Academic Journal of Architecture and Civil Engineering
ISSN: 2960-0243
DOI: 10.61784/ajace240102

RESEARCH PROGRESS ON THE APPLICATION OF ENGINEERED BAMBOO IN BUILDING STRUCTURES

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Abstract: Bamboo is a low-carbon renewable biomass material with abundant resources and excellent wood properties. Engineering bamboo is made from round bamboo through cutting, cooking, carbonizing, drying, gluing, reorganization and other processes. It has stable size specifications and performance, breaking through the limitations of round bamboo in terms of cross-sectional size, shape, connection, etc., and can meet the needs of low-rise multi-story buildings. Application requirements of building structures. A comparative analysis of the current research status at home and abroad in the fields of engineering bamboo's material physical and mechanical properties, component stress performance, connection performance and structure, fire protection and durability performance was conducted, and the current demonstration application status and technical standard preparation of engineered bamboo structures were summarized. It was pointed out that Promoting application of engineered bamboo structures key technical issues that need to be resolved urgently in application and standard formulation.
Keywords: Engineered bamboo; Physical and mechanical properties; Durability performance; Research progress

1. INTRODUCTION

The development of green and environmentally friendly building materials is an inevitable trend in the development of the construction industry. Compared with steel, concrete, masonry and other materials, bamboo and wood are low-carbon and renewable biomass materials, which have the advantages of being renewable, easily degradable, high in strength-to-weight ratio, lightweight and earthquake-resistant. Bamboo has a short growth cycle and can be matured in 4 to 6 years. It can store carbon dioxide during the growth process to improve the environment. From the perspective of the entire life cycle of growth, processing, construction, use, maintenance and disposal, bamboo is a green material. Environmentally friendly high-quality materials [1].

China is the world's largest bamboo producer, ranking first in the world in terms of bamboo species, area, storage volume and output, with a total bamboo forest area of 4.2 million hectares [2-3]. China 's bamboo resources are mainly distributed in subtropical areas south of the Yangtze River such as Fujian, Zhejiang, Jiangxi, Hunan, Guangdong, Anhui, and Hubei. In addition to China, other major bamboo producing areas in the world include India, Myanmar, Thailand, Japan in Asia and Argentina, Colombia, Brazil, Venezuela and other places in Latin America [3].

Bamboo has high tensile strength and strength-to-weight ratio, uniform material, good stability and wear resistance. Round bamboo has a long history of use in the construction field in China and even around the world. Early Chinese artifacts were unearthed at the Hemudu site in Zhejiang and Jinsha sites in Sichuan. bamboo structure house. Diaojiao buildings in Xiangxi, Hunan, China, and "ganlan-style" bamboo buildings of the Dai people in southwest China are representatives of traditional bamboo structure houses [4-5]. Bamboo is also commonly used as a tie material in the walls of Fujian earth buildings to enhance the overall performance of the wall. Bamboo is still one of the main scaffolding materials used in the construction or maintenance of multi-story buildings in China [6].

Although round bamboo has natural and environmentally friendly characteristics and profound resource advantages, its physical properties are unstable and easy to dry out. The bearing capacity of a single round bamboo is not high, the node connections are complex, and it is easy to split and damage, which limits its application in construction projects. It is subject to many restrictions; untreated bamboo is susceptible to damage by insects, decay and mildew, and its durability is generally poor [4]. Up to now, round bamboo is still difficult to meet the material requirements of the construction industry. The maturity of the engineering bamboo production process has achieved a breakthrough in the utilization of bamboo. The round bamboo is cut, steamed, carbonized, dried, glued, reorganized and other processes to make engineered bamboo with size specifications and stable performance.

2. RESEARCH ON THE PHYSICAL AND MECHANICAL PROPERTIES OF ENGINEERED BAMBOO

The currently widely used engineering bamboos include bamboo plywood, bamboo mat plywood, bamboo mat bamboo curtain composite plywood, bamboo particle board, bamboo strip laminated lumber, restructured bamboo, etc. [7]. Typical engineering bamboos used in construction include bamboo laminated lumber and bamboo laminated lumber. Reorganized Bamboo. Bamboo laminated lumber, also known as glued bamboo [8], is made from round bamboos processed into bamboo slices of fixed width and thickness, dried to a moisture content of 8% to 12%, and then glued with adhesive. Glued bamboo retains the round shape. The material properties of bamboo slice units are more closely related to round bamboo. Restructured bamboo further deepens the processing of bamboo. It uses bamboo filaments as the basic unit, which is dried, dipped, assembled, and hot-pressed to solidify. It is an engineering material with high strength, high density, and uniform texture [9].

