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# Experimental and Analytical Study on the Bending Behavior of Laminated Bamboo Sandwich Structures with Diverse Lattice Core Geometries

Tonglin Gu[a,*]

[a]*Anhui Jianzhu University, Anhui 230601, China*

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ABSTRACT

To enhance the utilization and development of bamboo resources and promote their application in engineering, this study designed four types of laminated bamboo sandwich panels with distinct lattice cores: triangular, square, and Kagome configurations. The panels were fabricated using laminated bamboo as the raw material and manufactured via two methods: interlocking and partitioning. Four-point bending tests were conducted on the sandwich panels with different lattice cores to evaluate their flexural performance. The failure mechanisms under bending load were analyzed, along with variations in mid-span deflection, bending stiffness, and ultimate load-bearing capacity. The specific stiffness and specific strength of the four sandwich panel types were also compared.A finite element model of the four-point bending test was established using ABAQUS software to perform numerical simulations. The results indicated that all three interlocked lattice-core sandwich panels exhibited shear failure during bending. Among them, the triangular lattice panel demonstrated the highest load-bearing capacity and the greatest specific strength. In contrast, the partitioned square lattice panel failed due to compressive yielding of the top layer and tensile damage of the bottom layer. Its load-bearing capacity and specific strength exceeded those of the three interlocked panels, showing improvements of 21.6 % and 43.6 %, respectively, compared with the interlocked triangular lattice panel.The numerical simulations showed good agreement with experimental results, with an error margin of less than 5 %, confirming the model's ability to effectively predict the bending behavior of laminated bamboo sandwich panels. These panels exhibit excellent flexural performance, leveraging the advantages of laminated bamboo—light weight and high strength. The findings provide a viable structural form and a theoretical basis for expanding the use of bamboo in engineering applications.

## 1.Introduction

In an era increasingly defined by sustainability and environmental awareness, the pursuit of eco-friendly building materials has gained significant importance. Bamboo, a traditional material, stands out as a paragon of sustainability in construction. It offers a compelling combination of light weight, high strength, excellent mechanical properties, good plasticity and toughness, alongside superior ecological performance. These characteristics provide an environmentally friendly solution that aligns with low-carbon development principles, making bamboo a prime candidate for modern green building[1,2]. Furthermore, the effective utilization of bamboo can help alleviate the pressure on diminishing natural forests in developing countries, thereby contributing to global environmental protection. Recognized as an important non-wood product, bamboo delivers excellent

* Corresponding author.
E-mail addresses:gutonglin2003@163.com
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social and ecological benefits. It features a short growth cycle and functions as a carbon sink while improving the environment during its growth. From a whole-life-cycle perspective of buildings, bamboo is a high-quality, environmentally friendly material with broad application prospects, well-suited to meet the strategic demands of dual-carbon goals[3].

As a green material, bamboo possesses a fine fiber structure, favorable physical-mechanical properties, and good workability. Consequently, it is regarded as a valuable supplement to conventional materials like steel and concrete [4,5]. To advance sustainable development and promote the architectural application of bamboo, it is essential not only to select bamboo as a green building material but also to explore advanced structural forms that are lightweight and efficient, thereby maximizing its potential. The sandwich panel is one such structure, known for its high stiffness-to-weight ratio. Due to its potential for lightweight and high-strength performance, it has been widely adopted in aerospace, marine, and construction engineering[6,10].

Processing laminated bamboo into lattice sandwich panel structures enables its use as flooring, bridge decks, or other components in modern building systems (as shown in Fig 1). This application not only provides a more environmentally friendly and sustainable choice for the construction industry[11] but also helps reduce the environmental impact of building materials. Moreover, it opens new avenues for the broader use of bamboo in construction, thereby supporting the advancement of green building and sustainable development.

(a) laminated bamboo office building with 1,500 square meters

(b) glued-laminated wood footbridge with 39.5 meters

Fig 1. Modern bamboo and wood structures

The sandwich panel structure consists of two thin, high-strength face sheets and a thick, lightweight core. This concept was first introduced in academic literature by Hoff and Mautner[12,13]. By varying the core geometry and the materials of the face sheets and core, the structure can be optimized for specific applications — such as improving mechanical performance or achieving multifunctional properties like a high stiffness-to-weight ratio, high strength-to-weight ratio, good thermal insulation, and efficient energy absorption. Due to the development of new lightweight, high-strength materials, sandwich panels have been widely adopted and continue to evolve in diverse forms.

The strength of a sandwich panel depends on several factors, including the face and core materials, the geometric configuration of the core, and the bonding conditions[14-17]. Consequently, various design parameters—such as face and core thickness, core geometry, and material selection—can be adjusted to meet different functional requirements. Researchers have proposed numerous core designs aimed at developing lightweight structures with higher stiffness, strength, and energy-absorption capacity. Increasing attention has been directed toward identifying ideal core geometries and materials for lightweight applications[18].

