect the strength of the substrate and the penetration of the adhesive, resulting in changes in the properties of the material. From the view of unit fracture morphology, the length, depth, ratio, and angle of the crack determined the effect of thinning [15]. The water absorption and the dipping amount can be used as the evaluation index [16]. Judging from the shedding of the outer part and the inner part of bamboo, the unit morphology was mainly aimed at the width of the shedding, the depth of damage, and the rate of shedding [14, 15, 17]. As seen from the morphology of the end face, the width, area, circumference, and the number of vascular bundles determined the uniformity of the unit [15, 18]. The establishment of the evaluation system of unit morphological characteristics objectively and comprehensively reflects the essential characteristics of the evaluated materials and promotes the scientific development of bamboo timber recombination technology.

The maximum width of fibrotic bamboo veneer after defibering is up to 500 mm, and its length depends on the length of bamboo. This breaks through the problem of size limitation of bamboo processing and realizes the scale industrialization utilization of clumping bamboo, *Miscellaneous* bamboo and moso bamboo [19]. At present, nearly 17 kinds of bamboo such as *Phyllostachys pubescens*, *Bambusa distegia*, *Neosinocalamus affinis*, *Phyllostachys bissetii* McClure, *Phyllostachys bambusoides f. shouzhu* Yi, *Phyllostachys viridis*, *Phyllostachys glauca* McClure, *Phyllostachys praecox f. perversalis*, *Dendrocalamus oldhamii*, *Dendrocalamus latiflorus* Munro, *Bambusa pervariabilis* McClure \times *Dendrocalamus*, *Dendrocalamus sinicus*, *Dendrocalamus albonudus*, *Dendrocalamus tomentosus*, and *Bambusa burmanica* Gamble have been studied for the adaptability of bamboo unit. The differences of properties and anatomical structure of

different bamboo species ultimately affect the properties of bamboo scrimber [12, 16, 20–25]. In recent years, with the continuous maturity of industrial production technology of bamboo recombination, the technology of unit preparation and veneer lengthening provides a technical reference for the manufacture of large-span and large-size bamboo scrimber [26–28]. Usually, overlapping method is used to lengthen veneers to prepare bamboo scrimber with different specifications [29]. The technical parameters of veneer lengthening affect the mechanical properties of subsequent products. A lap length of 16.1 mm as well as a medium target density (1.01 g/cm^3) was beneficial to the improvement of mechanical properties of bamboo scrimber.

2.2.2. Technology of Heat Treatment on the Unit. The technology of heat treatment on the unit is based on hot air or overheated saturated steam as a medium to conduct high-temperature treatment of the preparation unit to improve the quality and added value of the product. The results showed that, with the increase of heat treatment temperature and the prolongation of time, the color of the unit gradually deepened, the brightness index decreased, the color difference and the mass loss increased, and the bending strength decreased at the macrolevel [29]. At the microlevel, cracks were observed in the fibrous cap, parenchyma cell wall, and intercellular layer of the unit, and the pits on the vessel wall became larger, but the morphology of the fiber cells remained unchanged [30]. In terms of chemical components, the content of alpha cellulose, hemicellulose, starch, and sugar decreased, the content of extraction and lignin increased, the pH value decreased, and the hydroxyl and hydrogen bonds of the cell surface decreased [31]. As for performance, the unit surface free energy and polarity decreased, the density, volume shrinkage, and equilibrium moisture content decreased, the hydrophobicity increased, and the elastic modulus of fibroblast and parenchyma cell wall remained unchanged, and the hardness increased significantly [32–34]. In the course of the above changes, the formation of cracks and the increase of grain size are conducive to the subsequent penetration of PF resin into the microstructure of bamboo. The decrease of the matrix material such as cellulose led to a decline in mechanical properties and the change of extract and lignin was the main reason for the color change of the unit. The decrease of starch and carbohydrate content had a positive effect on the antimildew performance of the product. The decrease of hydroxyl and hydrogen bond led to the poor hygroscopicity of the material, which benefited the improvement of the water resistance of the product. At present, the unit's heat treatment technology is built on the market demand to coordinate the temperature and time. In order to facilitate the production process of bamboo recombination technology and reduce the cost, the research on the combination of drying and heat treatment technology of bamboo has also emerged [35].

