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ARTICLE

Evaluation of Physical and Mechanical Properties of Glued Bamboo: A Review

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ABSTRACT

The use of glued bamboo (GB) in structural engineering is growing interest in the construction industry, as it is a kind of natural material with strong regenerative ability. In addition, the utilizing of GB can reduce the demand for concrete, a possible way to decrease the destruction to natural environment and the consumption of fossil energy. This paper presents a comprehensive analysis on the properties of GB based on the experimental data available in the published researches. Some important physical, mechanical, and chemical properties of GB are discussed. It can be concluded that, at present, more emphasis has been given to study the mechanical property and gluing performance of GB. By analyzing existing research results, this paper provides some recommendations for future research.

1. Introduction

Light timber structures are widely used in developed countries such as North America, Japan, and Europe. However, in many developing countries, the shortage of wood resource greatly restricts the development of timber structures. Bamboo is a perennial herb with fast growing rate [1,2]. Study shows that bamboo has excellent mechanical properties, with high tensile and compressive strength [3] and it can completely replace wood as a new kind of building material [4]. With green and sustainable development becomes the goal of human society, applying renewable materials in construction market has been an important topic for structural engineers. By using bamboo instead of concrete is obviously a good option for promoting environmentally friendly society.

Glued bamboo (GB) overcomes the shortcomings of the raw bamboo with hollow structure, and the shape and cross section of the components used in the building structures can be made according to actual needs [5]. A conclusion has been obtained after a series of experimental studies that GB has the potential to be a structural building material [6]. However, as a natural composite material, many factors affect the mechanical properties and application of GB [7,8]. In general, the mechanical properties of raw bamboo, glued property of gluing surface and moisture content are the main factors that influence the

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work performance of GB. In recent years, may research works have been carried out to investigate the property of GB. Yang and Saikia studied the methods to improve the durability of GB [9,10]. The microstructure and mechanical properties of moso bamboo have been extensively studied [11]. Verma investigated the stiffness and strength of laminated bamboo lumber (LBL) [12]. In 2001, the fundamental properties of LBL were tested [13]. Li proposed methods to improve the interface properties of LBL [14]. Hakkou found the optimum temperature for the hot pressing process of GB is between 130°C and 160°C [15]. In addition, the constitutive relationship of bamboo is the basis for the design and analysis of bamboo structure. Shao and Askarinejad proposed a simple mechanical model and damage criterion through tests [16,17,18]. In a word, the using of GB has the potential of providing environmental benefits by reducing the consumption of concrete.

This paper collates the study results published to date regarding the research status of GB. Based on the available research results, the mechanical properties, durability and failure criterion of GB are discussed in this paper. Although many research works have been conducted in these areas, it is necessary to conduct more tests and analysis on GB. In the process of summarizing the current research results, this paper identifies the shortcomings of these researches and presents some research suggestions for future investigations.

2. Classification of GB

According to the difference in production process, GB can be divided into the following three main types.

2.1 Parallel Strand Bamboo (PSB)

PSB is produced by stacking bamboo strips along the direction of the grain and then glued by high pressure [19]. In this method, the original bamboo is smashed into small units along the direction of the grain, and the units were dipped in adhesive, then PSB was produced through hot pressing. Since the bamboo strip is impregnated in the adhesive, the production of the PSB requires a large amount of the adhesive.

2.2 Laminated Bamboo Lumber (LBL)

LBL is made up of bamboo strips which are processed into a certain length and have a rectangular cross section. After series of processes of carbonization, drying, gluing, the bamboo strips are laminated and hot-pressed in the direction of the grain, as seen in Figure 1(a) [20,21]. In this method, the adhesive is sprayed on the surface of the bamboo strips, so the amount of adhesive is much less than that of PSB.