Two-dimensional periodic cellular structures, a classic type of lattice core, refer to cellular shapes designed in two-dimensional space and arranged in a repeating pattern. Common configurations include triangular, honeycomb, square, and Kagome lattices[19]. For example, Wu et al.[20] conducted systematic experimental and numerical studies on the bending capacity and failure modes of composite sandwich panels with different face sheets. Wang et al.[21] used ABAQUS to analyze the relationship among fiber-ply orientation, lattice density, and bending stiffness in fiber-reinforced composite sandwich panels, validating their simulation method through experimental comparison. Li et al.[22] performed four-point bending tests to investigate the static and fatigue behavior of wood-fiber-based triangular sandwich panels; static failure occurred in the face sheet within the pure-bending region, while fatigue failure initiated at the face-core interface in the shear zone. Wang et al.[23] studied the bending performance of a honeycomb sandwich structure with ceramic face sheets via three-point bending tests, noting a distinct failure progression compared with traditional aluminum honeycomb panels. Fan et al.[19] fabricated a carbon-iber Kagome lattice sandwich panel and conducted in-plane compression, out-of-plane compression, and three-point bending tests, comparing the results with theoretical failure-mode formulas to refine the analytical models.

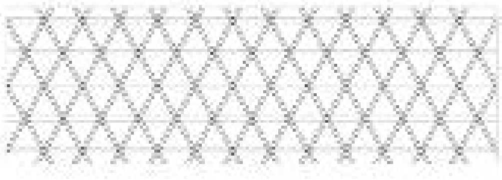
In addition to finite element software such as ABAQUS, the bending performance of sandwich panels can also be analyzed using various numerical modeling methods. Charles W. Bert and Moinuddin Malik[24] applied the differential quadrature method (DQM) to the study of composite laminated panels and determined their natural frequencies via DQM. This approach provides an accurate and computationally efficient means for analyzing the vibration of laminated structures, demonstrating that DQM is a powerful technique for composite panel analysis. Wang et al.[25] proposed a novel stress-analysis framework for three-dimensional composite elastic materials, which combines the generalized finite difference method (GFDM) with domain decomposition to solve structural stress problems. This framework can readily handle large-scale problems involving up to 500,000 unknowns on a standard desktop computer. Hossein Kabir and Mohammad Mohammadi Aghdam[26] developed a stress-analysis method for notched epoxy plates reinforced with graphene nanoplatelets. The method first introduces the Bezier technique to solve one-dimensional initial value problems and subsequently extends it to simultaneously address boundary value problems in orthogonal directions. This yields a reliable numerical scheme for solving complex fourth-order partial differential equations. The accuracy and performance of the method were verified through comparison with exact analytical solutions using Bayesian statistical analysis.

In summary, extensive research has been conducted on the mechanical properties of sandwich panels. However, studies on laminated bamboo sandwich panels with lattice cores remain limited, and their bending behavior and failure mechanisms are not yet fully understood. Therefore, this paper designs and fabricates sandwich panels with different core configurations using laminated bamboo. The bending performance of these structures is investigated through finite-element analysis and four-point bending tests to elucidate their failure mechanisms. The findings are expected to provide theoretical support for the practical engineering application of laminated bamboo sandwich panels.

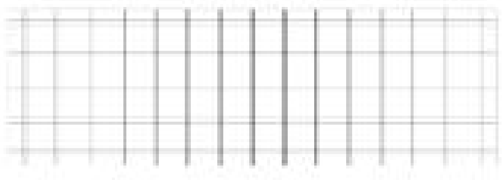
## 2.Preparation of material and specimen

### *2.1.Design and preparation of laminated bamboo sandwich panel*

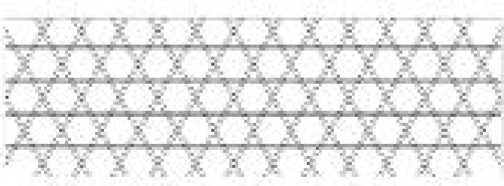
In this study, the geometric configuration of the core layer in the lattice sandwich panel was designed, including triangular, square, and Kagome lattices, as shown in Fig 2(a)-(c). Sandwich panels with these lattice cores were prepared using both the interlocking method and the partition method.



(a) Triangular lattice



(b) Square lattice



(c) Kagome lattice

Fig 2. Lattice core of laminated bamboo sandwich panel

The interlocking method employed a CNC milling machine to cut specific grooves into 8 mm-thick laminated bamboo boards for both the face sheets and the core layer according to a programmed path. The lattice core was then assembled by interlocking the milled parts. Resorcinol adhesive was applied to the grooves of the face sheets at a spread rate of 260 g/m$^2$. After adhesive application, the lattice core was placed between the upper and lower face sheets, laid in a hydraulic cold press, and pressed at 1 MPa and 30℃ for more than 4 hours. Following cold pressing, the panel was trimmed using a cutting machine to produce a laminated bamboo lattice sandwich panel with final dimensions of 1200 mm (length) × 384 mm (width) × 64 mm (thickness), as illustrated in Fig 3(a)-(c).

