

# Study on FEM Model of Stretching Resistance of Bamboo Culm Integrated Bamboo Bundles Glulam

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**Abstract.** In this paper, a new bamboo glulam is proposed. The material fully utilizes the characteristics of the hollow bamboo culm and easy integration of bamboo bundles, and realizes a hollow bamboo glulam. A three-dimension finite element model of the bamboo culm integrated bamboo bundle glulam was established using the continuum damage mechanics and cohesion element model, and the failure process of the glulam material under the tensile load was analysed. The results show that the fibers in the 1st and 2nd plies of the 90<sup>0</sup> bamboo bundles were stretched and failed, and the fibers in the 1st and 2nd plies of the 0<sup>0</sup> bamboo bundles didn't fail. 90<sup>0</sup> bamboo bundles ply 2 matrix compression failure occurred, the bamboo culm integrated bamboo bundles glulam tensile strength is 4 times higher than bamboo bundles glulam.

## 1. Introduction

In modern buildings, reinforced concrete structures are used as supporting beams and columns, and the building structure material compression and bending resistance properties are improved by the tensile properties of the reinforcement bars. The raw material such as steel bars and cement is a non-renewable natural resource, and it consumes high energy and severely pollutes the environment. At present, it is urgent that green building material is used for a replacement of traditional reinforced concrete building material. Bamboo is a natural longitudinal fiber distribution material and a natural gradient material with good longitudinal tensile properties, and can be used as a building structural material. Compared with wood, bamboo growth cycle is short, and its tensile and bending resistance is a good, is a good for green engineering material. Because of natural bamboo irregular size, it is necessary to modify the natural bamboo for reorganization. At present, many scholars have made the research on the bamboo reorganization. Now the bamboo reorganization method only uses the nature bamboo culm or the bamboo bundles to create the bamboo reorganization material. There is no reorganization method to use bamboo culm and bamboo bundles simultaneously. A new bamboo reorganization material is proposed in this paper. The bamboo culm integrated bamboo bundles glulam was manifested using bamboo culm and bamboo bundles. The bamboo bundles were made by rolling, flattening and sparing the nature bamboo culm. This material has a hollow skeleton, it is similar to a hollow reinforced concrete prefabricated floor slab. The bamboo bundles with adhesive were placed around bamboo culm, the gape between bamboo culm was filled with bamboo bundles, they all were placed in a model, they became a reorganization material by hot or cold pressing.

There were many successful wood reorganization examples, many scholars have done researches about bamboo reorganization. They found that bamboo reorganization material has good axial compression and bending resistance compared to wood reorganization material<sup>[1-6]</sup>. Many traditional



building reinforced concrete beam resisted bending only by the bar pulling resistance. But for bamboo laminated material, the fibers down the middle all can withhold the pulling, so there was more load capacity. Finite element analysis has been used in steel structure and concrete structure design successfully. Many scholars used FEM for wood structure design<sup>[7,8]</sup>, but in bamboo reorganization design field there were litter reports. In this paper a three dimension finite element model of the bamboo culm integrated bamboo bundle glulam was established, the failure process of this material pulling was analysed.

## 2. Establishment of a mathematical model

The bamboo culm integrated bamboo bundles glulam can be regarded as a multilateralism laminated composite material and is an anisotropic orthogonal composite material with bidirectional fiber distribution. It is also different from wood and its composite materials. The maximum stress theory, Tsai-Wu theory, and Tsai-Hill theory are often used for the destruction of wood and composite materials. These theories are mostly used for the analysis of unidirectional lamination materials and rarely used in bidirectional fiber composites. Because the bamboo bundles of the bamboo culm integrated bamboo bundles glulam are similar to composite materials, the Hashin criterion is used to determine whether the material is damaged or not. The in-plane damage model was established based on the Hashin criterion and the damage mechanics of continuous media. Bamboo fiber tensile failure,

$$\left(\frac{\sigma_{11}}{X_T}\right)^2 + \left(\frac{\tau_{12}}{X_T}\right)^2 + \left(\frac{\tau_{13}}{S_{13}}\right)^2 \geq 1 \quad (1)$$

In the equation,  $\sigma_{11}, \tau_{12}, \tau_{13}, X_T, S_{13}$  are the tensile stress in the X direction of the fiber axis, X-Y plane shear stress of the fiber, X-Z plane shear stress of fiber, the tensile strength in the X direction of the fiber axis, the X-Z plane shear strength, respectively.