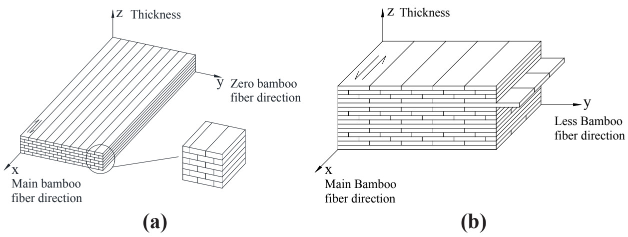

Figure 1. The arrangement of bamboo grain in GB: (a) LBL; (b) Glubam

2.3 Glubam

Glubam has great differences from the above two kinds of GLB, if a coordinator system is established with x axis represents the main fiber direction(longitudinal grains direction), y axis represents the less-fiber direction (transverse grains direction), z axis represents the thickness or glue surface direction, as shown in Figure 1(b). The ratio of longitudinal grains and transverse grains is typically 4:1 [21].

3. Properties of GB

3.1 Physical and Chemical Properties

3.1.1 Environmental Load

The environmental load of GB is from transportation and production processes, including carbon dioxide emissions, water consumption, energy consumption and sewage discharge. It is well known that the growth process of bamboo is also a carbon sequestration process. Although a certain carbon emission is existed in the manufacturing process, the total carbon emission of GB is a negative value in terms of the entire growth-manufacturing-application cycle [22]. The other indicators are summarized in Table 1; the corresponding indicators of other building materials are also included in the table. From Table 1, it can be concluded that a large amount of carbon is discharged to the natural environment during the production of cement and steel, and the energy consumption of GB is much lower than that of steel.

Table 1. Environmental load of GB and other kinds of building materials

Material	Carbon emission (kg/m³)	Energy consumption (GJ/m³)	Water consumption(t/m³)
GB	-261	2.7	-
Engineered wood	-168	4.5	-
cement	2040	11	-
Steel	8117	448	23.5

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3.1.2Apparent Density

Obviously, the apparent density of material influences the harm of the building after its damage, especially after earthquake. Japan and China belong to countries with large population densities. Historical data show that after the same level of earthquakes, the number of casualties in China is generally higher than that in Japan. One of the main reasons for this is that wooden houses in Japan account for a large proportion of the whole buildings, while the houses in China are almost reinforced concrete structures. Fig.2 displaces the density of several different construction materials [6,22], it can be seen that although there are differences in the density of GB, all of the three types are much smaller than concrete and a little bit higher than spruce. This shows that GB can still be regarded as a lightweight building material.

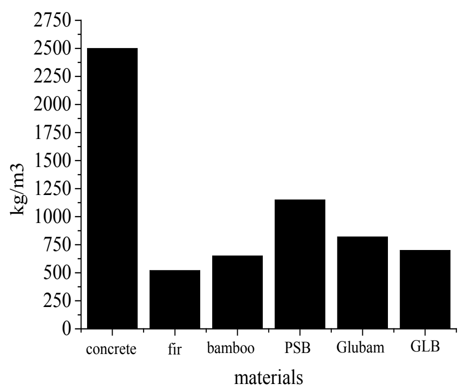

Figure 2. Density of different construction materials

3.1.3 Gluing Property

The use of adhesives enables the idea of GB to be realized, and the gluing property of glued surface determines the depth and breadth application of GB in building market. Yan found that phenolic resin adhesives have stable and reliable gluing properties [23]. In addition, the use of microwave-assisted phenolic resin curing can effectively improve the strength of the gluing surface [24]. By continuously improving the hot pressing gluing process, the strength at glued surface has been stabilized [25].

3.1.4 Durability

The durability of the material influences the length of the building life cycle. For GB, a new kind of composite material with natural material bamboo as the substrate, dry and wet, hot and cold cycles greatly reduce its life span [26]. This process accelerates the degradation of bamboo fiber, which is similar to the rusting process of steel. Many researches have been conducted to improve the durability of GB. The key idea of these kinds of researches is to avoid direct contact between GB and the external environment, which is also similar to the anti-corrosion method of steel. There are two main methods to achieve this goal: pre-treatment and post-treatment. Pre-treatment consists of drying, carbonizing and immersing the raw bamboo in chemical preservatives. Saikia and Anwar are the representatives to use this method to improve the anti-corrosion ability of GB [27,28]. The post-treatment method is much simpler than pre-preservative treatment, which is mainly applying a waterproof material on the surface of GB. Zhang and Zhang concluded that this method can effectively slow the penetration of water into GB [29,30]. Post-treatment needs to solve the problem of rapid loss of anti-corrosion materials, and the best way to solve this problem is repainting anticorrosive materials regularly.