(a)Triangular lattice

(b) Square lattice

(c) Kagome lattice

Fig 3. Schematic diagram of laminated bamboo sandwich panel processing by interlocking method

Fig 4. Schematic diagram of laminated bamboo square lattice sandwich panel processing by partition method

The partition method differed from the interlocking method in that only the face sheets were milled with specific grooves using the CNC machine. The core layer was prepared by cutting laminated bamboo into the required lengths and then bonded to the grooved face sheets. All other processing steps remained the same as in the interlocking method. A laminated bamboo square lattice sandwich panel fabricated by the partition method is shown in Fig 4.

To meet practical engineering requirements, the sandwich panel dimensions were designed as a full-scale model based on the deck size of a glulam demonstration bridge (Fig 1b) and in compliance with the Chinese guideline GB/T 50329-2012[27]. Three specimens were prepared for each configuration, and the detailed geometric parameters of the sandwich panel structures are summarized in Table 1.

Table 1 Geometric parameters of laminated bamboo sandwich panel

| Specimen number | Specimen quantity | Laminated bamboo sandwich panel | | | Core layer thickness(mm) | Surface layer thickness(mm) | Long lattice quantity | Short lattice quantity |
|---|---|---|---|---|---|---|---|---|
| | | Length (mm) | Width (mm) | Thickness (mm) | | | | |
| T-IBP | 3 | 1200 | 384 | 64 | 48 | 8 | 5 | - |
| S-IBP | 3 | 1200 | 384 | 64 | 48 | 8 | 5 | 15 |
| K-IBP | 3 | 1200 | 384 | 64 | 48 | 8 | 4 | - |
| S-PBP | 3 | 1200 | 384 | 64 | 48 | 8 | 5 | 15 |

Note: In this table, T-IBP is laminated bamboo triangular lattice interlocking sandwich panel; S-IBP is laminated bamboo square lattice interlocking sandwich panel; K-IBP is a laminated bamboo Kagome lattice interlocking sandwich panel; S-PBP is laminated bamboo square lattice partition sandwich panel.

Table 2 Basic properties of laminated bamboo

| Material | Density ($g \cdot cm^{-3}$) | Tensile strength parallel to grain(MPa) | Compression strength parallel to grain(MPa) | Shear strength parallel to grain(MPa) |
|---|---|---|---|---|
| laminated bamboo | 0.64 | 114.5 | 59.7 | 18.9 |

### *2.2.Laminated bamboo lattice sandwich panel materials*

In this experiment, laminated bamboo supplied by Taohuajiang Bamboo Technology Co., Ltd. (Hunan, China) was used as the face-sheet and core material for the sandwich panel structure. The physical and mechanical properties of the laminated bamboo were tested in accordance with the Chinese standard GB/T 1927.2-2021[28]; the results are presented in Table 2.

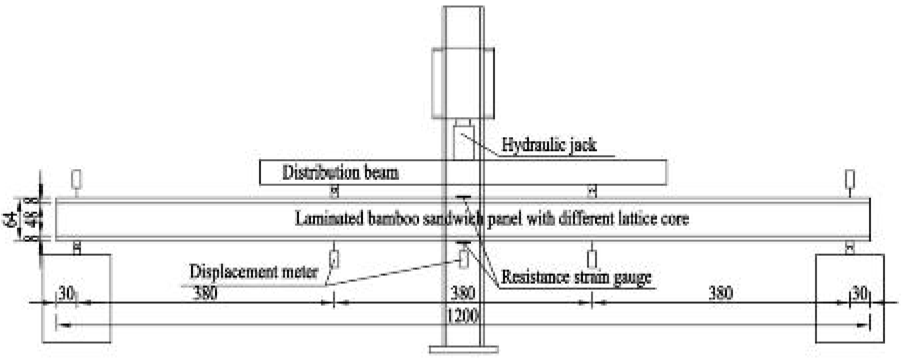
The adhesive employed was a resorcinol-modified resin (Zhiyi New Material Technology Co., Ltd., Shanghai, China) with a viscosity of 15 Pa·s and a solid content of 65 %. To ensure adequate bonding, the surfaces of both the face sheets and the core components were polished prior to assembly. This treatment promoted effective, high-quality adhesion between the layers. After application of the adhesive, the assembled structure was cured under appropriate pressure for one day, guaranteeing a robust bond and ensuring the structural integrity of the final sandwich panel.