Bamboo matrix tensile failure,

$$\left(\frac{\sigma_{22}}{Y_T}\right)^2 + \left(\frac{\tau_{12}}{S_{12}}\right)^2 + \left(\frac{\tau_{23}}{S_{23}}\right)^2 \geq 1 \quad (2)$$

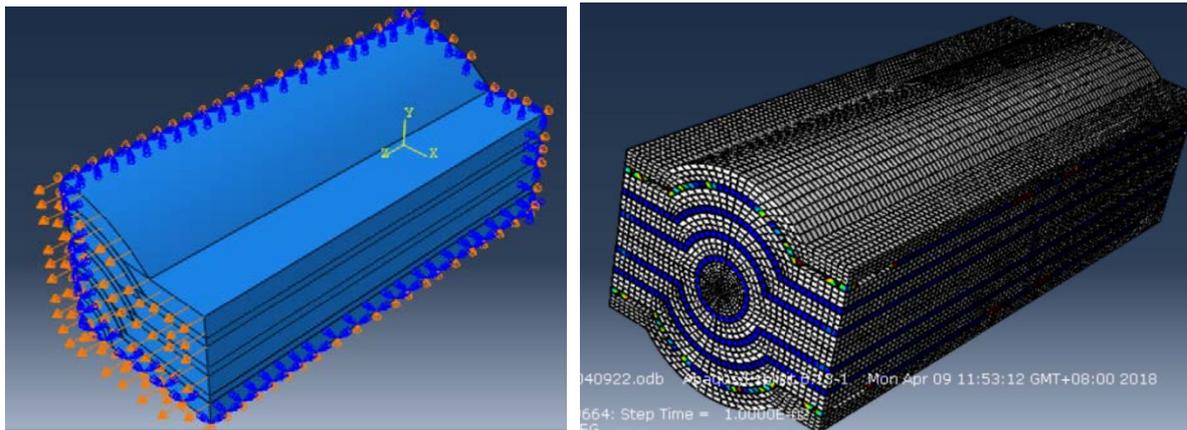
In the equation,  $\sigma_{22}, \tau_{23}, Y_T, S_{23}$  are the tensile stress in the X direction of the matrix, Y-Z plane shear stress of the matrix, the tensile strength in the Y direction of the matrix, the Y-Z plane shear strength, respectively.

The adhesive layer between bamboo bundles also is damaged under load. The adhesive layer is modeled with a certain thickness cohesive element, and a zero thickness cohesive element is used for the interface layer between the adhesive layer and the bamboo bundle layer. The cohesive element degradation uses a bilinear constitutive relational model. For the adhesive layer between layers, linear elasticity is used when no damage occurred at the beginning. When load in the adhesive layer reaches a certain value, ie when the inner tensile stress and the shear stress reach the tensile stress strength and the shear stress strength respectively, the adhesive layer cracks. Both of the above stresses will affect the cracking of the adhesive layer.

## 3. Finite element model calculation results and analysis

Using the in-plane and between layer damage models previously established, a three dimension finite element model of the bamboo culm integrated bamboo bundles glulam was realized in ABAQUS, and the model was used to analyze the damage of this material under pressure loading. The boundary condition of the model was that the tensile displacement load was applied to both ends until the material was failure. Because of the symmetry of the model, a quarter-model calculation was chosen to reduce calculations. The bamboo culm as a skeleton was simulated using a linear elastic model. The cohesive layer between the bamboo culm and the bamboo bundles was modeled with a cohesive element. The bamboo bundle layer was modeled with a composite material model, and the adhesion layer between the bamboo bundle plies was simulated with a cohesive element. Displacement and

