

Bond Performance of Adhesively Bonding Interface of Steel-Bamboo Composite Structure

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Abstract: The steel-bamboo composite structure is a newly developed structure, combining phyllostachys pubescens (also called Moso bamboo) plywood and cold-formed thin-walled steel with structural adhesive. The reliability of steel-bamboo interface is the premise of composite effect. 13 specimens were prepared to investigate the failure modes and mechanism of the steel-bamboo interface on the basis of push-out test, and the strain difference analysis method was proposed to study the distribution of shear stress. The results show that the main failure modes of steel-bamboo interface are adhesion failure and splitting of bamboo plywood. The shear stress is not evenly distributed along the longitudinal direction of the interface, showing a shape of "larger at two ends and smaller in the middle". The lower end of the interface is the initial location of the interface failure and the shear stress concentration degree is positively correlated with the thickness of the externally bonded bamboo plate. The shear resistance of steel-bamboo interface can be enhanced by improving the adhesion between steel and structural adhesive and ameliorating the quality of bamboo products.

Keywords: Cold-formed thin-walled steel; bamboo plywood; strain difference; steel-bamboo interface; push-out test

1 Introduction

China is rich in bamboo plant resources and ranks first in the world in terms of bamboo species, planting area, storage volume and felling volume [1]. In recent years, more and more attention has been paid to the application of environment-friendly bamboo materials, which has the advantages of rapid growth, high yield, high strength, excellent rigidity, natural degradation and non-pollution when compared with traditional building materials. Xiao et al. [2], Huang et al. [3] and Li et al. [4] have systematically studied the mechanical properties of modified bamboo and a variety of modern bamboo structure building systems have been developed [5–10]. The application of bamboo in practical projects after reasonable design will help to promote green and sustainable development of construction industry [11].

In order to make a difference in the application status of bamboo in the form of raw bamboo or simple processing in the construction industry and to improve the additional value and technical content of bamboo,



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the steel-bamboo composite structure was proposed, which combined bamboo plywood and cold-formed thin-walled steel with structural adhesive. Components of steel-bamboo composite structure are characterized by flexible cross section, light weight and excellent mechanical properties. The composite building has the advantages of green, energy saving and good aseismic performance [12]. So far, a large number of experimental studies have been carried out on steel-bamboo composite components, including composite columns [13], composite beams [14,15], composite slabs [16,17], composite walls [18] and composite joints [19]. Results show that the reliable bonding between bamboo and steel is the basic premise of the composite effect of steel-bamboo composite structure, therefore, the research on shear stress of steel-bamboo interface is of great significance.

Both steel-bamboo composite structure and steel reinforced concrete (SRC) structure are modern composite structure. The bonding theory has always been an important research field of SRC structures, its research route and achievements have great reference significance for the study of steel-bamboo interface shear stress. Scholars represented by Bryson et al. [20] used push-out test and short column test to study the bonding performance between steel and concrete. It is found that the push-out test can better simulate the bond-slip stress state and more accurately measure the interfacial bonding strength [20]. Hawkins fabricated 22 specimens for push-out test, taking the steel section, concrete type and the degree of encasement for the steel section into consideration, then a procedure was proposed for predicting the behavior up to collapse of the beam [21]. Hamdan et al. [22] examined the effects of surface condition and transverse stirrup ratio on the bonding strength of steel reinforced concrete by push-out test, results showed that increasing the transverse stirrup ratio and sand blasting on the surface of the steel can significantly improve the bond strength of the steel reinforced concrete. Wium investigated the mechanism of force transfer from steel to concrete in composite columns by means of several tests on short composite columns, it is reported that shear resistance is closely related to the dimension of the embedded steel section [23]. Zhang has carried out a series of push-out test and short column test on the bond-slip behavior of steel reinforced high-strength concrete, showing that the bonding stress is exponentially distributed and the distribution in various parts of the cross section of steel is uneven [24]. Zhao has made a systematic and further study on the bond-slip problem of steel reinforced concrete, independently developed the built-in steel-concrete electronic slip sensor, which solved the difficult problem about the measurement of internal slip and obtained the position function which illustrates the local bonding stress-slip constitutive relationship [25,26]. Zheng carried out a large number of tests on bond-slip behaviors of SRC specimens, put forward the distribution characteristics, composition and transforming mechanism of the bond stress on the steel-concrete surface, which provide a theoretical basis for the numerical analysis of SRC composite structures [27,28].