## 3.Experiment and finite element simulation

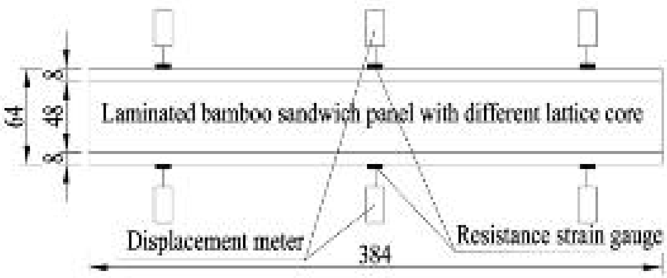
### *3.1.Four-point bending test*

In this experiment, a four-point bending test was conducted in accordance with the Chinese standard GB/T 50329-2012[27]. Loading was applied using a hydraulic jack, which transferred force through a distribution beam to the specimen via supporting brackets. The distance between the two loading points was 380 mm, and the span between the two outer supports was 1140 mm.

Test data were collected using a Donghua DH3818Y static strain gauge. Displacement meters were positioned to measure vertical deflection at mid-span, at one-third and two-third span points, and at the support pedestals. Resistance strain gauges were mounted at mid-span on both the upper and lower face sheets of the sandwich panel to capture strain responses.




(a)Loading arrangement for test




(b) Displacement and strain measuring point arrangement in test

Fig 5. Loading diagram and measuring point arrangement of bending test for laminated bamboo sandwich panel

Four types of sandwich panel structures with different core configurations were tested. Load was applied incrementally at a uniform rate, with each load step held for three minutes to allow stabilization before readings were recorded. Loading continued until specimen failure. The experimental setup is shown in Fig 5(a), and the arrangement of displacement meters and strain gauges is illustrated in Fig 5(b).

### *3.2.Analysis of finite elements*

The finite element software ABAQUS 2020 was employed to simulate and analyze the four-point bending behavior of four different configurations of laminated bamboo lattice sandwich panels. A three-dimensional finite element model was established to simulate the displacement and stress evolution during the test. Both the face sheets and the core of the structure were modeled using solid elements to represent the laminated bamboo material.

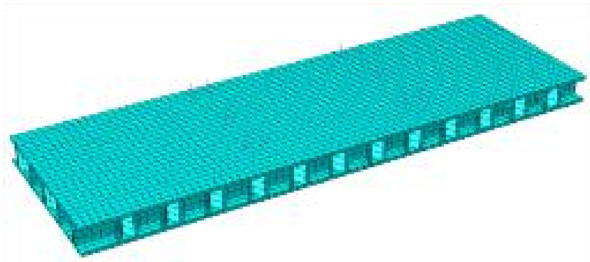


Fig 6. Finite element model of four-point bending test

In the actual specimen preparation, the face sheets and core were bonded into an integral structure using adhesive. Since no debonding was observed between the face sheets and the core in the final failure modes, the adhesive layer was not explicitly modeled in the simulation. Instead, it was assumed that the interface between the face sheets and the core was perfectly bonded, and tie constraints were applied at these interfaces. The finite element model, shown in Fig 6, had the same dimensions as the physical bending specimens.

Von-Mises stress and principal stress were used to represent the stress distribution in the sandwich panel structure. According to the Von-Mises yield criterion, the Von-Mises stress calculated by Eq. (1) can be used to determine whether the material has entered the yield stage:

$$\sigma_e = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \tag{1}$$

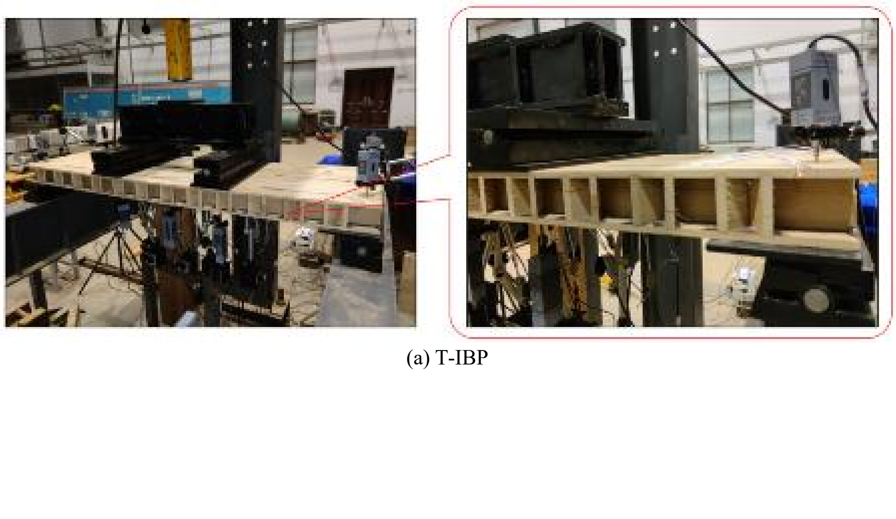
where $\sigma_1$, $\sigma_2$ and $\sigma_3$ are the first, second, and third principal stresses, respectively.