2.2.3. Drying Technology after Resin Impregnation. Reactive phenolic resin with low viscosity is used in the process of resin impregnation. After resin impregnation, the bamboo unit is

dried to prepare prepreg. The prepreg is required to have two-phase matching with low content of volatile components, long storage life, appropriate viscosity, and fluidity. At present, the research on the effects of drying process after resin impregnation on the performance of products as well as the property of the resin is relatively comprehensive [36, 37]. However, few studies have been done on the characterization of the properties of adhesives during the drying process.

During the dipping process, the resin is coated with a uniform film of phenolic resin on the surface of the veneer through flow, infiltration, and wetting. At the same time, the resin adheres to or deposits on cracks formed by rolling and defibering and the cavity of parenchyma cell, as well as the cell wall of basic tissue near the crack extension [30, 38]. Impregnation capacity of the unit is achieved by the coordinated regulation of the solid content of the adhesive, the impregnation method, the impregnation time, and the water content of the unit. The solid content has a significant impact on the impregnation capacity [39–41], and the impregnation capacity is designed according to the properties and uses of the boards. At this stage, the resin used in bamboo recombination technology is mainly phenolic resin. On this basis, the impregnation properties of modified melamine resin [42] and phenolic resin/polyvinyl acetate mixed resins with different ratios [43] were studied to avoid surface cracking and improve the preloading properties of slabs.

The drying process of the impregnated unit mainly solves the problem of the moisture content brought by the adhesive in the dipping process, increases the degree of polymerization of phenolic resin, and reduces the pressing time. During the drying process, the retention value of enthalpy of resin after drying is required to be high to ensure that the adhesive has sufficient activity. If the drying temperature is too low, the final moisture content of the impregnated unit will be too high, and bubbling and other defects will occur while molding; otherwise, the precuring of adhesive will be intensified, thus affecting the bonding strength of the board [44]. It is easy to lay when the impregnated material after drying is used.

2.2.4. Molding Technology. Molding technology of bamboo is mainly composed of hot pressing and cold pressing (hot curing). In the process of molding, the microstructure, chemical composition, physical and mechanical properties of bamboo, and resin have changed significantly. The results showed that the parenchyma, vessels, and fibers of bamboo were compacted to different degrees, and the cell walls were folded or even crushed [22, 45–48]. Phenolic resin was redistributed and cured under hygrothermal condition with high pressure, forming the macrobonding interface between the resin and the substrate surface, the microscale interface between the resin and the vessel as well as the cell cavity of parenchyma cells, and the nanoscale interface between the resin and the cell wall of parenchyma cells [49]. In terms of chemical composition, hemicellulose in the cell wall was degraded, soluble extracts were further decomposed, and the relative crystallinity of cellulose was

decreased [15, 50]. Hydrogen bonds between phenolic resins and hydroxyl groups on the surface of holocellulose were formed, and hydrogen on the aromatic ring of lignin was condensed and substituted. Meanwhile, crosslinking reaction took place to form a three-dimensional network structure composed of hydrophobic groups [22, 30]. Using the cold pressing technology, the static bending strength can reach 364MPa, and the fatigue life of tension-compression can reach $3.96 \times 10_6$ times (maximum loading was 90MPa). The weatherability and dimensional stability of the reconstituted bamboo have been greatly improved. For example, in the case of 28 h-boiling treatment (4 h-boiling water, 20 h-drying, and then another 4 h-boiling water), the thickness swelling rate is lower than 2.7% and the width swelling rate is less than 0.4%. In addition, the products have strong corrosion resistance.

High pressure is required in the molding process for the two methods. The difference is that the hot-pressing process is accompanied by a process of moisture and heat transfer, and the slab has a process of gradual heating and softening while the cold pressing is not. The influence of two molding processes on the properties of materials was linked to temperature, time, pressure, pressure reduction process, density, and molding type. These factors affected the rheological behavior of the resin in the process of gluing and then determined the properties of the bonding interface, which was finally manifested in the differences in the properties of the products [51–56].