In this paper, 13 specimens in 6 groups were designed and fabricated for the push-out test. The failure modes of steel-bamboo interface and the longitudinal strain distribution of specimen were analyzed, furthermore, on the basis of the strain difference method and data fitting, calculation methods of shear stress at the steel-bamboo interface and bearing capacity were established respectively.

2 Specimens and Loading

2.1 Specimens

To study the shear bonding properties of the steel-bamboo interface, it should be designed as close as possible to the pure shear stress state, therefore the push-out test is a preferable method to simulate this state [29]. When designing the test scheme, two problems need to be noticed: the thickness of the cold-formed thin-walled steel is relatively small, so it is prone to buckling easily under compression; the lower end of the specimen has a high local stress thus the premature failure of the material at the lower end should be avoided. After a series of scheme comparison, the structure of the push-out specimen is determined, shown in Fig. 1.





Thirteen specimens were designed and fabricated in the test. According to the different thickness of the bamboo plywood, they were divided into 6 groups, which are denoted as TZb, TZe, TZf, TZg, TZh and TZi, parameters of the specimens are shown in Tab. 1. The bonding interface is 500 mm in length and the short column is 100 mm higher at the top and 100 mm lower at the bottom than bamboo plywood C. In Fig. 1, the black solid line indicates two cold-formed thin-walled steel placed face to face. According to ISO 6892-1 "Metallic materials-Tensile testing-Part 1: Method of test at room temperature" and ISO 16978 "Wood-based panels-Determination of modulus of elasticity in bending and of bending strength", mechanical properties of the steel and bamboo plywood in the test were investigated. The inner dimension of the 2 mm thick steel is 120 mm \times 60 mm, and the modulus of elasticity and yield strength are 177 GPa and 260 MPa respectively.

The fabrication of the specimen is described as follows: first, the cold-formed thin-walled steel was bent into U shape and two pieces of bamboo plywood A were adhesively bonded to internal web surface of the U shape steel. Then, two pieces of bamboo plywood B were attached to the steel flanges to form the short column. Finally, two pieces of bamboo plywood C were respectively bonded to the external surface of the steel web and the lower end of the bamboo plywood C was reinforced to prevent compression failure.

Specimen	Quantity	Thickness of bamboo plywood A/B (mm)	Thickness of bamboo plywood C (mm)	Elastic modulus of bamboo plywood C (MPa)	Dimension of steel (mm)	Yield strength of steel (MPa)	Elastic modulus of steel (GPa)	Overlap length (mm)
TZb	3	26	26	6554	$120 \times 60 \times 2$	260	177	500
TZe	2	10	18	4931	$120 \times 60 \times 2$	260	177	500
TZf	2	10	22	9640	$120 \times 60 \times 2$	260	177	500
TZg	2	22	22	9640	$120 \times 60 \times 2$	260	177	500
TZh	2	18	22	9640	$120 \times 60 \times 2$	260	177	500
TZi	2	22	18	4931	$120 \times 60 \times 2$	260	177	500

Table 1: Parameters of specimens

Strain gauges were equally spaced on the surface of bamboo plywood C and bamboo plywood A at the corresponding positions.