Regarding the physical and mechanical properties testing methods of bamboo, there is currently an international ISO standard Bamboo-determination of physical and mechanical properties-part 1: requirements (ISO 22157-1-2004) [10] for round bamboo, and China has a standard for bamboo sheets. The national standard "Test Methods for Physical and Mechanical Properties of Bamboo Materials" (GB/T 15780- 1995) [11] and the industry standard "Test Methods for Physical and Mechanical Properties of Bamboo Materials for Construction" (JG/T 199- 2007) for defect-free small samples [12]. For engineered bamboo, there is currently no targeted physical and mechanical performance testing standard. Instead, the relevant testing methods for wood and composite wood products are often referred to, such as the Standard specification for evaluation of structural composite lumber products (ASTM D5456-17) [13]. various testing standards. At present, domestic and foreign scholars have conducted extensive research on the physical and mechanical properties of engineered bamboo.

2.1 Physical and Mechanical Properties of Laminated Bamboo

As major bamboo production areas and users of bamboo products, scholars from China, Japan, the United States, India, South America and other regions and countries are committed to studying the application prospects of engineered bamboo, among which glued bamboo has been the most extensively studied. Jiang Zehui et al.[14] tested the moisture content, horizontal shear strength, aging performance and conventional mechanical properties (elastic modulus and static bending strength) of bamboo laminated lumber, and compared it with common construction wood, confirming its use as a building material. feasibility, but its anti-aging properties need to be improved. Zhang Yetian et al.[15] studied the tension, compression, bending and shear mechanical properties of bamboo strip laminated timber and bamboo finger -jointed laminated timber, and compared them with the performance indicators of several common construction woods, C20 concrete, and sintered porous brick masonry. It is confirmed that bamboo laminated timber has superior comprehensive mechanical properties and has broad prospects for use in building structures. Sulastiningsih et al. [16] studied the effects of bamboo species and the number of gluing layers on the flexural strength and elastic modulus of laminated bamboo, and compared them with the performance indicators of wood. Mahdavi et al. [17-18] summarized the manufacturing process, physical and mechanical properties, production costs and environmental benefits of laminated bamboo (including flat-pressed, side-pressed and flat-sided bamboo laminated lumber), and introduced a simple manual manufacturing of bamboo plywood. process and can be used in areas where heavy processing machinery is not available. Correal et al. [19-20] studied the physical and mechanical properties of flat-pressed bamboo laminated lumber made from Guado bamboo, which is abundant in Central and South America. Compared with most other glued bamboo products, Guado bamboo laminated bamboo has higher strength and Stiffness, its strength is higher than commonly used engineering wood, it is a high-quality building material. Xiao Yan et al. [4, 21] developed Glubam glued bamboo based on bamboo mat and bamboo curtain composite plywood and conducted systematic and in-depth research on its basic mechanical properties such as tension, compression, bending and shear, and obtained the basic mechanical performance indicators of Glubam glued bamboo. ; With reference to the method for determining the allowable stress of wood, the stress reduction method from material testing to component level was analyzed, and the weakening effect of cold-pressed gluing surfaces on the compressive strength was studied. Verma et al. [22-23] studied the tensile, compressive and bending capabilities of flat-pressed bamboo laminated timber made from different parts of Dendrocalamus strictus bamboo slices and glued at three different angles. And the resistance to screw pullout, and compared with the mechanical property statistics of hardwood and softwood commonly used in engineering, it was found that the average strength of glue-laminated bamboo is equivalent to that of high-quality wood such as teak, and is better than softwood and wooden composite materials, and can replace wood as a A building load-bearing material. Li Haitao et al. [24-26] used larger specimens to test the compression properties of side-pressed bamboo laminated lumber made from different parts of round bamboo, and analyzed the crushing process, failure mechanism, stress and strain of glued bamboo. Model, judging from the test results, side-pressure glued bamboo is a building material suitable for engineering structures. Sharma et al. [27-28] conducted tensile, compression, bending and shear properties tests on laminated bamboo specimens produced using different processes, studied the impact of production processes on the mechanical properties of laminated bamboo, and compared it with commonly used engineering woods (Douglas fir, spruce). were compared.

According to the test results in the literature [14-28], the density of various types of glued bamboo products is 600-1000kg/m3, the moisture content is 8%-12%, the compressive strength is mostly 40-60MPa, and the tensile strength is mostly 90 ~ 140MPa, the flexural strength is mostly 90 ~ 120MPa, the flexural elastic modulus is mostly 8 000 ~ 12 000MPa, it shows good plastic properties under compression and bending damage, and the material strength-to-weight ratio is higher than that of steel. It is a It is a building material with excellent comprehensive mechanical properties that can replace engineered wood for stress-bearing components such as beams, columns, and boards. However, the mechanical properties measured through small specimens cannot fully reflect its strength characteristics. Large-scale tests are needed to study its performance in full-scale structures. Its promotion and application still need to solve problems in technology, cost, and specifications.