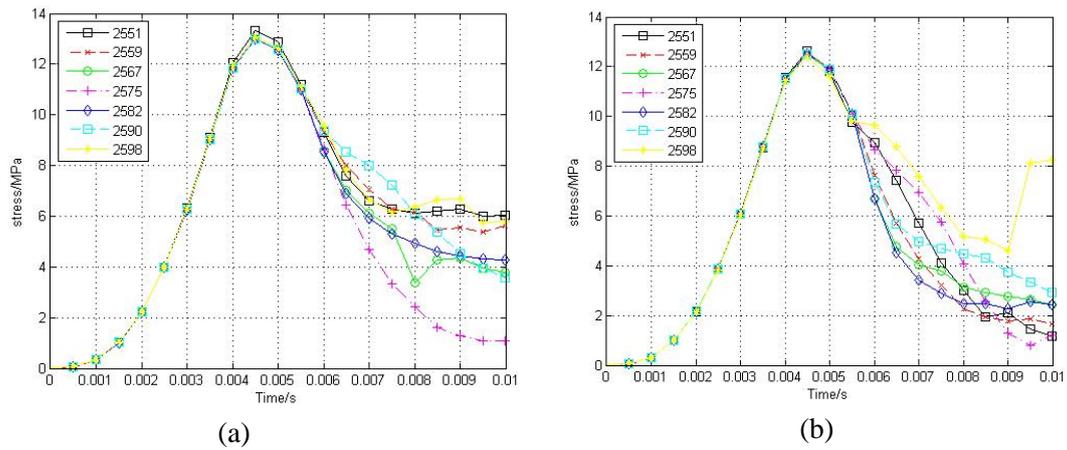
boundary conditions are shown in Figure 1.a. The overall model established is shown in Figure 1.b.  $0^{\circ}$  first layer,  $90^{\circ}$  first layer,  $0^{\circ}$  second layer,  $90^{\circ}$  second layer of bamboo bundles are laid along the positive direction of the Y axis, respectively. The bamboo culm is placed at the center. The sizes of the model were:  $72\text{mm} \times 80\text{mm} \times 200\text{mm}$ . The bamboo culm is 16mm in outer diameter, 6mm in inner diameter, and 100mm in length. Bamboo bundles thickness is 5mm, glue thickness is 2mm. The bamboo bundles layer adopts 8-node continuous shell element SC8R, and the adhesive layer thickness is 0.1mm cohesive element COH3D8. The four layers are arranged according to  $0^{\circ}/90^{\circ}/0^{\circ}/90^{\circ}$ . The model established is shown in Figure 1.