3.1.5 Fire Resistance

Compared with concrete, bamboo is more flammable, thus fire resistance research of GB becomes an important task. However, since GB has not been applied to the construction market on a large scale, there is little research on its fire resistance. Under the protection of fireproof gypsum board, the fire resistance time of Glubam can reach 1.0h [31]. However, the adhesive and anti-corrosion materials are usually oily organic materials with poor fire resistance ability. Therefore, it is necessary to do further study on the fire resistance of GB in the future.

3.2 Mechanical Properties

The mechanical properties of GB mainly depend on the mechanical properties of raw bamboo. However, the effects of adhesives and anti-corrosion treatments cannot be completely ignored. In general, GB is a kind of composite and anisotropic material; its mechanical properties also show some complexity. From the available literature, it was found that the mechanical properties of GB are still practical [20,21,22,24,32]. The test results are summarized and displaced in Table 2 and Table 3.

Table 2. Mechanical properties of GB (parallel to the grain direction)

Material	Compression strength(MPa)	Tension strength(MPa)	Shear strength(MPa)	Bending strength(MPa)	MOE(GPa)
PSB	129	248	15	119	25
LBL	73	85	17	115	15
Glubam	51	83	16	99	9.4

Table 3. Mechanical properties of GB (perpendicular to the grain direction)

Material	Compression strength(MPa)	Tension strength(M-Pa)	Shear strength(M-Pa)	Bending strength(M-Pa)	MOE(GPa)
PSB	40	3	-	-	-
LBL	24	-	17	109	10
Glubam	25	17	16	24	4.9

3.2.1 Compression Strength

As seen from Table 2 and Table 3, the compression strength parallel to the grain is about 3 times of that perpendicular to the grain. Among the three types of GB, PSB has the highest compression strength, and this is due to the larger amount of glue applied during the production process. For LBL, the cracks of the specimens do not always along the glued surface, which can be a proof of the excellent gluing performance of GB [21].

3.2.2 Tension Strength

For PSB and LBL, bamboo fibers are arranged in one direction, the tension strength in the transverse direction is small. For Glubam, special manufacturing process makes sure there are bamboo grains in two orthogonal directions; therefore, the tensile strength in the transverse direction is much higher. It can be concluded that Gluban has better working performance under multi-directional stress. Chen tested the effect of specimen size on the tension strength of bamboo and concluded that with the increase of the section, the tension strengths of bamboo strips were reduced [33].

3.2.3 Shear Strength

The shear strength parallel to grain is more sensitive to the bonding performance of gluing surface. As seen from Table 2, there is almost no difference in the shear strength of the three types of GB. The results reveal that gluing surface has no influence on the shear strength of LBL [21].

3.2.4 Static Bending

According to the relevant test results, the dispersion of bending capacity and bending stiffness of LBL is larger than the other test results, such as compression test [21]. This is caused by the density distribution of bamboo fibers in the same cross section [18]. The failure type of test specimen indicates that the static bending damage of GB is brittle and there is obvious deflection before the damage [34,35]. Some of specimens undergo interlaminar shear failure before the bamboo fiber breaks in the tension zone [36,37].

4. Factors Affecting the Properties of GB

4.1 Properties of Raw Bamboo

The property of raw bamboo is the main factor affecting the property of GB, while the density of grain on the other hand influence the property of raw bamboo. Test study indicates that the bearing capacity of the bamboo increases with the increase of grain density [38]. The density of bamboo changes with the change of bamboo variety, and it also changes in different parts of a same bamboo [39,40,41,42]. Askarinejad discovered that the fiber density decreased from the outer radial diameter, as shown in Figure 3 and the stiffness and flexural capacity also decreased from the outer diameter [43], PSB is made by using this character of bamboo [44]. However, the increase of fiber density will lead to brittle failure. In addition, there are differences in the mechanical properties of bamboo with different growth ages and altitudes [7,38,45,46].