## **4.Results and analysis**

### *4.1.Failure mode and mechanism of four-point bending test*

In the experiments, all four sandwich panel configurations exhibited similar behavior during testing. The failure modes observed in the four-point bending test are illustrated in Fig 7. Under bending load, the upper face sheet primarily resisted compressive stress, the core layer carried transverse shear, and the lower face sheet sustained tensile stress.

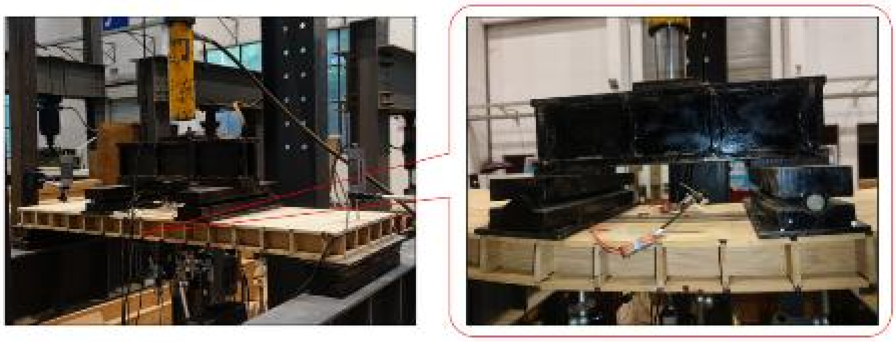
During the initial loading stage, none of the four structures showed visible damage. When the load reached approximately 65 % of the ultimate capacity, audible sounds emerged under continued loading, though no obvious surface cracks were detected. As the load was further increased to the ultimate limit, the sandwich panel structures emitted a sudden, loud noise. For the three panels fabricated using the interlocking method, shear cracks appeared abruptly within the core layer in the bending-shear regions and propagated rapidly, leading to structural failure by shear in the core. In contrast, the laminated bamboo lattice sandwich panel produced via the partition method failed due to tensile rupture of the lower face sheet.



(a) T-IBP

(b) S-IBP

(c) K-IBP



(d) S-PBP

Fig 7. Failure mode of four-point bending test for laminated bamboo sandwich panel

*4.2.Load-midspan deflection curve and load-strain curve*

The load–mid-span deflection curves obtained from the four-point bending tests of the laminated bamboo sandwich panels are presented in Fig 8. The test results showed good repeatability across each group of specimens; for clarity, a representative result from each group is displayed. As seen in Fig. 8, during the initial loading stage, the slopes of the load-deflection curves for all four structures were similar, exhibiting linear behavior and comparable stiffness.

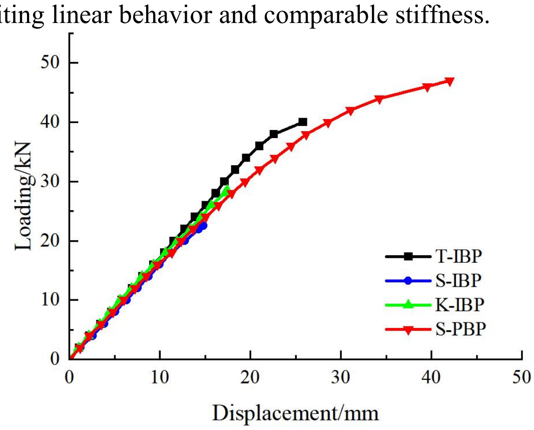



Fig 8. Load-mid span displacement curve

With increasing load, the interlocked square-lattice panel (S-IBP) reached its ultimate load first, followed by the Kagome-lattice (K-IBP) and triangular-lattice (T-IBP) panels. The partitioned square-lattice panel (S-PBP) ultimately sustained the highest load before failure. For S-IBP and K-IBP, structural failure occurred abruptly: at approximately 22 kN for S-IBP, where the core layer underwent shear failure at the slotted connections, and at about 28 kN for K-IBP, where similar core-layer shear failure took place—indicating that K-IBP possesses better bending resistance than S-IBP.

T-IBP and S-PBP displayed two-stage deformation behavior due to their higher load-bearing capacity. In the first stage, like the other configurations, they deformed elastically. Beyond a certain load level, the upper face sheet reached its yield strength, causing the slope of the load-deflection curve to decrease and the structure to enter a plastic stage, during which mid-span displacement increased rapidly with load. T-IBP failed at approximately 38 kN when the core layer reached its shear strength, making it the strongest among the three interlocked configurations. S-PBP failed at about 47 kN due to tensile rupture of the lower face sheet, exhibiting the highest ultimate load among all four panel types.