2.2.5. Functionalization and Its Application Technology. Bamboo recombination technology for high-performance and multifunction products is the trend of technological progress in the industrial field. This process is based on the functionalization of materials, which will further expand the application of bamboo recombinant materials. At present, research on the preparation technology of functionalized bamboo scrimber mainly focuses on the reasonable manufacturing process, so that the product can reach the design performance, its reliability could be improved, and the cost could be reduced. Functional treatment mainly includes two methods, the treatment on bamboo (basic unit) by functional additives in the production process and postprocessing of products. The treatment of the basic unit can achieve the flame retardant and color matching function of the material. The flame-retardant function was achieved by optimizing the addition process of inorganic minerals [57] and compound flame retardant containing nitrogen, phosphorus, and boron [58–60]. Aiming at the requirements for visual and decorative properties of materials, pretreatment optimization technology on bamboo basic unit [61] and dye system screening and controllable dyeing process could improve dye-uptake and degree of fixation, which formed compounding technology system of dyeing for bamboo scrimber to achieve color regulation of bamboo scrimber. The posttreatment of the product can realize the antimildew property of the material. Physical selection of the surface of bamboo scrimber products by screening and optimizing the types and adding methods of fungicides could improve the fixation rate and antiloss ability

of the antimildew agents, achieving good prevention and control effects [62–64].

The performance of the product is controllable, the structure is designable, and the dimension is adjustable via the bamboo recombination technology, which causes the product application domain to expand unceasingly. For example, bamboo scrimber products with different mechanical properties can be obtained from different bamboo species. The bamboo scrimber prepared from *Neosinocalamus affinis* bamboo has tensile strength of 119.69 MPa and tensile modulus of 24.46 GPa. Its flexural strength and modulus are 151 MPa and 23.4 GPa, respectively. Also, it has a high shear strength of 37.33 MPa [65]. These properties are sufficient to make it suitable for structure applications. In the field of architectural structure, the related research focuses on the analysis of mechanical properties of bamboo scrimber under different environmental temperature and humidity conditions [66–69]. The mechanical properties [70–76] and creep properties [77] were characterized. The performance design [78–82] and the mechanical characteristics of connection joints [83–85] were also investigated to optimize the design method of enhanced bamboo scrimber components [86–88]. The above research is expected to provide scientific basis for rational utilization of bamboo scrimber in the field of building structure. In the field of outdoor weathering, the changes of properties of bamboo scrimber under different aging treatments [89–94] were mainly discussed. The decay resistance of bamboo scrimber [47] was also studied, and its reliability was predicted and evaluated to realize the scientific protection and application of bamboo scrimber in outdoor products [95]. In the field of indoor decoration, the finishing technology [96, 97] and corrugated lightweight design [98] were studied to improve the decorative performance of materials. In addition, the environmental protection performance [99] and secondary processing performance [100, 101] of bamboo scrimber were investigated to promote the diversification and serialization of products. According to the above research, bamboo scrimber materials have been expanded from indoor floor, furniture [102], and cement template to wind power blade [103], building structure [104], and outdoor materials [105].

3. The Technical Problems to Be Solved in China's Bamboo Recombination Technology

Although bamboo recombination technology has made breakthrough progress, as a new technology, there are relatively few basic research and applied basic research on bamboo scrimber, which limits the development of new products based on this material. Therefore, it is necessary to further summarize and refine the related technical problems related to bamboo recombination technology and systematically study bamboo recombination technology by referring to the advanced theories and research methods of traditional composite materials, so as to further promote the popularization and application of this material.

3.1. Preparation Technology of Defibered Unit. The preparation technology of defibered unit breaks through the bottleneck of bamboo veneer utilization and improves the production efficiency of bamboo by 5 times compared with bamboo strips. At present, equipment for defibering bamboo has basically achieved mechanization, but it is urgent to upgrade the continuity and automation level of existing equipment and achieve the precise control of the equipment. Meanwhile, the problems of unit adaptability for continuous, highly efficient, and automatic production during the preparation of defibered units need further research and discussion.

3.2. Technology of Heat Treatment on the Unit. Currently, the technology of heat treatment on the unit is used as a green physical modification method to improve the color and dimensional stability of products. However, the increase of heat treatment temperature and the extension of time will cause the decline of mechanical properties of the unit and greatly aggravate the loss of materials. Thus, firstly, it is necessary to explore the mechanism of strength chemical change and its effect on material properties under heat treatment and to reveal the influence of related components on bonding interface and resin permeability after heat treatment. Finally, the controllable heat treatment technology system of material unit is formed. The analysis and solution of the above problems will play a great role in guiding the adjustment of preparation technology for bamboo scrimber and the development of functional products.