2.2 Physical and Mechanical Properties of Restructured Bamboo

Recombinant bamboo has experienced more than 20 years of development in China. Traditional recombinant bamboo uses bamboo bundles formed by simply unraveling the remaining "bamboo silk" from bamboo curtain processing as the main raw material; In recent years, the Chinese Academy of Forestry's Wood Industry Research The latest manufacturing technology of bamboo-based fiber composite materials developed by the institute has greatly improved the utilization rate and production efficiency of round bamboo, and can realize the industrial production of restructured bamboo [9].

Guan Mingjie et al.[29] compared the flexural elastic modulus and static bending strength of poplar reconstituted wood and moso bamboo reconstituted bamboo, studied the correlation between strength, elastic modulus and density, and explored the bamboo-wood reconstituted composite made of bamboo and wood. The feasibility of the material as a structural material. Zhang Junzhen et al.[30] tested the tensile and compressive properties of recombinant bamboo from Cizhu and compared it with the corresponding parameters of wood. It was confirmed that the strength of recombinant bamboo in all directions was better than that of commonly used wood. Huang et al. [31-32] studied the mechanical properties of recombinant bamboo made from 4 to 5-year-old Moso bamboo, and analyzed its failure mechanism in tension, compression, and shear in all directions. According to the fiber composition characteristics of recombinant bamboo, two-way tensile strength, two-way strength, and two-way strength were used to test the recombinant bamboo. A total of 7 characteristic curves for compression resistance and three-way shear resistance are used to describe the mechanical properties in each direction in detail, and the uniaxial constitutive structure of the restructured bamboo in each direction is given in the form of polynomials. Sharma et al. [28] referred to the relevant specifications of wood and tested the tensile, compression, bending and shear mechanical properties of recombinant bamboo in the along-grain and cross-grain directions, and compared it with commonly used engineering woods Douglas fir, spruce and round bamboo. Li Haitao et al. [33] used larger-size specimens to test the compressive properties of restructured bamboo along and across the grain, analyzed the compressive failure mode of restructured bamboo, and gave its compressive strength and elastic modulus in each direction. and Poisson's ratio.

The physical and mechanical properties of recombinant bamboo are closely related to the preparation process and bamboo species. Under the current production process, according to the test results in the literature [28-33], the density of recombinant bamboo can reach 1 000 ~ 1 100kg/m3, and the water content The rate is 8% ~ 10%, the compressive strength is mostly 50 ~ 80MPa, the tensile and flexural strength can reach more than 120MPa, even as high as 250MPa [30], the compressive and flexural elastic modulus is 12 000 ~ 13 000MPa, Its comprehensive mechanical properties are excellent and stable.

The above studies on the mechanical properties of glued bamboo and reconstituted bamboo mostly refer to the testing standards for wood properties. The sizes and shapes of specimens corresponding to each standard are different, especially the Standard specification for evaluation of structural composite lumber products (ASTM D5456-17) [13] used small specimens without defects, and the mechanical properties measured in the test are quite different from those when used in large components. The mechanical properties of engineered bamboo are significantly affected by the size effect. The larger the size of the specimen, the more material defects it contains, and the load-bearing capacity of the laminated bamboo is directly affected by the gluing surface. The larger the size, the more gluing surfaces it contains, and the load-bearing capacity The lower. In addition, the production process and environmental factors have a direct impact on the mechanical properties of engineered bamboo. How to combine the physical and mechanical properties measured in the laboratory with reality to obtain mechanical parameters that can be used for structural design to ensure sufficient safety and economical reasonableness requires a lot of experimental research and theoretical analysis. Current research generally compares the material properties of engineered bamboo with engineered wood, and the constitutive model and failure criteria of engineered bamboo need to be further discussed.

