Connection Performance Examination of a New Bamboo-Oriented Strand Board Connector

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Bamboo-oriented strand board (BOSB) with superior physical properties can be used in the furniture industry to alleviate wood shortages. Two types of plug-in connectors were designed in this paper: a splint-type connector and V-type connector. By cantilever bending, corner tension, and compression tests of L-type corner joints of BOSB and wood-oriented strand board (WOSB), the connection performance of the new connectors and six typical connectors was compared. The new connectors function like clamps, do not require that a screw or bolt pass into or through the board, and can be assembled repeatedly. The V-type connectors were more suitable for BOSB, and the joints exhibited the highest ultimate bending moment values (133.9 N·m, 86.8 N·m, 117.7 N·m). The splint connectors were more suitable for WOSB and their ultimate bending moment values (57.1 N·m, 45.3 N·m, 61.3 N·m) were greater than the joints fixed by V-type connectors (50.4 N·m, 35.4 N·m, 46.1 N·m). The results revealed that the connector performance affects the joint strength and that different plates were suitable for different connectors. A joint failure analysis revealed two simple failure modes for the two new connectors.

Keywords: Bamboo-oriented strand board; Plug-in connector; Removable connector

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INTRODUCTION

Although China has a large wooden furniture industry, the lack of timber resources mainly limits wooden furniture development (Fu *et al*. 2017). Bamboo is the second largest forest resource. The species, area, and stock volume of bamboo forests in China are among the top in the world. Hence, China is recognized as the "bamboo kingdom". The short growth cycle of bamboo can alleviate the wood shortage problem (Biswas *et al*. 2011; Akinlabi *et al*. 2017; Bahari *et al*. 2017; Fu *et al*. 2017). Bamboo materials currently used for furniture production include round bamboo, bamboo-laminated timber, reconstituted bamboo lumber (Li 2001), bamboo plywood, *etc*. (Chaowana 2013), which are mainly processed from large-diameter moso bamboo. The bamboo utilization rate is less than 50% which means that there is a large resource waste. The process flow of bamboo-oriented strand board (BOSB) is similar to wood-oriented strand board (WOSB). It can be produced by subjecting bamboo waste to crushing, screening, drying, sizing, paving, and hot pressing (Sumardi and Suzuki 2013). Therefore, BOSB production can effectively improve the bamboo utilization rate. Meanwhile, BOSB density is 600 to 900 kg/m³ (Yong *et al*. 2018), which is 1.5 to 2 times that of WOSB (Chen *et al*. 2010). In addition, its elastic modulus, tensile strength, and hardness are notably greater than those of WOSB (Apriani 2012; Febrianto *et al*. 2012; Febrianto *et al*. 2015). Bamboo-oriented strand board is a reputable material for furniture because of its dimensional stability (Wan-Si and Huang 2007; Zhang and Du 2007). However, in contrast to WOSB, BOSB is a harder material, leading to facile tool breakage which makes it difficult to perform machining. Can a plug-in connector be specifically developed for a BOSB connection? The plug-in connection can reduce the plate processing steps, thereby reducing the processing difficulty and costs.

The structural strength of furniture considerably depends on the connector type, the connector material, and the connection form (Qiang 2008; Ratnasingam and Ioras 2013). Sadegh *et al*. (2012) have examined the effect of spline material and connection form on the strength of a medium-density fiberboard joint and report that different materials need different connection forms. Guo *et al*. (2019) have reported that the moment resistance capacity of BOSB members connected by a converse-spine nut joint is greater than the two-in-one and three-in-one connectors, while the moment resistance capacity of particleboard members connected by a converse-spine nut joint is less than the two-in-one and three-in-one connectors. This further demonstrates that connector types affect the strength of members and that different materials need to match different connectors. In addition, Dalvand *et al*. (2013) and Vassiliou and Barboutis (2005) have independently reported that the connector material and connection form affect the strength, force condition, and failure mode of the members. The plate is inserted into the connector by the plug-in structure (Seitz *et al*. 2003), which is fixed by friction between the connector and plate. Therefore, if the connector material and connection form cannot match the plate, it may cause damage to the plate surface and reduce the strength of the members.

Therefore, two new plug-in connectors were designed in this work: a splint-type connector and a V-type connector. Through a comparison between WOSB and six typical connectors, the strength and failure mode of the members were analyzed, which provided a research basis for the application of BOSB in the furniture industry.