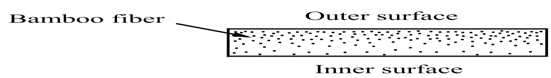

Figure 3. distribution of bamboo fiber

4.2 Moisture Content

The effect of moisture content on GB is transmitted by affecting the mechanical properties of raw bamboo. The compression strength parallel to fiber direction decreases with the increase of moisture content [7]. Askarinejad investigated the humidity on shear behavior of bamboo and concluded that bamboo kept in an environment with humidity level of 60% demonstrated the highest shear modulus [47]. Xu observed that the mechanical properties were observed to degrade significantly with increased moisture content [48]. But it does not mean that the mechanical properties of GB can be improved by reducing the moisture content. When the moisture content is close to 0, early cracks will appear when subjected to pressure. A moisture content of 10% is considered to be the best condition for GB to exhibit its mechanical properties [21]. Moisture content also influence the density of GB, it is obvious that high moisture content will increase the density of GB.

4.3 Antiseptic Treatment

Anti-corrosion treatment mainly affects the durability of GB, but due to the introduction of chemical agents in this process, it will also affect the mechanical properties to a certain extent. Carbonization treatment of raw bamboo can effectively control the moisture content and improve

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its mechanical properties. Anwar found the bending elastic modulus of GB improved a lot with raw bamboo immersing in phenolic [28]. Quaternary ammonium copper and copper azole impregnation treatment can improve the shear strength of the gluing surface [49].

4.4 Processing Methods

Different processing methods are invented to improve the gluing performance and find ways to make the bamboo fiber better exert its bearing capacity. Sharma investigated the Effect of processing methods on the mechanical properties of engineered bamboo [50]. Nugroho studied the relationship between penetration rate of adhesive and internal gluing strength [51,52]. For LBL Tian concluded that, to obtain the best gluing performance it is better to keep a constant temperature of 130°C, 280g adhesive per square meter and a pressure of 2 MPa [25]. It is worth noting that compared to PSB and LBL, the process method of Glubam is more effective to prevent local damage before the overall failure [22].

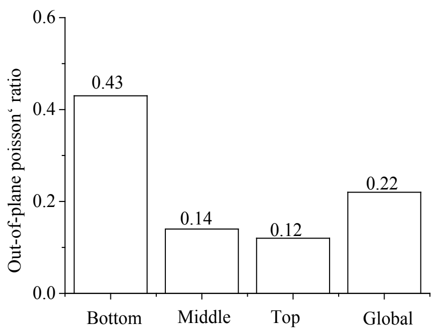

Figure 4. Radial-circumferential (out-of-plane) Poisson's ratios obtained from experiments

5. GB Constitutive Relation and Failure Criterion

At present, there are few related studies on bamboo failure mode, skeleton curve and hysteresis characteristics.

5.1 The Study of Raw Bamboo

Castanet investigated the effect of inner microstructural organization of grains on the tensile performance of bamboo, and established the structure and property relationships in elementary bamboo grains [53]. García studied the anisotropic elastic constants of raw bamboo through tests with rings [54], the coefficient of variation of the Poisson's ratio along the length of bamboo was obtained, as shown in Figure 4. Askarinejad presented the structure and toughening mechanisms in Moso culm bamboo, and concluded that cracks usually appear parallel to the longitudinal direction of grains [43].

5.2 The Study of PSB

Experiments indicate that the tensile stress curve of the PSB is linear, while the compressive stress-strain curve has a distinct linear stage and a nonlinear strengthening stages, the result is displaced in Figure 5 [55]. It is worth noting that the stress-strain curve is basically consistent with the author's test data.