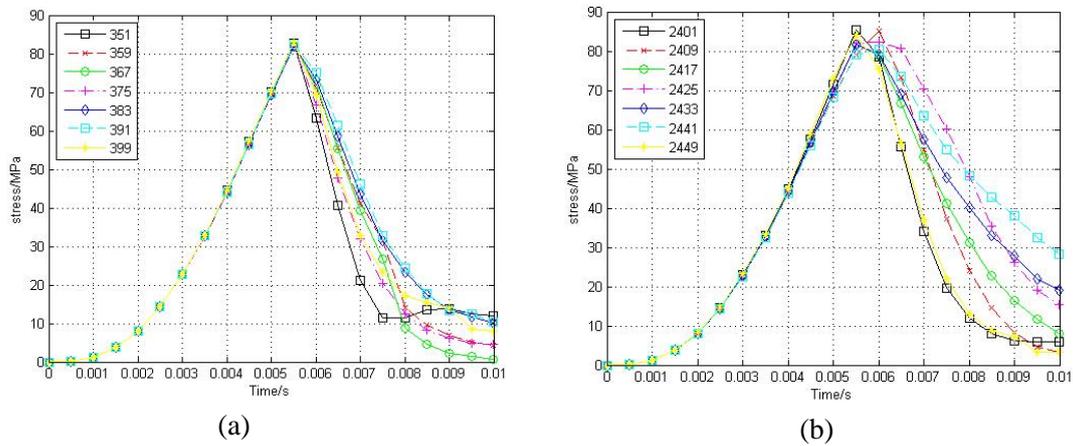
**Figure 1.** Finite element model

### 3.1. Failure mode in layer

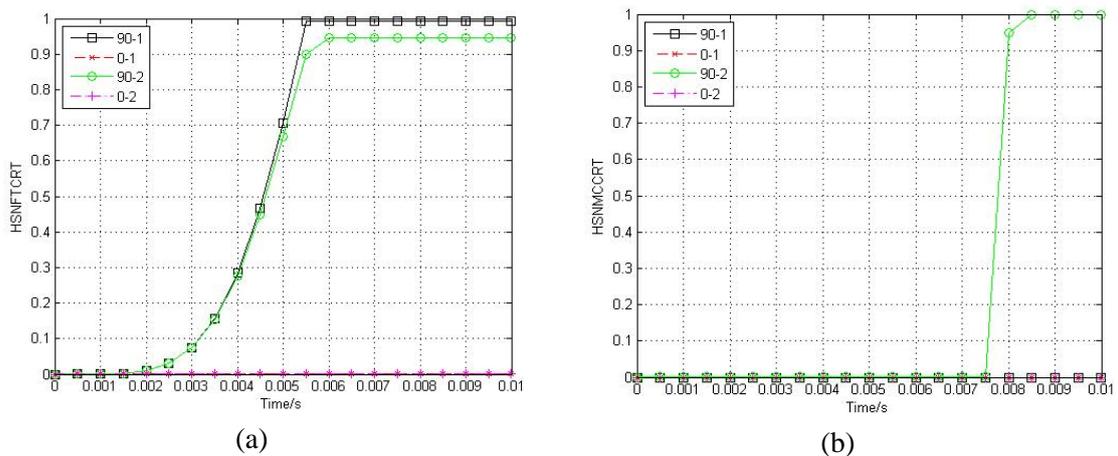
In order to study the damage of the bamboo culm integrated bamboo bundles glulam under tensile load, 7 elements along the Z axis of the model was selected to study the variation of the stress of the element with time. 7 elements selected on the first layer  $0^{\circ}$  ply bamboo bundles stress changes over time is shown in figure 3.a. It can be seen that the 7 elements have the same change trend at different positions, and the stress firstly increased with time, reached the peak value 13MPa at 0.0045s, then dropped to 4MPa. This is due to happening of plastic deformation at that moment. For the second layer  $0^{\circ}$  ply bamboo bundles, 7 elements at the same position were selected to see the stress changes with time. It can be seen that the stress reached 12.8MPa at 0.0045s, suddenly dropped to 2 MPa, and the plastic deformation occurred. For the first layer of  $90^{\circ}$  ply bamboo bundles, 7 elements were selected at the same position to see the stress change with time. It can be seen that the stress reached a peak value of 84 MPa at 0.0045 s, dropped to 0, the material was plastically deformed and the material was damaged. For the second layer  $90^{\circ}$  ply bamboo bundles, 7 elements at the same position selected to see the stress changes with time. It can be seen that the stress reached a maximum of 85 MPa at 0.0045 s and dropped to 8 MPa with time, and plastic deformation failure occurred in the material. The stress change curve is the same as the first layer  $90^{\circ}$  ply of bamboo. From the stress change curve, it can be seen that for the bamboo culm integrated bamboo bundles glulam, under the tensile displacement load, the  $90^{\circ}$  ply will fail, and the  $0^{\circ}$  ply has a certain plastic strain.



**Figure 2.** Stress in the bundles of the material changes with time (a) 0° first layer, (b) 0° second layer



**Figure 3.** Stress in the bundles of laminated bamboo bundles changes with time (a) 90° first layer, (b) 90° second layer