The curing of the structural adhesive refers to the process in which the adhesive transforms from liquid state to solid state by applying certain pressure on the bonding surface under appropriate temperature for a period of time. Therefore, special attention should be paid during the specimen fabrication: (1) the structural adhesive should be applied at room temperature; (2) afterwards, a certain amount of heavy objects should be evenly placed on the steel-bamboo interface, however, they should not be too heavy or it may lead to excessive overflow of the internal colloid; (3) then, the specimen was stationary placed in the laboratory for 48 hours for curing. In addition, at the beginning of interfacial bonding, the surface of the thin-walled steel and bamboo plywood should be sanded and polished, then wipe the surface with anhydrous alcohol, which can not only make the surface of the two materials have a certain degree of roughness, but also remove surface pollutants and oxidation layer, so as to obtain good bonding effect. During the curing process, the structural adhesive is in a liquid state before cured, it is necessary to use clamps to fix the adherends on both sides of the adhesive, the fabrication process and the specimens are shown in Fig. 2.

2.2 Test Schemes and Test Contents

Test was carried out in the civil engineering laboratory of Ningbo University and the loading instrument was an electro-hydraulic servo universal testing machine, of which the hinged support end plate with automatic centering function was in contact with the upper end of the specimen, as the movable automatic centering base contacted the lower end. To prevent the specimen from unexpected falling during the test, iron blocks were arranged on both sides at the reinforced end of bamboo plywood C. The loading process was controlled by a computer that the load of each stage is increased by 10 kN and maintained for 3 minutes. The strain data were collected three times for every stage using DH3816 static strain testing system. Before the formal loading, a preloading of 5 kN was performed to check whether the instrument and equipment were all in a normal state.

3 Failure Modes of Specimens

According to references [30-34], there are four common modes of bonding failure: (1) adhesion failure, which occurs between adhesive layer and adherends; (2) cohesion failure, which happens inside the adhesive layer; (3) destruction of the adherends; (4) multiple failure, in which various failure modes are found simultaneously.



Figure 2: Fabrication process of specimens (a) Bonding of bamboo plywood A and steel (b) Bonding of bamboo plywood C and short column (c) Cross section of specimen (d) Completed specimens

On the basis of above-mentioned classification of bonding failure, there are two failure modes for steelbamboo push-out specimen, including adhesion failure and destruction of the adherends. Fig. 3a illustrates adhesion failure of specimen TZb-2, deformation of bamboo plywood C and short column were small in the initial loading stage, due to the limitation of bamboo plywood production technology, there was a certain



Figure 3: Failure modes of specimens (a) Adhesion failure (b) Destruction of the adherends

clearance between bamboo strands, which was gradually compacted with the increasing load. When the load increased to 80% of the ultimate load, obvious extrusion deformation was found at the lower end of bamboo plywood C accompanied with slight degumming sound. As the load was about to reach the ultimate load, two pieces of bamboo plywood C were progressively separated from the short column along with continuous degumming sound. Meanwhile, the short column finally fell to the ground as the load instantly attenuated to zero. The failure exhibited obvious brittle characteristics, and more adhesive remained on the surface of bamboo plywood C. Fig. 3b shows the destruction of the adherends in specimen TZf-1, which was caused by inadequate bearing capacity of the bamboo plywood. The preliminary experimental phenomena were similar to adhesion failure. When the load reached a certain value, longitudinal cracks appeared at the lower end of the bamboo plywood C. As the load increased, the crack developed continuously along the longitudinal direction until penetrating cracks were formed, which eventually results in the transverse connection failure.

4 Analysis of Bonding Shear Stress

To analyze the structure, the coordinates in Fig. 4 is built. The origin of the coordinate is set at the upper end of the bonding interface. The following assumptions are adopted in the analysis process:

- 1. Only axial compression deformation is considered for bamboo plywood C and short column.
- 2. In the pre-experiment, strain gauges are attached on the internal surface of the steel and the external surface of the bamboo plate A in short column, data of strain gauges at corresponding positions are highly consistent during the test. Thus, it can be concluded that the short column conforms to the plane section assumption.
- 3. According to references [34,35], only the longitudinal shear deformation is considered for the adhesive layer and the shear stress remains constant along the direction of thickness and width in the adhesive layer, while other factors are neglected.