5.3 The Study of LBL

Since there are similarities between PSB and LBL, the axial stress-strain curve of LBL is close to that of PSB. Shao studied the microscopic mechanical behavior and stress-strain relationship of bamboo under compression strength [56,57]. The study also pointed out that the deformation process of the bamboo can be divided into three stages: the linear elastic stage, the weak linear strengthening stage after yielding, and the power strengthening stage, and the yield strength decreased with the increase of temperature. Li also studied on the stress-strain model and failure mechanism of LBL [58]. The result shows that the failure process can be summarized into three stages, namely elastic stage, elastoplastic stage and ductile fracture stage.

5.4 The Study of Glubam

Zhou proposed the failure criterion formula of Gluban under plane stress state with reference to the plane stress formula of Tsai-Wu failure criterion [59]. It can be found that most of the research on mechanical model of GB is in the stage of qualitative analysis based on experimental data, and no corresponding mathematical model has been established.

The study of GB constitutive relations is of great significance for quantitative analysis and design of bamboo structure.

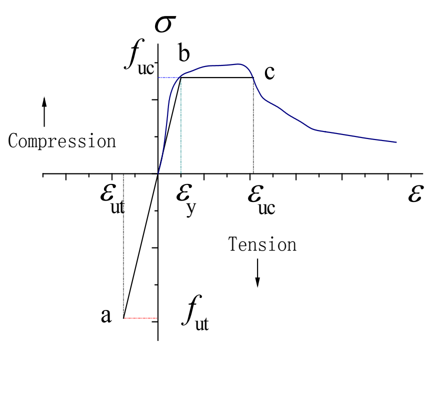

Figure 5. Axial stress-strain curve of PSB.

6. Concluding Remarks

There is a high potential for GB applying in building market to promote sustainable development and environmentally friendly society. The researches available have fundamentally revealed the properties of GB making with different processes. The following conclusions are summarized from this study:

(1) Bamboo has light weight with high mechanical properties. Obtained by rational material selection and the utilization of modern gluing production process, glued bamboo (GB) overcomes the shortcomings of the hollow structure of natural bamboo, which creates favorable conditions for its application in building structure.

(2) The use of adhesive does not reduce the mechanical properties of bamboo. At present, the mechanical properties of the glued surface of GB are comparable to bamboo itself. Oily adhesives can even reduce the sensitivity of GB to the changes external environment, thereby improving its durability.

(3) As a composite material based on bamboo, the mechanical properties of raw bamboo play a key role in the mechanical properties of GB. The density of bamboo grain significantly influences the stiffness and strength of GB. Moreover, the moisture content, manufacturing processes and anti-corrosion materials applied can affect the mechanical properties and durability of GB. The performance of GB can be enhanced by using raw bamboo parts with high grain density, adjusting moisture content, and reconstitution of bamboo grain during production process.

(4) The research on the micro-stress characteristics and resistance curve of GB needs to be further deepened. The understanding of failure mechanism can provide strong theoretical support for future analysis and calculation.

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References

[1] Xiazhen Li, Yong Zhong, Haiqing Ren. Development prospect of modern bamboo construction in China, Wood Processing Machinery, 2011, 22 (06): 44-47. (in Chinese)

[2] Rtironk, S., Elnieiri, M,. Investigating laminated bamboo lumber as an alternate to wood lumber in residential construction in the United States. Proc., 1st Int. Conf. on Modern Bamboo Structures, Taylor & Francis, Abingdon, UK, 2007: 83–96.

[3] Bo Zhang. Resource recycling of renewable bamboo material in building filed, New Chemical Materials, 2016, 44 (10): 30-32. (in Chinese)

[4] van der Lugt, P., van den Dobbelsteen, A. A. J. F., Janssen, J. J. A,. An environmental, economic, and practical assessment of bamboo as a building material for supporting structures. Construction and Building Materials, 2006, 20(9): 648–656.

[5] Xiao Yan, Shan Bo. Glubam Structures. Beijing: China Building Industry Press, 2013. (in Chinese)

[6] Sharma B, Gatóo A, Bock M, M Ramage. Engineered bamboo for structural applications. Construction and Building Materials, 2015, 81: 66-73.