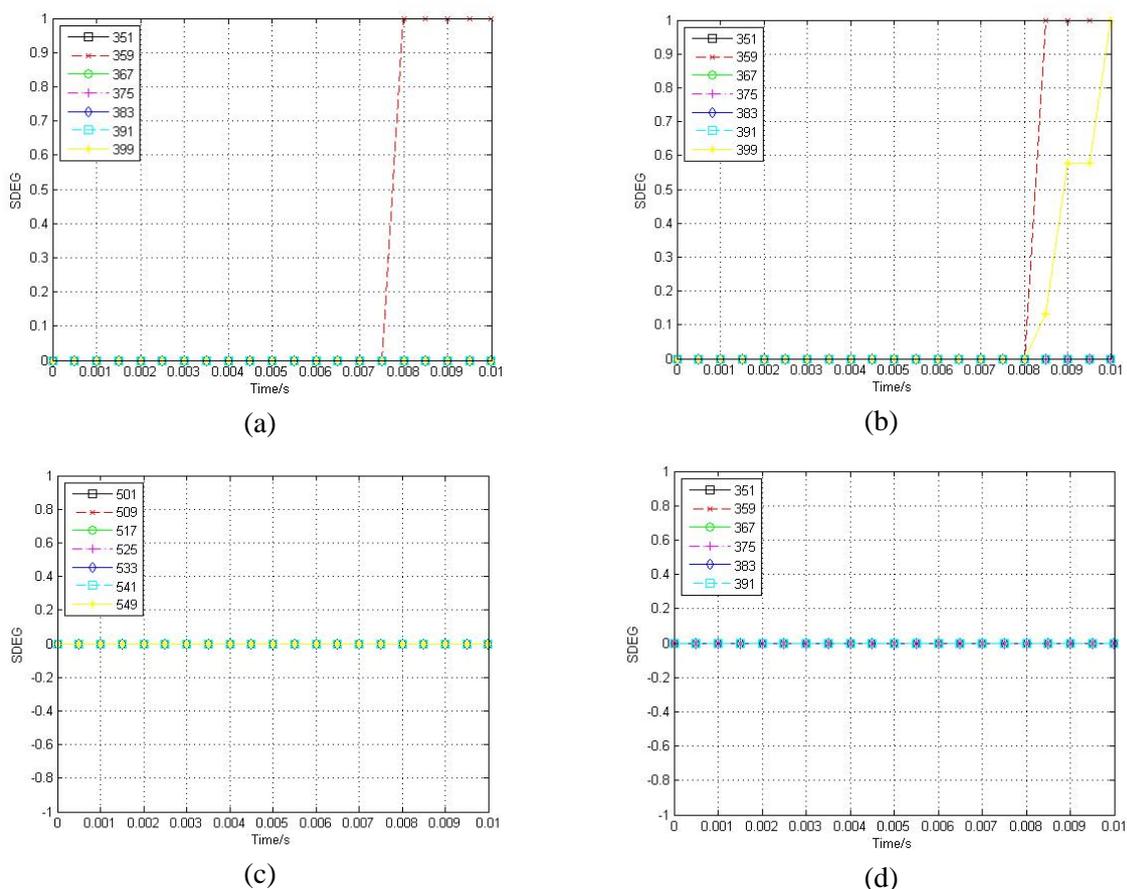
**Figure 4.** Fiber failure change with time (a) fiber tension failure, (b) fiber compression failure

Figure 4 shows that the main cause of the failure of the bamboo culm integrated bamboo bundle glulam is the damage of the bamboo bundles, which damage type are the tensile failure of the bamboo bundle fiber and the failure of the matrix. By analysing the failure process of the bamboo bundle

glulam, it can be seen that the failure of the fiber tensile damage in the bamboo bundle lays mainly in the  $90^0$  bamboo plies 1 and 2, the damage occurred in 0.0002s, and reached 100% at 0.0055s and the material complete failure occurred. There was no damage at the  $0^0$  bamboo bundles 1 and 2 plies. From tensile failure of the material matrix, it can be seen that there is no damage to the matrix in the  $0^0$  bamboo ply 1, 2, and  $90^0$  ply 1. In the  $90^0$  bamboo ply 2, the matrix began to be damaged at 0.0075 s, and the damage was 100% at 0.008 s.

### 3.2. Lamination failure between layers

In addition to the tensile failure of bamboo fiber bundles and the matrix, the layering's of the bamboo bundles also cause material failure. Once layering between the bamboo bundle layers occurs, the entire material fails. A mathematical model that describes the layering of bamboo bundles was established in the section. The size of the model was also a  $72\text{mm}\times 80\text{mm}\times 200\text{mm}$  bamboo bundle layer. The dimensions of the glue layer were the same as the layer, and the thickness was 0.2mm. The adhesive layer between bamboo bundles was simulated with a certain thickness of cohesive element, and the cohesive element was degraded by the bilinear method. In ABAQUS, a three dimension finite element model of the bamboo glulam considering the layering of bamboo bundles was established. In order to accurately simulate layering, the glue layer was subdivided into a layer of mesh along the thickness direction, and a reduced-integration 8-node continuous shell element (SC8R) was used. Cohesion element (COH3D8) with a thickness of 0.2 mm was used for the glue layer. Because of axisymmetric of the specimen, only 1/4 of the models is analyzed. Two ends of the model were applied a tensile displacement load.