3. RESEARCH ON THE MECHANICAL PROPERTIES OF ENGINEERED BAMBOO COMPONENTS AND CONNECTING NODES

3.1 Research on the Mechanical Properties of Engineered Bamboo Components

In the research on the mechanical properties of engineered bamboo components, the bending properties of beams and the compressive properties of columns are mainly studied, which are the two most basic forms of stress in engineered bamboo structures. Lu Qingfang et al. [34-35] studied the flexural properties of bamboo laminated timber beams and the compressive properties of restructured bamboo columns. The flexural damage of beams is mainly caused by layered pull-off and diagonal tearing of the bottom fibers. There are obvious signs of damage, which is an ideal damage form. The assumption of flat section deformation when the beam is bent is established; the restructured bamboo column has excellent elastic deformation recovery ability when the axial center is compressed, which is important for the component to maintain good ductility during earthquakes. The energy dissipation capacity and the production of smaller post-earthquake residual deformation are of great significance. Xiao Yan et al. [36] studied the mechanical properties of Glubam glued bamboo beams and columns, including the effects of different connection methods, different lamination methods and finger joints [37] and other factors on the bending performance of glued bamboo beams, as well as the effects of glued bamboo structural columns. Axial compression performance [38-39], the calculation model, calculation method and failure criterion of the bearing capacity of beams and columns are given, and the fatigue performance of glued bamboo beams is studied [37]. Varela et al. [40] studied the ability of laminated bamboo boards made from Guado bamboo, which is abundant in Central and South America, to be used on the outside of the wooden frame-shear wall and work together with the core board to resist lateral loads through pseudo-static hysteresis tests. It is confirmed that laminated bamboo boards have better energy dissipation capabilities when used in lateral force-resistant systems. Sinha et al. [41] studied the mechanical properties of laminated bamboo and beams made of it, and confirmed that laminated timber has better tensile and flexural strength than commonly used structural timber such as North American Douglas fir. Huang et al. [31] and Zhou et al. [42] studied the bending resistance of restructured bamboo beams made from 5-year-old moso bamboo, and compared the bending load-bearing capacity of restructured bamboo beams made from bamboo filaments taken from different parts of round bamboo. 42], analyzed the bending failure mode of restructured bamboo beams, and analyzed the flexural bearing capacity of the beams by measuring the compressive and tensile constitutive along the grain of the restructured bamboo [31]. Sharma et al. [27-28] conducted bending tests on laminated bamboo beams and restructured bamboo beams processed by several laminated bamboo manufacturing processes, and analyzed the bending failure process of the beams. Li Haitao et al. [43-45] studied the mechanical properties of a large number of laminated timber laminated bamboo beams and columns made of moso bamboo as raw materials. Through bending tests of laminated bamboo simply supported beams under different shear span ratios [43], they confirmed that when the beam bends The deformation characteristics of the plane section; through the axial compression test of glued bamboo columns under different slenderness ratios [44], the influence of the slenderness ratio on the compressive bearing capacity and failure mode of the columns was analyzed, and the column axis considering the slenderness ratio was given Compressive stability coefficient; Through the compression bending test of glued bamboo columns under different eccentricities [45], the eccentricity influence coefficient of the column's compressive bearing capacity was analyzed.

3.2 Research on Mechanical Properties of Engineering Bamboo Joints

The most traditional connection methods of round bamboo components are steel wire or rope lashing and mortise and tenon joints. Tying is mostly used on scaffolding and a few houses. Mortise and tenon joints refer to the connection method of traditional wooden structures, but the openings weaken the strength of the bamboo at the nodes, making it easy to split and crack. Break [3]. Hardware sleeve connections appear in modern bamboo structures. However, due to the non-uniform size of round bamboo and the high precision requirements of steel nodes, this kind of connection is difficult to achieve rapid mass production. The emergence of engineered bamboo solves this problem. The connecting nodes of engineered bamboo structures have very similar structures to those of wooden structure nodes.

The research on wooden structure connection nodes can be traced back to 1928 [46], which has a history of nearly 90 years. The research involves many influencing factors and has a relatively comprehensive theoretical basis, such as China's "Wood Structure Design Code" (GB 50005- 2003) [47] (2005 edition) adopts the elastic-plastic theory based on the Soviet Union, the American NDS regulations [48] and the European Eurocode 5.

The procedure [49] adopts the plastic yielding theory based on Johansen [50]. Referring to the connection methods of wooden structures, in engineered bamboo structures, the safer, more reliable and easy-to-operate connection method is steel bolt connection.

Regarding the connection nodes of the glued bamboo structure, Fei Benhua et al. [51] studied the bearing capacity of the bolted joints in glued bamboo through experiments and compared it with the formula recommended by the specification [48, 52]. It was confirmed that the bolted joints in glued bamboo have High strength, stiffness and good ductility. Yang Ruizhen[53-54] conducted the compression resistance test of Glubam glued bamboo bolt joints and the tensile performance test of a single bolt, analyzed the failure mode of bolt joints under tensile and compressive loads, and compared it with the Chinese and American wood structure specifications[47-48, 52] were compared with the recommended formulas, and a bearing capacity calculation model under specific loading conditions of compression and tension was established. Wang Zhaohui et al. [55] studied the shear bearing capacity of bamboo curtain plywood bolted connections through symmetric double shear tests, analyzed the influence of the direction and density of the glue layer in bamboo curtain plywood on the bearing capacity, and bolted the nodes with wooden components of the same structure. The bearing capacity was compared and found that the bearing capacity of the bamboo curtain plywood bolt connection was greater than that of the larch bolt connection, and could reach the bearing capacity calculated in the Sino-American Wood Structure Design Code [47-48]. Feng Li[50] analyzed the bolt connection principle on the basis of summarizing the performance of bolt joints of wooden structures, compared the bolt joint design methods in Chinese, American and European wooden structure design codes[47-49], and applied Johansen yield theory to modern times. In the bolted joints of bamboo structures, a calculation formula for the shear bearing capacity of glued bamboo bolt connections using Glubam glued bamboo as the base material was established and verified by frame tests.