[7] Fangchun Zhou. Study on physical and mechanical properties of bamboo. Journal of Nanjing Institute of Forestry Industry, 1981, 2 (1): 1-32. (in Chinese)

[8] Sharma B, Harries K A, Ghavami K. Methods of determining transverse mechanical properties of full-culm bamboo. Construction and Building Materials, 2013, 38: 627-637.

[9] T Yang, Lee C, Lee C, Y Cheng. Effects of different thermal modification media on physical and mechanical properties of moso bamboo, Construction and Building Materials, 2016, 119: 251-259.

[10] Saikia P, Dutta D, Kalita D, Dipul Kalita, Jayanta Jyoti Bora, Tridip Goswami. Improvement of mechano-chemical properties of bamboo by bio-chemical treatment. Construction and Building Materials, 2015, 101: 1031-1036.

[11] T. Tan, N. Rahbar, S.M. Allameh, S. Kwofie, D. Dissmore, K. Ghavami f , W.O. Soboyejo. Mechanical properties of functionally graded hierarchical bamboo structures, Acta Biomaterialia, 2011, 7: 3796–3803.

[12] C.S. Verma, V.M. Chariar. Stiffness and strength analysis of four layered laminate bamboo composite at macroscopic scale, Composites: Part B, 2013, 45: 369–376.

[13] Naresworo Nugroho. Naoto Ando. Development of structural composite products made from bamboo II: fundamental properties of laminated bamboo lumber, Journal of Wood Science, 2001, 47: 237-242.

[14] Tao Li, Dali Cheng, Magnus E.P. Wålinder b, Dingguo Zhou. Wettability of oil heat-treated bamboo and bonding strength of laminated bamboo board, Industrial Crops and Products, 2015, 69: 15–20.

[15] Hakkou, M., Pétrissans, M., Zoulalian, A., Gerardin, P.,. Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polym. Degrad. Stabil. 2005, 89(1): 1–5.

[16] Zhuoping Shao. Mechanical Behavior of Bamboo with Large Deformation: I. The Relationship between Stress and Strain. China Wood Industry, 2003,

  DOI: https://doi.org/10.30564/jaeser.v2i4.1780

17(02): 12-14. (in Chinese)

[17] Zhuoping Shao. Mechanical Behavior of Bamboo with Large Deformation II. The Characteristics of Microcosmic Deformation. China Wood Industry, 2004, 18(01): 27-29. (in Chinese)

[18] Askarinejad S, Kotowski P, Youssefian S, Nima Rahbar. Fracture and mixed-mode resistance curve behavior of bamboo. Mechanics Research Communications, 2016, 78: 79-85.

[19] Baolu Sheng, Aiping Zhou, Dongsheng Huang, Zhen Huang. Uniaxial strength and constitutive law of parallel strand bamboo. Journal of Nanjing Forestry University (Natural Sciences Edition), 2015, 39(5): 123-128.

[20] Nguyen Thi Huong Giang, Zhang Qisheng, Jiang Shenxue. Technology of glued laminated bamboo laminated in high frequency hot press and the properties,China Forestry Science and Technology, 2014, 28(04): 109-112. (in Chinese)

[21] Zhi Li, Guosong Yang, Quan Zhou, Yan Xiao. Bending Performance of Gluban Beam Made with Difference Processes. Advances in Structural Engineering, 2019, 22(2): 144.

[22] Ruizhen Yang. Research on material properties of Glubam and its application. Hunan University, 2013. (in Chinese)

[23] Shoubai Yan. Research on gluing outdoor glued structural laminated bamboo. Nanjing Forestry University, 2011. (in Chinese)

[24] Y Zheng, Z Jiang, Z Sun, Ren H,. Effect of microwave-assisted curing on bamboo glue strength: Bonded by thermosetting phenolic resin. Construction and Building Materials, 2014, 68: 320-325.