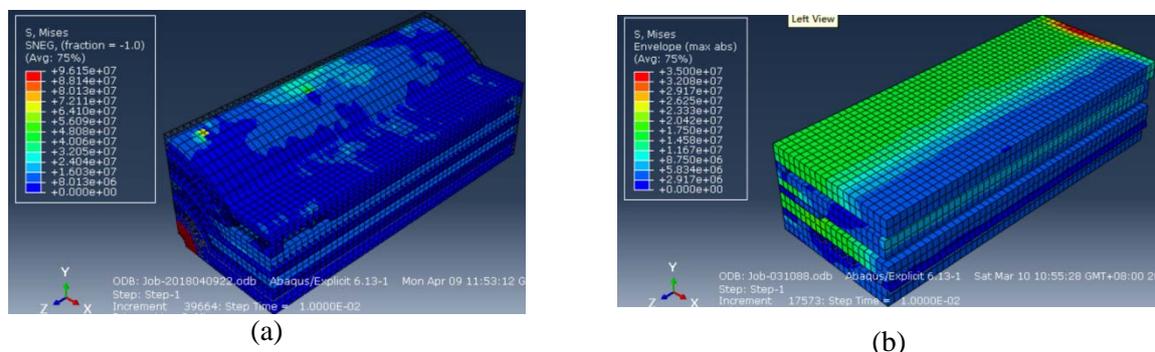


**Figure 5.** The stiffness degradation coefficient of each layer changes with time (a) first layer, (b) second layer, (c) first layer, (d) second layer

Figure 4 shows the change in stiffness degradation coefficient with time for different layers. It can be seen that the first and second layers of the adhesive layer were cracked, and the third and fourth layers were not cracked. 7 elements of the glue layer were taken to observe cracking of the glue layer. The cracks appeared in the adhesive layer partly, and only one of the seven elements selected in the first layer of the glue layer began to crack at 0.0075s, and the stiffness degradation coefficient reached 100% at 0.008s. Only two elements of the second layer of glue were cracked at 0.008s, completely cracked at 0.0085s and the stiffness degradation coefficient reached 100%.

### 3.3. Comparison between bamboo culm integrated bamboo bundles glulam and bamboo bundles glulam

The comparison of two tensile properties between the bamboo glulam and the solid bamboo bundle glulam were made. The bamboo culm integrated bamboo bundles glulam with the central bamboo skeleton had the same size as the bamboo bundle gluing material, and the tensile displacement load was applied to above two materials until the damage.



**Figure. 6** Distribution of tensile stress of the bamboo culm integrated bamboo bundles glulam and bamboo bundles glulam (a) the bamboo culm integrated bamboo bundles glulam, (b) bamboo bundles glulam

As shown in Figure 5.a, the bamboo culm integrated bamboo bundles glulam failed under a tensile displacement of 0.0005m. The maximum stress reached 96MPa. The outermost bamboo bundles failed, and the first layer of adhesive layer from the outside to the inside appeared cracking. Figure 5.b shows the failure of the bamboo bundles at a tensile displacement of 0.002. The maximum stress reached 35MPa, and the outermost bamboo bundles failed. Cracking occurred in the first to third layers of adhesive layer from the outside to the inside. The tensile resistance capacity of the bamboo glulam with bamboo skeleton was four times than the only bamboo bundles glulam. It was main due to the bamboo culm skeleton existence. At the same time, it was found that the outmost bamboo bundles and center bamboo culm of the bamboo glulam with skeleton bared most load, and 90<sup>0</sup> ply 1,2 of bamboo bundles glulam bared most load.

## 4. Conclusion

In this paper, a three dimension finite element model of the bamboo culm integrated bamboo bundle glulam under tensile is established. Through comparison with bamboo bundle glulam, the following conclusions are obtained:

- 1) Under tensile load, the fibers in ply 1,2 of the 90<sup>0</sup> bamboo bundles are stretched and failure, and the fibers in the ply 1,2 of the 0<sup>0</sup> bamboo bundles do not happen failure.
- 2) Under the tensile load, 90<sup>0</sup> bamboo bundle ply 2 matrix compressive failure occurs, and 90<sup>0</sup> bamboo bundles ply 1 and 0<sup>0</sup> bamboo bundles ply 1, 2 matrix have no compression failure.
- 3) In the four adhesive layers, cracking occur in the first layer of the adhesive layer from the outside to the inside, and no cracking occurs in the other three layers of the adhesive layer.
- 4) The tensile resistance properties of the bamboo culm integrated bamboo bundles glulam are more 4 times than the bamboo bundles glulam without bamboo skeleton. Failure of the bamboo culm

integrated bamboo bundle glulam mainly occurs in the first and second layers of the outermost 90<sup>0</sup> bamboo bundles, and the failure of the bamboo bundles glulam occurs in the first and second layers of 90<sup>0</sup> bamboo bundles.

### 5. Acknowledgments

This research was financially supported by National Natural Science Foundation of China (No.31470588) Science and technology project of Hebei Province (No.15211830).

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