Study on bamboo gluing performance numerical simulation

Z R Zhao1,3, W H Sun1, X M Sui2,4 and X F Zhang1

1 Department of Logistics, Beijing WUZI University, Beijing, 101149, China
2 Department of electronic and Information Engineering, North China Institute of
Science &Technology, Sanhe, 065201, China
3 National Natural Science Foundation of China （No.31470588）Science and
technology project of Hebei Province（No.15211830）
4 E-mail: Sunny7801@sina.com

Abstract. Bamboo gluing timber is a green building materials, can be widely used as modern
building beams and columns. The existing bamboo gluing timber is usually produced by
bamboo columns or bamboo bundle rolled into by bamboo columns. The performance of new
bamboo gluing timber is decided by bamboo adhesion character. Based on this, the cohesive
damage model of bamboo gluing is created, experiment results are used to validate the model.
The model proposed in the work is agreed on the experimental results. Different bamboo
bonding length and bamboo gluing performance is analysed. The model is helpful to bamboo
integrated timber application.

1. Introduction
Bamboo is similar to a gradient material for fiber longitudinal distribution characteristics, so it has
high tensile strength, excellent elastic properties, it is good for engineering materials. On the other
hand, as the growth time is a short, it is a sustainable green material. It is widely used in modified
bamboo-based panels, laminated material. At present, there are mainly bamboo reorganization
methods such as, the use of the original bamboo multi-party reorganization using for building beams
proposed by Wansi Fu [1].The bamboo unit of the same diameter is processing a regular
polygonization ,laying at cross-section side by side, extending the bamboo material along longitudinal
by finger.Yushun Li [2] proposes the bamboo composite plate made of two bamboo plywood at top
and steel profiles in the middle. Qisheng Zhang [3] proposes a bamboo strips laminated material
manufacturing method (CN100999092A), the use of bamboo strips applied adhesive hot pressing.
Yongfu Yang [4] proposes natural hollow structure bamboo/wood composite material manufacturing
method patent, the use of the same diameter of the bamboo section processed into four prism which
horizontal arbitrary into the honeycomb shape, the upper and lower surface pressure veneer to form a
natural hollow structure of bamboo composite sheet. The use of bamboo in the prior art can be a
reorganization of bamboo bundles or the use of whole bamboo for reorganization.
The property of the bamboo reorganization material depends on the performance of the bamboo units
and the performance of the bamboo gluing. So the gluing property of the whole bamboo and bamboo
bundles is key factor. The experimental method can be used to optimize the design of this new type of
bamboo reorganization material, but the experiment takes a long time, at the same time to achieve a
variety of parameters of high cost of experimental high cost. It is a better choice to study the bamb oo
reorganization material by numerical simulation. To achieve the digital design of bamboo composite
bamboo bundles, need to solve the mathematical properties of bamboo gluing simulation. To solve the problem, the research group studied the numerical simulation of bamboo gluing, and studied the bamboo slabs lap peeling. Many scholars have done research on the influence of process parameters on the properties of bamboo reorganization. Shan Huang [5] studied the relation between different phenolic resin amount of bamboo bundles and time under various states. Chungui Du [6] studied the effect of bamboo beam shape on its dipping, secondary drying process and the performance of bamboo. For the lap joint mechanics analysis, some scholars use analytical methods to solve the problems [7-8]. Lap joint numerical calculation aspects [9-11] are mostly concentrated in the adhesive layer stress distribution, optimization the adhesive layer stress distribution to improve the glue strength. It is difficult to obtain accurate solution by using the analytical method. The experimental data are very limited due to the limitation of the experimental conditions and the experimental time and cost reasons. Numerical simulation is a good method to intuitively get bamboo sticking model and get a reasonable answer. From the current literature, there is little research on the damage process and the influencing factors of bamboo sticks. In this paper, the finite element simulation method is used to study the shear failure process of the bamboo slab under the loading condition.

2. Methodology of modelling of lap bamboo peeling

2.1. Gluing lap bamboo slab stress analysis

In this paper, the properties of bamboo reorganization material are influenced by the properties of bamboo gluing, and the bonding of bamboo is the key factor of bamboo reorganization. Therefore, the study of bamboo gluing is an important point to realize the bamboo aggregate. Bamboo shape and gluing properties determine the overall performance of the material. In order to facilitate the establishment of the numerical simulation model of bamboo gluing capacity, the simplified analysis model was taken as bamboo lap, and the two bamboo slabs were glued together by adhesive. Through studying the various influencing factors of gluing failure of lap joint, Thickness and gluing can affect the gluing performance. The size of the bamboo slab is 200mm × 22mm × 6mm and the length of cement is 50mm. The model is shown in figure 1.

![Figure 1. Model of bamboo adhesive lap.](image)

One end of the bamboo slab is fixed, the displacement load is applied at the other end to analyze the damage of the adhesive layer. Under the load the elastic deformation of bamboo slab appears. A linear elastic mathematical model modeling is created. The failure of the gluing layer mainly appears in the shear failure of the adhesive layer, the disruption of the interface stripping, and the tensile failure of the bamboo slab. Through the experimental test, it is found that the bonding of the lap bamboo is broken due to the occurrence of shear failure in the adhesive layer. The numerical analysis of the lap bamboo is mainly analyzed in the separation of the adhesive layer under tensile stress and shear stress. Due to the crack tip stress singularity and the mesh size effects on crack tip unit integration point stress, a linear elastic fracture mechanics analysis of crack propagation is not suitable for calculating the crack tip a greater yield situation.