[25] Lei Tian. Outdoor Bamboo Strip Glulam Preparation and Properities Analysis. Nanjing Forestry University, 2013. (in Chinese)

[26] Bo Shan, Yan Xiao, Jie Chen. Experimental Research of Glubam after Artificial Accelerated Aging. Industrial Construction, 2015, 45(04): 26-32. (in Chinese)

[27] Saikia P, Dutta D, Kalita D, JJ Bora, T Goswami. Improvement of mechano-chemical properties of bamboo by bio-chemical treatment. Construction and Building Materials, 2015, 101: 1031-1036.

[28] Anwar U M K, Paridah M T, Hamdan H, S.M. Sapuan, E.S. Bakar. Effect of curing time on physical and mechanical properties of phenolic-treated bamboo strips. Industrial Crops and Products, 2009, 29(1): 214-219.

[29] Lusheng Zhang, Daochun Qin, Hongling Ren, Xiaobei Jin. Effects of Preservative Post-treatment of the Bamboo Glulam on it's Durability. China Forest Product Industry, 2013, 40(05): 55-57. (in Chinese)

[30] Rong Zhang, Lusheng Zhang, Benhua Fei, Daochun Tan. Ant mold and Waterproof Properties of the Bamboo Glulam Painted with Silane Modified Acrylate Latex. China Forest Product Industry, 2013, 40(6): 57-59. (in Chinese)

[31] Yan Xiao, Jian Ma, Bo Shan, Guo Chen, Liyong She. Experimental research on fire safety of lightweight bamboo frame buildings. Building Structure, 2012, 42(02): 165-169. (in Chinese)

[32] Yan Xiao, Ruizhen Yang, Bo Shan. Experimental research on mechanical properties of glubam. Journal of Building Structures, 2012, 33(11): 150-157. (in Chinese)

[33] Hong Chen, Haitao Cheng, Ge Wang, Zixuan Yu, Sheldon Qiang Shi. Tensile properties of bamboo in different sizes, Journal rhe Japan Wood Research Society, 2015, 61: 552–561.

[34] Haitao Li, Jingwen Su, Qisheng Zhang, Guo Chen. Experimental study on mechanical performance of side pressure laminated bamboo beam. Journal of Building Structures, 2015, 36(03): 121-126. (in Chinese)

[35] Djoko S M H P, 2014. Influence of shape and dimensions of lamina on shear and bending strength of vertically glue laminated bamboo beam. Procedia Engineering, 2014, 95: 22-30.

[36] Lingfei Zhang, Haitao Li, Jingwen Su, Xiuyu Chen , Wei Liu,Minhui Xu , Jian Dai , Fan Wu, Zhao Song, Bin Li, Zhengqiang Zhou , Jian Chen,. Experimental study on glued bamboo beam, Advanced Materials Research, 2014, 919-921: 123-127.

[37] Arijit Sinha, A.M.ASCE, Daniel Way, and Skyler Mlasko. Structural Performance of Glued Laminated Bamboo Beams, J. Struct. Eng, 2013, 140(1): 04013021-1~8.

[38] Lo T Y, Cui H Z, Leung H C,. The effect of fiber density on strength capacity of bamboo [J]. Materials Letters, 2004, 58(21): 2595-2598.

[39] Lingfei Ma, Naixun Ma. Study on the Variation of Moso Bamboo, Forestry science, 1997, 33(04): 356-364.

[40] Yanwen Huang, Xiahua Wu, Jun Qian. The Comparison of Mechanical Properties of the Softening Treated Bamboos at Various Position and Different Age. Journal of bamboo research, 2015, 34(02): 40-46. (in Chinese)

[41] Xiaodong Zhang, Xiucai Cheng, Yixin Zhu. Variation of Bending Performance with Different Location of Bamboo. Journal of Nanjing Forestry University (Natural Sciences Edition), 2006, 30(06): 44-46. (in Chinese))

[42] Zhuoping Shao, Shengxia Huang, Fushe Wu, Liang

Zhou. A Study on the Difference of Structure and Strength between Internodes and Nodes of Moso Bamboo. Journal of bamboo research, 2008, 27(02): 48-52. (in Chinese)

[43] Askarinejad S, Kotowski P, Youssefian S, N Rahbar. Fracture and mixed-mode resistance curve behavior of bamboo. Mechanics Research Communications, 2016, 78: 79-85.