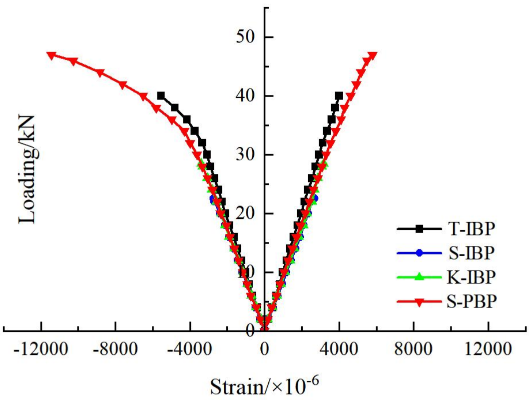



Fig 9. Load-strain curve

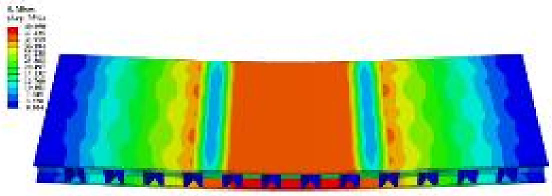
Strain was measured at three points across the upper and lower face-sheet cross-sections (Fig 5), with reported values representing the average strain in each section. Representative specimens were selected to verify the plane-section assumption. The load–strain curves (Fig 9, where negative values indicate compression and positive values tension) show that in the elastic stage, the curves are linear and tensile and compressive strains are symmetrically distributed about the neutral axis, confirming the plane-section assumption. The load-bearing capacities of S-PBP and T-IBP are notably higher than those of S-IBP and K-IBP. As loading progressed into the plastic stage, compressive strain growth slowed after the compressive face yielded, while tensile strain continued to increase linearly.

The test results demonstrate that core-layer geometry and manufacturing method significantly influence the ultimate load-bearing capacity. Among the three interlocked configurations, the triangular lattice panel exhibited the highest ultimate load and bending stiffness, followed by the Kagome and square lattices. Compared with the interlocked square lattice, the triangular and Kagome lattices showed increases in maximum load of 71.9 % and 22.2 %, and in bending stiffness of 12.5 % and 6.0 %, respectively. The partitioned square-lattice panel exhibited a 108.9 % higher maximum load than its interlocked counterpart, although the bending stiffness of the two square-lattice designs did not differ significantly.

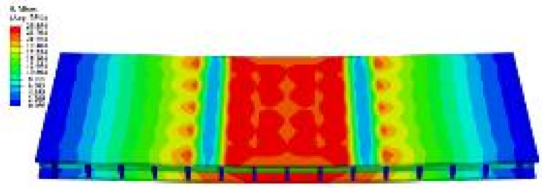
*4.3.Finite element simulation and analysis*

The stress distribution obtained from the finite-element simulation of the four-point bending tests on the laminated bamboo sandwich panels is presented in Fig 10. The figure illustrates the stress states of the four specimen groups—T-IBP, S-IBP, K-IBP, and S-PBP—at applied loads of 38.5 kN, 23.5 kN, 27.0 kN, and 46.9 kN, respectively. Under bending load, all four sandwich-plate configurations exhibited similar stress patterns. As shown in Fig. 10(a)–(d), stress was concentrated in the mid-span region of both the upper and lower face sheets. The maximum compressive stress in the upper face sheet was 37.2 MPa, 25.9 MPa, 30.0 MPa, and 43.4 MPa for T-IBP, S-IBP, K-IBP, and S-PBP, respectively. Correspondingly, the maximum tensile stress in the lower face sheet reached 40.7 MPa, 24.4 MPa, 28.5 MPa, and 53.7 MPa.

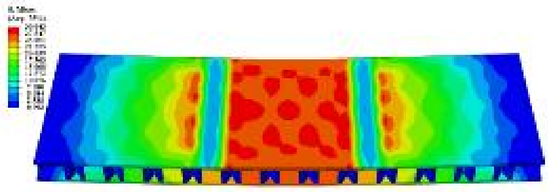
For the laminated bamboo lattice sandwich panels examined in this study, structural failure occurs when the material reaches its ultimate stress, at which point the panel can no longer sustain additional load. This failure condition defines the bending strength of the sandwich panel structure.



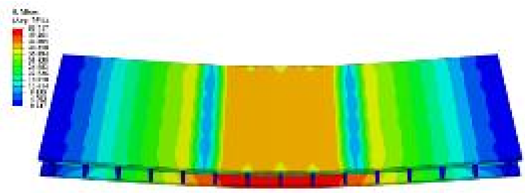
(a) T-IBP



(b) S-IBP



(c) K-IBP



(d) S-PBP

Fig 10. Stress distribution of laminated bamboo sandwich panel

Table 3 gives the ultimate load, displacement, and stress values of the sandwich plate obtained by experiments and finite element analysis. The possible reasons for the error between the test results and the simulation results are as follows: (a) The sandwich plate structure is subjected to complex stress states including tension, compression and bending in the four-point bending test. At present, the simplified constitutive model used to describe the mechanical behavior of laminated bamboo materials in the finite element model may not fully capture the stress changes, which leads to the difference between the finite element and the experimental results; (b) In the finite element model, it is assumed that the surface layer and the core layer are well bonded, but there may be glue seams in the actual processing; (c) Grooving the material will affect the mechanical properties of the material to some extent.