Figure 4: Free body diagrams

Based on assumption Eq. (2), the composite elastic modulus E_{sc} of the short column can be expressed as

$$E_{sc} = E_s C_s + E_b C_b \tag{1}$$

where E_s and E_b are the elastic modulus of cold-formed thin-walled steel and bamboo plywood, C_s and C_b respectively represent the area proportion of thin-walled steel and bamboo plywood in cross section of the short column.

According to the analysis of the infinitesimal element shown in Fig. 4, the predict model of shear bond stress distribution can be derived as follows.

The equilibrium relationship between internal forces can be obtained according to Fig. 4.

$$N_c + \tau b \mathrm{d}x = N_c + \mathrm{d}N_c \tag{2}$$

$$N_{sc} = 2\tau b \mathrm{d}x + N_{sc} + \mathrm{d}N_{sc} \tag{3}$$

where N_c and N_{sc} are axial force of the bamboo plywood C and short column respectively. τ is the shear bond stress in the adhesive layer and b is width of the bamboo plywood C as well as the web height of the cold-formed thin-walled steel.

Then, the constitutive relationships can be expressed as

$$\varepsilon_c = N_c / (E_b A_c) \tag{4}$$

$$\varepsilon_{sc} = N_{sc} / (E_{sc} A_{sc}) \tag{5}$$

$$\tau = G \cdot \gamma \tag{6}$$

The longitudinal strains of bamboo panel C and the short column are denoted as ε_c and ε_{sc} respectively. The cross-sectional areas of bamboo panel C and the short column are presented as A_c and A_{sc} respectively. The shear elastic modulus is G and the shear strain of adhesive is γ .

Further, geometric relations can be expressed as

$$\varepsilon_c = \mathrm{d}u_c/\mathrm{d}x \tag{7}$$

$$\varepsilon_{sc} = \mathrm{d}u_{sc}/\mathrm{d}x \tag{8}$$

$$\gamma = s/\delta \tag{9}$$

$$s = u_c - u_{sc} \tag{10}$$

where u_c and u_{sc} are the longitudinal displacement of the bamboo plywood C and the short column at the same position on both sides of the interface, s is the relative displacement and δ is the thickness of the adhesive layer.

Define the strain difference function as

$$f(x) = \varepsilon_c - \varepsilon_{sc} \tag{11}$$

Substitution of Eqs. (7), (8) and (10) into Eq. (11) yields

$$f(x) = \mathrm{d}u_c/\mathrm{d}x - \mathrm{d}u_{sc}/\mathrm{d}x = \mathrm{d}s/\mathrm{d}x \tag{12}$$

Then, substitute Eqs. (6) and (9) into Eq. (12) to obtain the following expression:

$$f(x) = d(\tau \cdot \delta/G)/dx = (\delta/G) \cdot d\tau/dx = (1/k) \cdot d\tau/dx$$
(13)
where $k = C/\delta$

where $k = G/\delta$.

Further, taking derivative with respect to x in Eq. (13),

$$d^{2}\tau/dx^{2} = kdf(x)/dx = kd(\varepsilon_{c} - \varepsilon_{sc})/dx$$
(14)

Substitution of Eqs. (4), (5) into Eq. (14) yields

$$d^2\tau/dx^2 = k(1/E_bA_c \cdot dN_c/dx - 1/E_{sc}A_{sc} \cdot dN_{sc}/dx)$$
(15)

Substitution of Eqs. (2), (3) into Eq. (15) yields

$$d^{2}\tau/dx^{2} = kb\tau(1/E_{b}A_{c} + 2/E_{sc}A_{sc}) = kb\tau/EA$$
(16)

where $1/E = A/(E_bA_c) + 2A/(E_{sc}A_{sc})$ and $A = 2A_c + A_{sc}$.