In terms of reorganizing the connection nodes of bamboo structures, Li Xiazhen [56] studied the influence of factors such as end distance, main member thickness, bolt diameter, bolt spacing and number on the load-bearing performance of bolt nodes, and evaluated the calculation formula of bolt nodes of modern wooden structures. It is applicable to the calculation of the bearing capacity of bolted connections of restructured bamboo, and the calculation formulas of the pin groove pressure-bearing strength and the calculation formula of the bolted connection bearing capacity suitable for restructured bamboo are derived. Zhou Aiping et al. [57] conducted experiments to study the along-grain tensile bearing capacity of restructured bamboo components using steel filler plate bolt joints, as well as the compressive capacity and deformation capacity of single bolt steel filler plate connections, and compared them with the Chinese and American wood structure specifications [47 -48] and the calculation formulas of the Timber Structure Design Manual [58] were compared. Due to the high hardness and poor processing performance of recombinant bamboo, it is difficult to

popularize the node structure such as tooth connection in traditional wooden structures. Steel filler plate bolt connection is an effective connection method. Zhang Congjun et al.[59] conducted low-cycle repeated loading tests on cross-shaped joints connected by bamboo laminated timber beams and restructured bamboo columns, as well as shaking table tests on the overall structure of the engineered bamboo frame, and studied the dynamic characteristics of the engineered bamboo frame structure. Energy consumption performance, seismic performance, and node form optimization.
The node structure of the engineered bamboo structure is similar to that of the wooden structure. Therefore, its calculation and design methods are basically based on the existing calculation methods of the wooden structure nodes, and have been modified and improved according to the material properties of the engineered bamboo. The design of the engineered bamboo components and nodes A unified design theory and calculation system has not yet been formed.