3.3. Drying Technology after Resin Impregnation. Phenolic resin is invoked as the reinforcing phase in bamboo recombination technology. By controlling its content, the performance of the material can be enhanced. During the impregnation process, the bonding interface formed between phenolic resin and bamboo basic unit has a great influence on the subsequent process and properties of the material. At this stage, there is still a need to concentrate on the following aspects: (1) qualitative and quantitative analysis of the soaking rate, uniformity and degree of impregnation of resin in the substrate, and the response mechanism of the final product properties to the degree of impregnation in the impregnation process; (2) quantitative characterization of changes in physical and chemical properties of resins such as molecular weight, active groups and aggregates in drying process, and effects of resin precuring on processing, manufacturing, and final product properties; (3) the influence of moisture content of prepreg after drying on the performance of the final product; (4) developing low temperature and fast drying equipment and technology to improve the quality and efficiency of drying process and reduce the cost.

3.4. Molding Technology. The molding technology belongs to liquid forming technology for adhesive. In this process, the adhesive goes through a physical process characterized by flow and a chemical process characterized by reaction. The two subprocesses coexist and interact. The adhesive

changes from low viscosity liquid resin to a solid material, forming the bonding interface, which has a great influence on the properties of the material. During the two forming processes, the flow and long-distance infiltration of resin will become ever more difficult. The rediffusion permeation of resin and the similarities and differences of flow path paths in substrates by short-range flow have yet to be studied. Secondly, prepreg at this stage needs to carry out manual laying process. Automated paving equipment and technology are required to improve production efficiency and reduce cost. At last, it is desired to develop a new adhesive to realize low-temperature curing process, and at the same time digital simulation of curing forming process needs to be carried out to guarantee product quality.

The basic units are densified during the molding process, which greatly improves the mechanical properties of the final product. The synergistic enhancement effects of unit preparation, dipping amount, and density contribute to this improvement. However, this synergistic effect is not a simple linear relationship, and the difference of bamboo species has a significant influence on the mechanical properties. For specific materials, the ultimate crushing value varies according to different molding processes. The correlativity between the microstructure and mechanical properties during the forming process and the variation of mechanical properties and ultimate mechanical properties of bamboo scrimber prepared from different bamboo species under the condition of synergistic reinforcement deserve further discussion and explanation.

3.5. Application Technology. As a newly developed biobased composite material, the durability of bamboo scrimber is one of the technical indexes for the long-term preservation of its performance in the process of use and storage, which has attracted more and more attention. Although aging properties of bamboo reconstituted materials have been explored at the present stage, there is a lack of research on the microstructure and properties of bamboo under the synergistic effect of radiation, moisture, and heat. There is still a certain distance to study the mechanism of climatic aging and the prediction methods of natural aging life based on the law of artificial accelerated aging are still lacking, which are very important to evaluate the reliability of bamboo scrimber.

Furthermore, as a novel material, the standardization system of this product is still imperfect, especially the lack of standards in the field of product structure, which limits its application in wood structure building. It is necessary to establish and optimize the evaluation method and system of bamboo recombinant materials as soon as possible so as to standardize and lead the healthy and rapid development of the industry. In addition to the above-mentioned technical issues, other issues such as flame retardant, antimildew, anticorrosion mechanism, surface properties of recombinant materials, and its response mechanism to finishing process need further research and exploration, in order to better promote its technical progress and industry development.

4. Conclusion

Bamboo recombination technology is an effective means for highly efficient and high value utilization of bamboo. In the process of production, both technology and equipment have independent intellectual property rights, which provides strong scientific and technological support for improving the quality and efficiency of bamboo processing industry in China. Also, it is at the international leading level in similar research. With the development of biomass building materials and bamboo structure in China, bamboo recombination technology will enter a period of rapid development.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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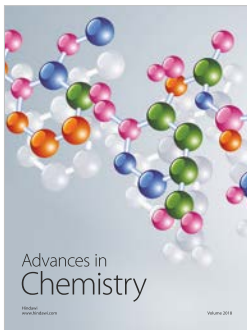
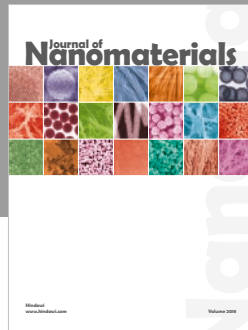
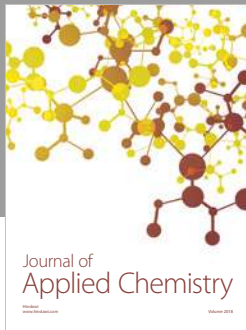
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