The strain difference function f(x) in Eq. (13) is differentiated with respect to x to obtain:

$$df(x)/dx = (1/k) \cdot d^2\tau/dx^2 = (1/k) \cdot kb\tau/EA = b\tau/EA$$
(17)

Then, the general solution of Eq. (16) can be obtained

$$\tau = p_1 \exp(-vx) + p_2 \exp(vx) \tag{18}$$

where $v = \sqrt{kb/(EA)}$, p_1 and p_2 are undetermined parameters. Substitution of Eq. (18) into Eq. (13) yields

$$f(x) = \left[-p_1 \operatorname{vexp}(-vx) + p_2 \operatorname{vexp}(vx)\right]/k \tag{19}$$

To consider other influencing factors on the distribution of strain difference, the parameter q_4 is introduced. The dimensionless form of the strain difference function can be expressed as

$$f(x) = -q_1 \exp(-q_3 x/L) + q_2 \exp(q_3 x/L) + q_4$$
(20)

where $q_1 = p_1 v/k$, $q_2 = p_2 v/k$, $q_3 = v$.

According to the strains of the bamboo plywood C and the short column at the same longitudinal position measured in the experiment, the strain difference can be calculated. Meanwhile, the undetermined parameters q_1 , q_2 , q_3 and q_4 can be obtained through curve fitting, then the distribution of longitudinal shear stress can be obtained according to Eq. (13) or Eq. (17). However, considering the calculation error caused by derivation is smaller than that caused by integral, and the derivative calculation is more convenient, therefore Eq. (17) is adopted. Finally, the nominal shear bond stress $\bar{\tau}$ can be derived as

$$\bar{\tau} = k_1 \exp(-k_3 x/L) + k_2 \exp(k_3 x/L) \tag{21}$$

where $\bar{\tau} = \tau/\tau_m$, $\tau_m = N/(2bL)$, and N is the load applied on the top of the short column, k_1 , k_2 and k_3 are defined as characteristic coefficients of shear bond stress which can be expressed as $k_1 = 2q_1q_3EA/N$, $k_2 = 2q_2q_3EA/N$, $k_3 = q_3$.

Taking specimen in TZb group as an example, the process of solving shear bond stress by strain difference is explained in detail. The strain-load curves of bamboo plate C and the short column are shown in Fig. 5. The strain of the specimen basically shows a linear relationship with the load, indicating that the specimen can maintain a good linear elasticity throughout the whole loading process, which



Figure 5: Strain-load curves of specimen TZb-1 (a) strain-load curve of bamboo plywood C (b) strain-load curve of the short column

brings a certain convenience to the study of interfacial bonding properties that the plastic mechanical behavior of materials can be neglected.

The strain distribution curves of specimen TZb-1 at different load levels are shown in Fig. 6. Due to the existence of interfacial shear bond stress, strain of bamboo plywood C is smaller at the upper end and presents an increasing trend toward the lower end, which is consistent with the fact that the lower end contacts the loading plate while the upper end is free. However, the strain distribution characteristic of the short column is just on the contrary. The appearance of the strain distribution curve is similar to that of exponential curve, indicating that the distribution of shear bond stress at steel-bamboo interface is not uniform. For bamboo plywood C and the short column which only consider the axial compression deformation, distributions of strain, stress and the internal force are similar in curve characteristics, therefore the distribution of the strain can also reflect the distribution characteristics of the stress and the internal force.



Figure 6: Strain distribution curve of TZb-1 (a) Strain distribution of bamboo plywood C (b) Strain distribution of the short column

According to the measured strains along the longitudinal direction, the strain of bamboo plate C is subtracted from the strain of the short column at the corresponding position to obtain the strain difference at each measuring point, shown in Fig. 7. Further, a curve fitting with 4 undetermined parameters is performed according to Eq. (20). Then, the distribution of the nominal shear bond stress can be obtained by substituting it into Eq. (21).

Substitution of Eqs. (9) and (10) into Eq. (6) yields

$$\tau = G \cdot (u_c - u_{sc}) / \delta \tag{22}$$

Taking derivative with respect to x in Eq. (22),

$$d\tau/dx = G/\delta \cdot (\varepsilon_c - \varepsilon_{sc}) \tag{23}$$

It should be noted that the pressure is positive during the formula derivation, while the collected strains is specified to be negative, so that the formula and the strain difference are opposite in signs. It can be seen that the shear bond stress decreases gradually from the upper end of the interface to the middle, and increases gradually from the middle to the lower end.