4. RESEARCH ON FIRE PROTECTION AND DURABILITY PERFORMANCE OF ENGINEERED BAMBOO

4.1 Fire Performance

Similar to wood, bamboo is also flammable. It absorbs heat under high temperature and fire. The temperature rises, the water in the material evaporates, the change in moisture content, and the decomposition and carbonization of the material itself cause changes in the physical and mechanical properties of the material. It is resistant to high temperatures and Fire resistance limits the promotion and use of bamboo engineering materials.
Zhou Quan et al. [60] combined the examples of Glubam glued bamboo structure resettlement houses built in Guangyuan North Street Primary School and Nanying Primary School in Sichuan after the Wenchuan earthquake, and took a full-scale prefabricated glued bamboo structure house as an object to study the prefabricated bamboo structure. The changes in the temperature field of the walls of structural houses under fire conditions and the damage and destruction of the houses in the fire were compared with the light steel structure board houses of the same size. The results showed that the prefabricated glued bamboo structure houses were lighter in comparison. Steel house has better safety and fire resistance. Ma Jian [61] studied the fire resistance of Glubam glued bamboo and lightweight bamboo structure frame houses, conducted a combustion performance classification test on the glued bamboo wood after flame retardant treatment with fire retardant paint, and confirmed that the flame retardant treated glued bamboo board can reach Class B combustion performance; a full-scale fire test of a lightweight bamboo structure frame house was also conducted to determine the fire resistance limit of the house, confirming that the overall structure fire resistance time of the lightweight bamboo structure frame house built using the construction method described in the article can reach 1 hour. Mena et al. [62] studied the combustion and fire protection properties of Guado bamboo and Guado laminated bamboo, and compared them with pine glulam. Through the ignition time, flame propagation rate, and flame propagation rate of the three materials under different heat fluxes, Mena et al. Comparing the carbonization speed and flexural strength at high temperatures, it was found that the ignition time of Guado bamboo round bamboo and Guado bamboo glued bamboo is longer than that of pine glulam, and the flame propagation is slower. The carbonization speed of round bamboo is significantly slower than that of glued bamboo and glued bamboo. For wood, the degradation trends of the flexural strength of the three materials at high temperatures are similar. Generally speaking, the fire resistance of bamboo is better than that of glulam and is equivalent to that of various commonly used woods. Zhong Yong et al.[63] studied the bending performance of bamboo laminated timber after high temperature and high temperature. Through the bending test of bamboo laminated timber at different temperatures, they established the relative resistance of bamboo laminated timber after high temperature and high temperature. Model of the relationship between flexural strength and temperature. Xiang Jinhua [64] studied the thermophysical properties of recombinant bamboo, the mechanical properties of recombinant bamboo at high temperatures, and the carbonization properties of recombinant bamboo when exposed to fire on one or more sides, and obtained the changes in various mechanical properties of recombinant bamboo with temperature. The law, as well as the law of carbonization speed changing with fire time, moisture content and texture direction. Shah et al. [65] used the transient plane heat source method to study the thermal conductivity of several engineered bamboo products made from Moso bamboo and Guado bamboo, and confirmed the influence of bamboo composition and density on thermal conductivity; Zhong et al. [66] studied recombinant bamboo The compressive strength and elastic modulus under and after high temperature, as well as the critical temperature at which the thermal decomposition of recombinant bamboo leads to changes in material properties; Xu et al. [67] studied the tensile and compressive properties of recombinant bamboo at high temperature, providing The stress-strain curves of restructured bamboo along the grain and across the grain at different temperatures, as well as the reduction coefficients of strength and elastic modulus with temperature; Xu et al. [68] tested the glued bamboo through a cone calorimeter test. And the combustion performance of recombinant bamboo, comprehensive test indicators show that the fire resistance of recombinant bamboo is better than that of engineered cork, the fire resistance of glued bamboo is equivalent to that of cork, and the cone calorimeter test can quickly evaluate the combustion performance of engineered bamboo.
At present, the test data on the high temperature resistance and fire resistance of engineered bamboo structures are still relatively limited. Most of them draw on the testing methods and evaluation standards of wooden structures and compare them with the fire resistance of wooden structures. The fire protection measures of engineered bamboo structures are also limited. Reference was made to related timber structures. Generally speaking, the fire resistance of engineered bamboo is comparable to that of commonly used engineered wood (softwood).

4. 2 Durability

The organic components of bamboo are similar to those of wood. Its inherent biomass components such as cellulose, hemicellulose, and lignin are affected by climate conditions such as light and moisture in the natural environment, and are susceptible to insect corrosion during storage and processing. Rotten and mildewed, bamboo without antiseptic treatment is difficult to use for permanent construction.

Regarding the decay mechanism of bamboo, Murphy et al. [69], Sulaiman and Murphy [70], and Razak et al. [71] studied the mechanism of decay bacteria invading bamboo and degrading the cell wall; Qin Daochun [72] observed white rot fungi using a scanning electron microscope. The process of invading rotten bamboo; Xu Ming, Ren Haiqing et al. [73-74] used scanning electron microscopy to observe the process of white rot fungi and brown rot fungi invading moso bamboo, and discussed the decay pathways and mechanisms of bamboo; Huang Anmin et al. [75], Ren Hongling et al.[76] used X-ray diffraction, Fourier transform infrared spectroscopy, and two-dimensional correlation spectroscopy to analyze the changes in the main chemical components of moso bamboo during the decay of moso bamboo by white rot fungi and brown rot fungi, and revealed that the round bamboo material was eroded by rot fungi. mechanism.

There are relevant laboratory test methods [77-78] and field test methods [78-79] for the durability performance of wood, which can consider the impact of mold, microorganisms, termites, etc. on the long-term performance of wood. The evaluation of the durability performance of bamboo is currently based on reference The above test methods and evaluation criteria. For research on the durability of engineered bamboo, current research methods include natural or artificial accelerated aging performance tests, natural corrosion resistance tests and anti-mildew tests. The durability is evaluated through the degree of change in appearance and physical and mechanical properties of the material after aging or corrosion and mildew performance.