Virtual crack closure technology based on fracture mechanics (VCCT) and cohesion model based on the damage mechanics are used for calculating the fracture. Virtual crack closure technology based on fracture mechanics (VCCT) assumes that when the strain energy release rate reaches the critical value, the fracturing crack is developing. It is necessary to set the initial crack, but in most of the actual situation the crack cannot be preset where the occurrence of cracks, it is only solve the crack start time but the crack direction is not resolved. In addition, it is more dependent on the thickness of the grid. Based on the cohesive force model of damage mechanics, the cohesive model is used to simulate the
interface failure, which is consistent with the actual physical mechanism. This method is still effective when the plastic deformation occurs in the cracked area. Compared with the fracture mechanics virtual crack closure technique (VCCT) method, the cohesive model based on the damage mechanics is not dependent on the grid. Based on the above reasons, this paper uses the damage mechanics cohesive force model to analyze the cracking of glued lap bamboo.

2.2. Glue layer cohesion model

Using the cohesive model analysis on the gluing layer, the tensile force increases with the increase of the cracked displacement at the beginning. When the force reach a point, the crack appears in gluing layer, the tensile force decreases with the increase of the crack displacement, the force will be zero until gluing layer completely cracked. There is also a peak between the shear stress and the cracking displacement. When the displacement reaches the cracking, the shear stress reaches the maximum value, and the glue layer begins to crack until the entire adhesive layer is completely broken. The relationship between force and cracking displacement in cohesive force model is:

\[
T = \begin{cases} 
\frac{T_u}{u_c} & (u \leq u_c) \\
\frac{u_c - u}{u_c} T_c & (u > u_c) 
\end{cases} 
\]

\[
\tau = \begin{cases} 
\frac{\tau_u}{u_c} & (u \leq u_c) \\
\frac{u_c - u}{u_c} \tau_c & (u > u_c) 
\end{cases} 
\]

In the above equation, \( T_u, u_c, T_c, \tau_u, \tau_c, u_c \) are the tensile stress, the tensile stress under the action of tensile stress, the crack propagation under tensile stress, the shear stress intensity, the shear displacement under shear stress, Stress propagation under the crack, respectively. Under the action of internal tensile stress and shear stress, the bond strength of the adhesive layer is:

\[
G_{tc} = \int T du_c 
\]

\[
G_{\tau} = \int \tau du_c 
\]

3. Results of model analysis

3.1. Calculation and verification of the model

In order to test the bamboo plywood bonding performance, the research group made lab bamboo samples, bamboo size is selected 200mm × 22mm × 6mm, bonding length of 50 mm, the use of urea-formaldehyde resin, the amount of coating 200g / m² ~ 260g / m² evenly is applied to the lap. Under external force and cold curing 6 hours, a lap bamboo is made. The lap bamboo sample is placed in hydraulic universal test machine WE-300A of Jinan Test Group Co. Ltd.. One the holder of the holdings of test machine hold a lab bamboo in one end, the next holder hold a lap bamboo at the other end, a strain gauge and a force sensor are provided to read the displacement and force readings by applying a force to the two ends of the upper and lower retainers until the t lap bamboo is peeling. The broken lap bamboo specimen is as shown in figure 2.
According to the experimental sample, a three-dimensional lap bamboo model is created in Abaqus. The property of bamboo is set to be elasticity, elastic modulus and poison’s ratio is 0.65GPa, 0.36 respectively. The property of gluing layer is such as: the tensile strength is 74.6MPa, the shear stress intensity is 68MPa, the energy release of the adhesive layer is \( G_I = 2.1 \text{KJ/m}^2 \), \( G_c = 0.3 \text{KJ/m}^2 \). The part of bamboo is used hexahedral mesh C3D8I, glued layer is used hexahedral bonding unit COH3D8. The grid of lap is encrypted, the same structure is built by experiment. A lap bamboo length 50mm cracking deformation is shown in figure 3, the lab bamboo cracking comparison between experimental and finite element simulation of the is shown in figure 4.

It can be seen from figure 5 that under the displacement load, the force of the adhesive layer increases with the increase of cracking displacement, and cracks occur when the cracking force reaches 5.4KN. It can be seen that the experimental value and the simulated values are consistent. But the experimental value in the fracture moment did not drop sharply to 0, there is a slow process of change, this shows that the adhesive layer began to crack is a process, to a certain stage to achieve the dissipation of the adhesive layer, cracking occurred violently. The stress cloud of the lap is shown in As can be seen from figure 5, the stress occurs at the maximum near the boundary of the glue layer.
4. Conclusion
In this paper, in order to improve the performance of bamboo reorganization material, this paper focuses on the numerical modeling of bamboo gluing performance. The fracture peeling strength of the adhesive layer is 5.4kN when the lap length is 50mm, and the proposed model was verified by experiments.

In this paper, the finite element model of bamboo gluing performance is established, and the influence of some gluing parameters on the performance is analyzed. The established model has a certain guiding effect on the numerical optimization design of bamboo reorganization.

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