Figure 7: Strain difference of TZb-1

Under the loads of 20 kN, 40 kN, 60 kN and 80 kN, the strain difference distribution curves and the fitting curve of specimen TZb-1 are shown in Fig. 8, among which the red line represents the fitting curve and the solid black line represents the strain difference distribution obtained by connecting the original data with smooth curves. Comparison shows that fitting curves are close to the test curves, which implies the fitting effect is desirable. The above is the whole fitting process of specimen TZb-1 and the analysis method of the remaining specimens is similar to this process.

Parameters q_i obtained by curve fitting are shown in Tab. 2, which were substituted into the expression to calculate the characteristic coefficients of shear bond stress k_i , it is found that the fluctuation of k_i values under various loads is relatively small. Therefore, the nominal shear stress distribution of specimens in TZb group can be obtained by taking the average value of k_i under various loads, shown in Fig. 9. As can be seen from the figure, the distribution of shear bond stress in TZb group is close to each other. The distribution of shear bond stress along the longitudinal interface is uneven, with obvious stress concentration at the end. The maximum stress is close to the lower end of bamboo plate C, while the stress value and variation range in the middle are relatively small. This also coincides with the fact that the failure begins near the lower end of the adhesive layer during the test.



Figure 8: Comparison of fitting curves and raw data of TZb-1

Table 2: Parameters of specimens TZb-1

Specimens	Load (kN)	$q_1(10^{-6})$	$q_2 (10^{-6})$	q_3	$q_4 (10^{-6})$	k_1	<i>k</i> ₂	<i>k</i> ₃
TZb-1	50	-175.43	-1.16	6.96	98.20	0.778	0.017	6.96
	60	-218.33	-1.51	6.89	114.44	0.776	0.012	6.89
	70	-262.84	-1.70	6.95	132.03	0.795	0.009	6.95
	80	-307.05	-2.02	6.94	156.01	0.799	0.011	6.94



Figure 9: Distribution of nominal shearing stress in TZb group

For specimens in group TZe, TZf, TZg, TZh and TZi, which includes two specimens in each group, taking the average strains of specimens in same group at the corresponding location to calculate the strain differences, as shown in Fig. 10. It can be concluded that the overall shape of the strain difference distribution is same, the maximum strain difference occurred at the lower end of the interface is greater than that at the upper end, and the middle area of the interface is the low stress area. According to the method mentioned above, the undetermined coefficient q_i and characteristic coefficient k_i are determined respectively. As shown in Fig. 11, the shear bond stress distribution of specimens in each group is



Figure 10: Strain difference of each group (a) Specimen in TZe group (b) Specimen in TZf group (c) Specimen in TZg group (d) Specimen in TZh group (e) Specimen in TZi group



Figure 11: Distribution of nominal shearing stress in each group

obtained and the shear stress concentration level is positively correlated with the thickness of the externally bonded bamboo plate.

5 Analysis of Bearing Capacity

In the above analysis, it can be seen that the stiffness of bamboo plywood C and short column is one of the influencing factors of shear stress distribution. So that the stiffness ratio of bamboo plate C and short column is defined as λ :

$$\lambda = 2E_b A_c / E_{sc} A_{sc} \tag{24}$$

As the distribution of shear stress is determined by the characteristic coefficient k_i , combined with the above analysis process, it can be found that the characteristic coefficient k_1 and k_2 is positively correlated with $1/\lambda$, while k_3 is positively correlated with $\sqrt{E_{sc}A_{sc}}$. Thus, characteristic coefficient k_i are fitted in the following forms:

$$k_1 = \exp(k_3)/r\lambda + s \tag{25}$$

$$k_2 = \exp(-k_3)/m\lambda + n \tag{26}$$

$$k_3 = w/\sqrt{E_{sc}A_{sc}} \tag{27}$$

where r, s, m, n and w are undetermined coefficients. Finally, characteristic coefficients are determined as follows:

$$k_1 = \exp(k_3)/8\lambda + 40 \tag{28}$$

$$k_2 = 15\exp(-k_3)/\lambda + 1 \tag{29}$$

$$k_3 = 32.6 / \sqrt{E_{sc} A_{sc}} \tag{30}$$

Divide both ends of Eq. (21) by $k_2 \exp(k_3 x/L)$ yields

$$\bar{\tau}/k_2 \exp(k_3 x/L) = k_1/k_2 \cdot \exp(-2k_3 x/L) + 1$$
(31)

Considering the maximum shear stress is located at the lower end of the interface where x=L, thus

$$\bar{\tau}_{\max}/k_2 \exp(k_3) = k_1/k_2 \cdot \exp(-2k_3) + 1$$
(32)

Substitution of Eqs. (28)-(30) into right side of Eq. (32) yields

$$\bar{\tau}_{\max}/k_2 \exp(k_3) = (\lambda+1)/30(4\lambda+20) + 1$$
(33)

Considering the first item of Eq. (33) is approximately equal to zero, then it can be simplified as

$$\bar{\tau}_{\max} = k_2 \exp(k_3) \tag{34}$$

Since $\bar{\tau} = \tau/\tau_m$, $\tau_m = N/(2bL)$, when $\bar{\tau}$ increased to its maximum value $\bar{\tau}_{max}$, the load N reached N_{max} , so that the bearing capacity N_{max} can be expressed as:

$$N_{\rm max} = 2bL(\lambda + 1)\bar{\tau}_{\rm max}/15\tag{35}$$

In Tab. 3, the theoretical bearing capacities of specimens in each group are calculated in accordance with Eq. (35), which agrees well with the experimental results.

Specimens	TZb	TZe	TZf	TZg	TZh	TZi
N _{max} (kN)	93.15	94.44	97.57	96.67	100.99	94.00
$N_{\rm exp}$ (kN)	130	110	120	130	100	80
$N_{\rm max/} N_{\rm exp}$	0.72	0.86	0.81	0.74	1.01	1.18

 Table 3: Theoretical and experimental bearing capacities

6 Conclusions

On the basis of the elasticity theory, a strain difference analysis method for solving the shear bond stress and a calculation method for bearing capacity are proposed. The following conclusions can be drawn from the study:

- 1. When the thin-walled steel and bamboo plywood are only sanded on the surface and bonded with structural adhesive, the failure of the interface exhibits obvious brittle characteristics. The main failure modes of steel-bamboo interface are the adhesion failure and the splitting of bamboo plywood along the longitudinal direction.
- 2. The shear bond stress distributes unevenly along the longitudinal direction. The stress value in the middle of the adhesive layer is small, and the value and variation range become greater at both ends. The maximum value occurred near the lower end of the adhesive layer, it is the position where failure initiates. Measures should be taken to strengthen the end of the interface in engineering application to improve the shear resistance of the interface.
- 3. The distribution pattern of shear bond stress is basically the same for specimens made of bamboo plywood and thin-walled steel with different thickness. The distribution of nominal shear stress at the end of the two groups is significantly different. The amplification effect of nominal shear stress at the end is positively correlated with the thickness of bamboo plywood C.
- 4. According to the failure phenomena of specimens and the distribution characteristics of interfacial shear stress, the shear resistance of steel-bamboo interface can be increased by improving the bonding performance between thin-walled steel and structural adhesives, and the quality enhancement of bamboo plywood is also effective. The failure of the steel-bamboo interface should be ductile, which can be achieved through the development and application of new structural adhesives, as well as the innovation of combination method for steel-bamboo interface.
- 5. A calculation method of bearing capacity is proposed on the basis of maximum shear stress. The calculated value is in good agreement with the experimental results, which also proves the validity of the calculation method for shear stress.

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