The deviations between the measured and simulated values were less than 4.4 %, 4.0 %, and 4.7 %, respectively, indicating good agreement. These results demonstrate that the numerical simulations align closely with the experimental data and can reliably represent the bending behavior of the laminated bamboo lattice sandwich panels.

To quantitatively assess the influence of different core geometries on the flexural performance of the sandwich structures, the specific stiffness and specific strength of each configuration were calculated. The results are presented in Table 4 and illustrated in Fig 11 and Fig 12. The bending stiffness of the structure was calculated using the following formula:

$$D=\frac{a\cdot\Delta P}{48f_1}(3l^2-4a^2) \quad (2)$$

Where $D$ is the bending stiffness of sandwich panel structure ($N\cdot mm^2$), $a$ is the distance from the support point to the loading point (mm), $\Delta P$ is the bending load increment in the elastic deformation stage (N), $l$ is the span length of the structure (mm), $f_1$ is the mid-span deflection value corresponding to $\Delta P$ (mm), and $\Delta P/f_1$ is the linear part of the load-displacement curve (N/mm).

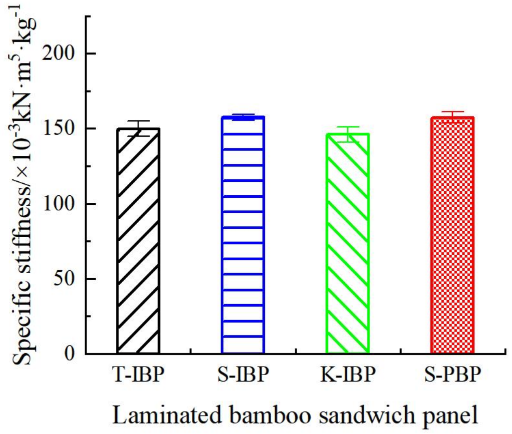



Fig 11. Specific stiffness of laminated bamboo sandwich panel

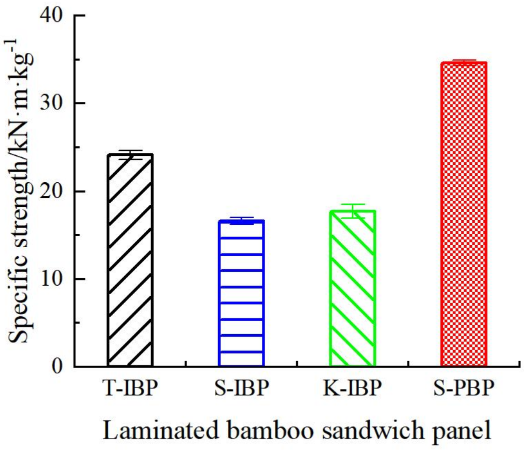



Fig 12. Specific strength of laminated bamboosandwich panel

Table 4 shows that among the three interlocking-fabricated sandwich panels, the square-lattice panel (S-IBP) exhibited the highest specific stiffness. The specific stiffness values of the triangular-lattice (T-IBP) and Kagome-lattice (K-IBP) panels were comparable, reaching 95.2 % and 92.8 % of that of S-IBP, respectively. In contrast, the fabrication method—interlocking versus partition—had little influence on the specific stiffness of panels with the same core geometry. Under equivalent mass, the square-lattice configuration can provide the same stiffness and performance with a lighter weight.

For bamboo and timber structures, the fundamental frequency is typically low (generally between 1.5 and 2.0 Hz), which can lead to significant human-induced vibrations and adversely affect occupant comfort. A high specific stiffness allows engineers to reduce the total mass of a structure while maintaining the required stiffness, thereby raising the fundamental frequency and improving the comfort and serviceability of bamboo- and wood-based constructions[29].

Furthermore, among the interlocking-manufactured panels, T-IBP displayed the highest specific strength. The specific strength of the partition-fabricated square-lattice panel (S-PBP) was markedly improved, exceeding that of T-IBP, S-IBP, and K-IBP by 43.6 %, 108.9 %, and 95.3 %, respectively. This indicates that the partitioned square-lattice sandwich panel offers superior material efficiency and meets lightweight design requirements—beneficial for enhancing both structural performance and sustainability. Structures with high specific strength can withstand greater external loads (e.g., wind, snow, and seismic forces), improving building safety and resilience under varying environmental conditions. Simultaneously, meeting strength requirements with less material reduces overall material consumption.