Qin Li et al.[80-81] studied the artificial simulated climate accelerated aging performance, outdoor natural aging performance, cyclic accelerated aging performance, and mildew and corrosion resistance of recombinant bamboo prepared from bamboo bundles after heat treatment, and discussed the relationship between artificial accelerated aging and outdoor natural aging. The relationship between aging reveals the changes in the performance of recombinant bamboo materials under different aging environments. The research results show that recombinant bamboo can meet the requirements of Class I strong corrosion resistance, but its preventive effect on mold is limited, especially its ability to inhibit cyanobacteria. Poor. Wei Wanshu et al. [82] studied the natural rot resistance and mildew resistance of recombinant bamboos of different ages. In terms of natural rot resistance, the recombinant bamboos of Ci bamboo were subjected to laboratory accelerated corrosion by brown rot fungi and white rot fungi, and the weight loss rate was Less than 5%, reaching a strong corrosion resistance level. However, in terms of natural mildew resistance, the natural mildew resistance of Cizhu recombinant bamboo boards is extremely poor. It needs to be treated with mildew to improve its use value and economic benefits. However, bamboo recombinant bamboo boards have extremely poor natural mildew resistance. The effect of age on corrosion resistance and mildew resistance is not significant. Zhang Yahui et al. [83] conducted cyclic exposure tests on bamboo-based fiber composites produced from 3 to 4-year-old Moso bamboo and Ci bamboo, simulating the impact of changes in outdoor natural conditions on mechanical properties and dimensional stability, and conducted experiments with commercial recombinant bamboo products. The comparison shows that the durability of bamboo-based fiber composite materials for outdoor use is better than that of commercialized outdoor restructured bamboo products. Chen Jie [84] conducted an artificial accelerated aging test of Glubam glued bamboo to simulate the impact of sunlight and rainfall on Glubam glued bamboo in the natural climate. After a certain period of light and spray cycles, the aged Glubam glued bamboo was tested. The physical and mechanical properties of the untreated Glubam glued bamboo specimens are shown in the test results. After accelerated aging, the bonding ability of the fiber layer is greatly reduced, and various mechanical properties are reduced to varying degrees. The edge sealing treatment can improve the resistance of the specimens. Aging ability. Zhang Lusheng et al. [85] studied the corrosion resistance of laminated bamboo after anticorrosion treatment. They used water-borne copper-based preservatives quaternary ammonium copper and copper azole for anticorrosion treatment, and evaluated its corrosion resistance through weight loss rate. The test showed that: Post-preservation treatment can significantly improve the anti-corrosion performance of glued bamboo, but the anti-loss performance of the preservative needs to be improved.

The above overall research results show that engineered bamboo products will age to varying degrees under the influence of natural conditions. Generally speaking, the anti-aging performance of recombinant bamboo is better than that of glued bamboo. In terms of corrosion resistance, the restructured bamboo has undergone high-temperature drying and phenolic resin dipping, and its corrosion resistance has basically reached a strong corrosion resistance level. However, the bonding area between bamboo fiber and adhesive in integrated bamboo (glued bamboo) is smaller. Glued bamboo boards have poor resistance to wood-rotting fungi, so preservative treatment is necessary. In terms of anti-mildew performance, recombinant bamboo has poor anti-mildew properties and is easily susceptible to mildew without special anti-mildew treatment. There are currently no reports on the anti-mildew properties of glued bamboo.

5. PROJECT DEMONSTRATION

With the technical support of the International Bamboo and Rattan Organization and the Chinese Academy of Forestry, the dormitory of Pingbian Primary School in Yunnan was built in 2004. The school building roof trusses, roof panels and internal and external wall panels were made of bamboo laminated lumber and bamboo plywood respectively. This was the first time that bamboo artificial Boards are used in construction as structural materials [86]. Integer China's research team and Yunnan Shibo Xingyun Real Estate Co., Ltd. jointly completed a multi-story modern composite bamboo structure residence in Kunming in 2008. The structural system refers to the structural form of light wood structure residences, and is made of bamboo laminated timber connected by screws and stainless steel. The parts are assembled as a whole to form a box structure. Its ability to resist vertical load, lateral wind load, and earthquake action exceeds that of wooden structure houses, and it has the characteristics of economy, safety, ecology, and environmental protection [87]. Lu Qingfang et al. [88-89] introduced the new bamboo structure earthquake-resistant housing demonstration house project built on the campus of Nanjing Forestry University, which uses beams-columns + grid-wall stud columns to form a multi-constraint and multi-force transmission path stress system. Bamboo curtain plywood is used to make roof panels and wall panels, bamboo laminated timber is used to make beams, and bamboo restructured bamboo is used to make columns. The earthquake-resistant system, node structure, moisture-proof and fire-proof measures of modern bamboo structure design are discussed.

Based on the research on Glubam glued bamboo, the Hunan University research team designed and built a series of demonstration projects, including three structural forms: 1) Prefabricated bamboo structure houses, built in Nanying, Guangyuan City, Sichuan Province in June and November 2008 The more than 40 sets of prefabricated bamboo structure houses built in Xinmin Primary School, Xinmin Primary School and other places are represented [90]; 2) Light bamboo structure frame houses, the world's first modern bamboo structure two-story house was designed and built at the School of Civil Engineering of Hunan University in February 2009. In June 2009, a bamboo structure demonstration project was designed and built in Zizhuyuan Park, Beijing, funded by the International Bamboo and Rattan Organization (INBAR). It is composed of glued bamboo with smaller cross-sections and evenly densely connected [91-92]; 3) Modern bamboo structure bridges, the world’s first modern bamboo structure pedestrian bridge was designed and built on the campus of Hunan University in 2006 [93], and the world’s first bamboo structure bridge was successfully built in Liushang Village, Daozi Township, Leiyang City, Hunan Province [94].