[44] Junzhen Zhang, Haiqing Ren, Yong Zhong, Rongjun Zhao. Analysis of compressive and tensile mechanical properties, of recombinant bamboo, Journal of Nanjing Forestry University (Natural Science Edition), 2012, 36(4): 107-111. (in Chinese)

[45] Lingfeng Zhang, Haifeng Xu, Youhong Wang, Xinge Liu, Bin Xu, Chuangui Wang, Shuhua Ke. Impact on bamboo anatomical characteristics of different altitudes and slope and the relationship between them and the main physical & mechanical properties. Journal of Anhui Agricultural University, 2009, 36(01): 77-80. (in Chinese)

[46] Youhong Wang, Shan Wang, Chuangui Wwang, Shuhua Ke, Bin Xu, Xinge Liu. Difference in Main Physical and Mechanical Properties of Bamboo Located at Different Elevations and Slopes, Journal of Northeast forestry University, 2008, 36(01): 20-22. (in Chinese)

[47]Askarinejad S, Kotowski P, Shalchy F, N Rahbar. Effects of humidity on shear behavior of bamboo. Theoretical and Applied Mechanics Letters, 2015, 5(6): 236-243.

[48] Qingfeng Xu, Kent Harries, Xiangmin Li, Qiong Liu, Jennifer Gottron. Mechanical properties of structural bamboo following immersion in water. Engineering Structures, 2014, 81: 230–239

[49] Lusheng Zhang, Daochun Qin, Hongling Ren, Xiaobei Jin. Effects of Preservative Pre-treatment on the Mechanical Properties of the Bamboo Glulam. China Forest Product Industry, 2013, 40(04): 54-56. (in Chinese)

[50] Bhavna Sharma, Ana Gatóo, Michael H. Ramage. Effect of processing methods on the mechanical properties of engineered bamboo. Construction and Building Materials, 2015, 83: 95–101.

[51] Nugroho N, Ando N. Development of structural composite products made from bamboo I: fundamental properties of bamboo zephyr board. Journal of Wood Science (Japan). 2000, 46(1): 68-74.

[52] Nugroho N, Ando N,. Development of structural composite products made from bamboo II: fundamental properties of laminated bamboo lumber. Journal of Wood Science, 2001, 47(3): 237-242.

[53] Erwan Castanet, Quanxiang Li, Ludovic F. Dume ´, Christopher Garvey, Rangam Rajkhowa, Jin Zhang, Bernard Rolfe, Kevin Magniez. Structure–property relationships of elementary bamboo fibers, Cellulose, 2016, 23: 3521–3534.

[54] José Jaime García, Christian Rangel , Khosrow Ghavami. Experiments with rings to determine the anisotropic elastic constants of bamboo. Construction and Building Materials, 2012, 31: 52-57.

[55] Baolu Sheng, Aiping Zhou, Dongsheng Huang, Zhen Huang. Uniaxial strength and constitutive law of parallel strand bamboo, Journal of Nanjing Forestry University (Natural Sciences Edition), 2015, 39(05): 123-128.

[56] Zhuoping Shao. Mechanical Behavior of Bamboo with Large Deformation:I. The Relationship between Stress and Strain. China Wood Industry, 2003, 17(02): 12-14. (in Chinese)

[57] Zhuoping Shao, 2004. Mechanical Behavior of Bamboo with Large Deformation II. The Characteristics of Microcosmic Deformation. China Wood Industry, 2004, 18(01): 27-29. (in Chinese)

[58] Haitao Li, Qisheng Zhang, Dongsheng Huang, Andrew John Deeks. Compressive performance of laminated bamboo. Composites: Part B, 2013, 54: 319–328

[59] Quan Zhou. Experimental study and engineering application of glue laminated bamboo beam. Hunan University, 2013. (in Chinese)

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