Although the manufacturing cost of sandwich panels is relatively high, the total cost is significantly lower than that of a solid panel of equivalent volume—approximately 50 % lower due to reduced material usage. This not only helps lower material costs in construction projects but also offers considerable economic advantages. As an advanced structural form, the laminated bamboo lattice sandwich panel holds positive implications for promoting sustainable building practices and achieving economic benefits.

Table 3 Comparison between measured and calculated values of ultimate load, maximum displacement in midspan and strain.

| Specimen number | Measured value ① | | | | Calculated value ② | | | | Deviation (①-②)/① | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P_u$ (kN) | $\Delta_u$ (mm) | $\varepsilon_c$ ($\times10^{-6}$) | $\varepsilon_t$ ($\times10^{-6}$) | $P_u$ (kN) | $\Delta_u$ (mm) | $\varepsilon_c$ ($\times10^{-6}$) | $\varepsilon_t$ ($\times10^{-6}$) | $P_u$ | $\Delta_u$ | $\varepsilon_c$ | $\varepsilon_t$ |
| T-IBP | 38.7 | 25.1 | -5693.8 | 4424.9 | 38.5 | 25.2 | -5865.7 | 4235.3 | 0.5% | 0.4% | -3.0% | 4.3% |
| S-IBP | 22.5 | 14.7 | -2575.8 | 2580.3 | 23.5 | 15.3 | -2558.2 | 2549.8 | 4.4% | 4.0% | -0.7% | 1.2% |
| K-IBP | 27.5 | 16.8 | -3142.4 | 3124.5 | 27.0 | 17.0 | -3049.4 | 3004.5 | 1.9% | 1.0% | -3.0% | 3.8% |
| S-PBP | 47.0 | 42.0 | -11444.4 | 5793.0 | 46.9 | 41.2 | -10901.7 | 5567.1 | 0.2% | 1.9% | -4.7% | 3.9% |

Note: The measured values in the table are the average values under the bending test of the same group of specimens, $P_u$ is the ultimate load, $\Delta_u$ is the maximum displacement in the midspan, $\varepsilon_c$ is the compressive strain, and $\varepsilon_t$ is the tensile strain.

Table 4 Data Sheet of Stiffness and Strength of laminated bamboo sandwich panel

| Specimen number | Relative density($g\cdot cm^{-3}$) ① | Bending stiffness($kN\cdot m^2$) ② | Bending strength(MPa) ③ | Specific stiffness ($\times 10^{-3} kN\cdot m^5\cdot kg^{-1}$) ②/① | Specific strength ($kN\cdot m\cdot kg^{-1}$) ③/① |
|---|---|---|---|---|---|
| T-IBP | 0.30 | 45.7 | 7.3 | 149.9 | 24.1 |
| S-IBP | 0.26 | 40.6 | 4.3 | 157.5 | 16.6 |
| K-IBP | 0.29 | 43.1 | 5.2 | 146.1 | 17.7 |
| S-PBP | 0.26 | 40.6 | 8.9 | 157.4 | 34.6 |

## 5.Conclusions and Discussion

Based on the four-point bending tests and analysis of the laminated bamboo lattice sandwich panels, the following conclusions can be drawn.

1) The bending failure of the interlocking laminated bamboo lattice sandwich panels was governed by shear failure of the core layer. Shear cracks initiated near the neutral axis within the bending-shear span. In contrast, the partitioned square-lattice panel failed through compressive yielding of the upper face sheet and tensile rupture of the lower face sheet, exhibiting a brittle failure mode with no pronounced warning signs. During bending, the tension side of the laminated bamboo lattice sandwich panels remained linearly elastic, while the compression side showed elastic-plastic behavior as the load increased. The structural response was consistent with the plane- section assumption.

2) The geometric configuration of the core layer and the manufacturing method significantly influenced the bending performance of the laminated bamboo lattice sandwich panels. Among the three interlocking configurations, the triangular-lattice panel demonstrated the highest bending capacity, the square - lattice panel the lowest, with the Kagome-lattice panel performing between them. Compared with the square-lattice design, the ultimate load of the triangular and Kagome lattices increased by 71.9 % and 22.2 %, respectively. The triangular-lattice panel also exhibited the highest specific strength, exceeding that of the square and Kagome lattices by 45.5 % and 36.0 %, respectively. The partitioned square-lattice panel surpassed even the triangular-lattice panel in both bearing capacity and specific strength, with improvements of 21.6 % and 43.6 %, respectively, thereby more fully utilizing the mechanical potential of laminated bamboo.

3) The finite-element simulation results obtained with ABAQUS showed good agreement with the experimental data. The predicted values for ultimate load, maximum mid- span displacement, and peak tensile/compressive strain in the face sheets aligned well with the measured values, with relative errors below 5 %. This confirms that the modeling parameters for the laminated bamboo lattice-core sandwich panels are appropriate and that the simulation results are reliable.

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