6. STANDARD PREPARATION

In terms of technical standards, "Test Methods for Physical and Mechanical Properties of Bamboo" (GB/T 15780-1995), "Test Methods for Physical and Mechanical Properties of Bamboo for Construction" (JG/T 199-2007), International Organization for Standardization Standard Bamboo-determination of physical and mechanical properties-part 1: requirements (ISO 22157-1-2004) and Bamboo-determination of physical and mechanical properties-part 2: laboratory manual (ISO/TR 22157-2-2004) are both tests of the physical and mechanical properties of round bamboo. Method standard, China Engineering Construction Standardization Association standard "Technical Specifications for Round Bamboo Structure Construction" (CECS 434-2016) stipulates the design requirements for structure, fire protection, sound insulation, thermal insulation and other design requirements in round bamboo buildings.

At present, there is still a lack of technical standards for engineered bamboo structures. The research and design of engineered bamboo structures mostly refer to the relevant standards of engineered wood. However, there are obvious differences between engineered bamboo and engineered wood, and there are certain safety hazards in the reference use. In view of this, the Chinese Academy of Forestry Sciences is editing the forestry industry standard "Restructured Bamboo for Structural Use", which stipulates the classification, product requirements, test methods, methods for determining the characteristic values of mechanical properties and quality control of restructured bamboo for structural use. The Shanghai Academy of Architectural Sciences is editing the China Engineering Construction Standardization Association standards "Engineering Bamboo Structure Design Regulations", "Engineering Bamboo Structure Construction and Quality Acceptance Technical Regulations" and "Engineering Bamboo Structure Inspection Technical Regulations" to provide guidance on the design and construction of engineered bamboo structures., acceptance, testing, etc. shall be stipulated. The International Organization for Standardization is compiling Structural uses of laminated bamboo - physical and mechanical testing. The preparation of a series of technical standards for engineered bamboo will greatly promote the research, promotion and application of engineered bamboo structures in China.

7. CONCLUSION

Bamboo is a high-quality and environmentally friendly building material with a long history of application in civil engineering. As a deep processing of bamboo, engineered bamboo not only retains the excellent mechanical properties of bamboo, but also eliminates the uncertainty of bamboo as a biomass material, making it It is possible to use bamboo in modern industrial buildings. The engineered bamboo industry started late, and the current research on engineered bamboo structures is still in its infancy. The cost of engineered bamboo products is still high and the output is limited, which reduces the competitiveness of engineered bamboo for building structures. Developing efficient and stable production processes to reduce costs will help promote the development of engineered bamboo structures. The promotion of engineered bamboo in building structures still faces the following key technical issues, which require in-depth research.

(1) In the study of wood properties, there are differences in the properties of round bamboos from different origins, different varieties, and different bamboo ages. The production processes of different manufacturers also have a direct impact on the physical and mechanical properties of engineered bamboo products. Currently, there are no engineered bamboo products There are no unified production standards for engineered bamboo, and there are no evaluation

indicators for the properties of engineered bamboo. The understanding of the physical and mechanical properties of engineered bamboo is still in the individual data stage. It is necessary to establish a performance index system with sufficient confidence and compile relevant standards as soon as possible.
(2) Engineered bamboo has good ductility and elastic recovery capabilities, so engineered bamboo structures have great potential for use in high-intensity areas. The seismic analysis of structures needs to address the mechanical properties of components under complex conditions, so complex stress should be carried out. Study the mechanical properties of engineered bamboo under these conditions, and establish the three-dimensional constitutive and failure criteria of engineered bamboo for theoretical analysis and numerical simulation, supplemented by complete seismic structural measures.
(3) The inherent biomass properties of engineered bamboo make it susceptible to corrosion by the natural environment and insects and fungi, resulting in aging, decay and mildew. With limited research foundation and engineering experience, accelerated aging and laboratory decay and mildew tests It is an effective means to study its durability performance, but the durability performance is affected by the coupling of multiple complex factors. Whether the durability enhancement measures are effective and reliable still needs time to be tested.
(4) There are currently a small number of demonstration projects for engineered bamboo structures, but they have not yet entered the promotion stage. Given that China is vigorously promoting green building materials and prefabricated buildings, it is necessary to research and compile technical standards for engineered bamboo structures to provide key technical support for the construction of engineered bamboo structures.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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