EXPERIMENTAL

Materials

Two new connectors

The two new connectors used friction to fix the panel, and the bonding force between the connector and panel could be increased by the pressure applied on the panel surface (using bolts to tighten). Traditional connectors of furniture joints, such as two-in-one, three-in-one, and corner code, all need to drill holes, with embedded nuts or set screws inserted into the plate. Obviously, this complex process will reduce production efficiency and increase production costs. Not only that, these processing steps will also cause damage to the board, thus affecting the strength of the connection. The two new connectors used friction to fix the panel, and the bonding force between the connector and panel could be increased by the pressure applied on the panel surface (using bolts to tighten). Thus, through the application of two new connectors, there was no need to punch or screw, and the panel was not damaged. In addition, multiple disassembly and assembly processes could happen. Concurrently, the number of disassembly and assembly processes slightly affects the connection performance. The molds were made by 3D printing technology, and then new connectors were obtained by casting aluminum alloy with the molds.

Figure 1 shows the V-type connector dimensions. The V-type connector was mainly composed of a fixed screw and two V-type splints. To use the connector, the screw length was first adjusted according to the panel thickness, the panels were then placed between the two V-type splints, and the screw was finally tightened using the two V-type splints to clamp the panel.

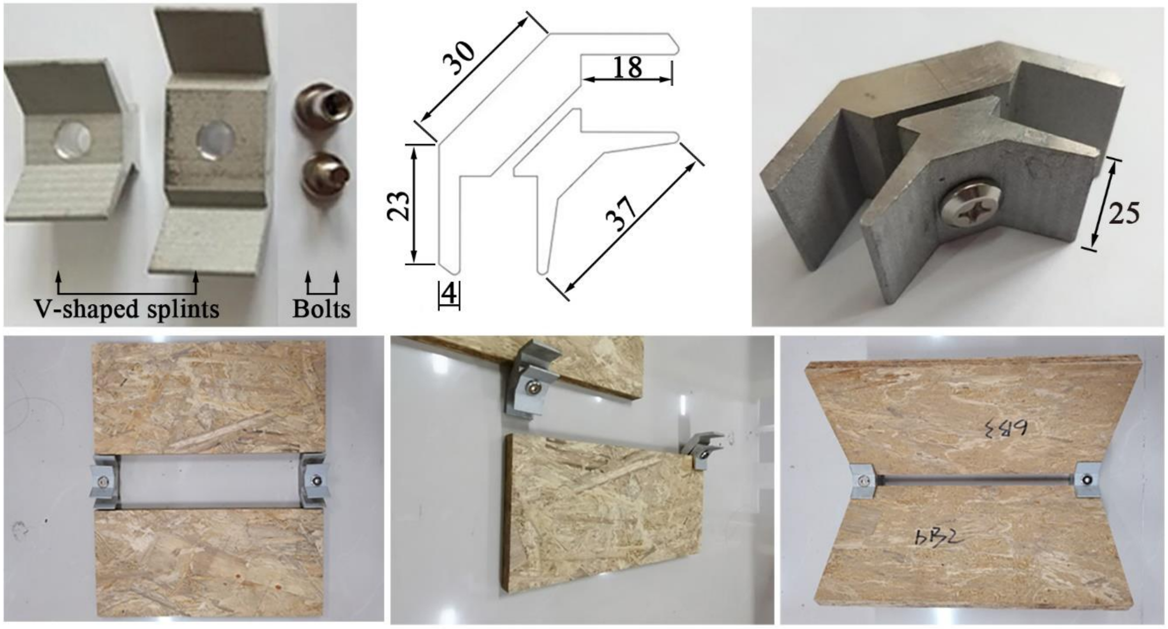

Fig. 1. V-type connector dimensions (mm) and installation modes

Figure 2 shows the splint-type connector. With an angle adjustment function, the connector mainly was composed of bolts, a central shaft, and splints. The bolts passed through the holes in the central shaft and head of the splints. The bolts were connected with a nut on the other side of the hole with a hexagon wrench to complete the splint pair assembly. Then, the same method was employed to assemble another pair of pliers. Notably, there was no need to completely tighten the bolts, thereby facilitating panel insertion. Finally, when the panel was inserted into the gap between the splint, the bolt was further tightened again with a hexagon wrench until the panel and splint-type connector were completely assembled.

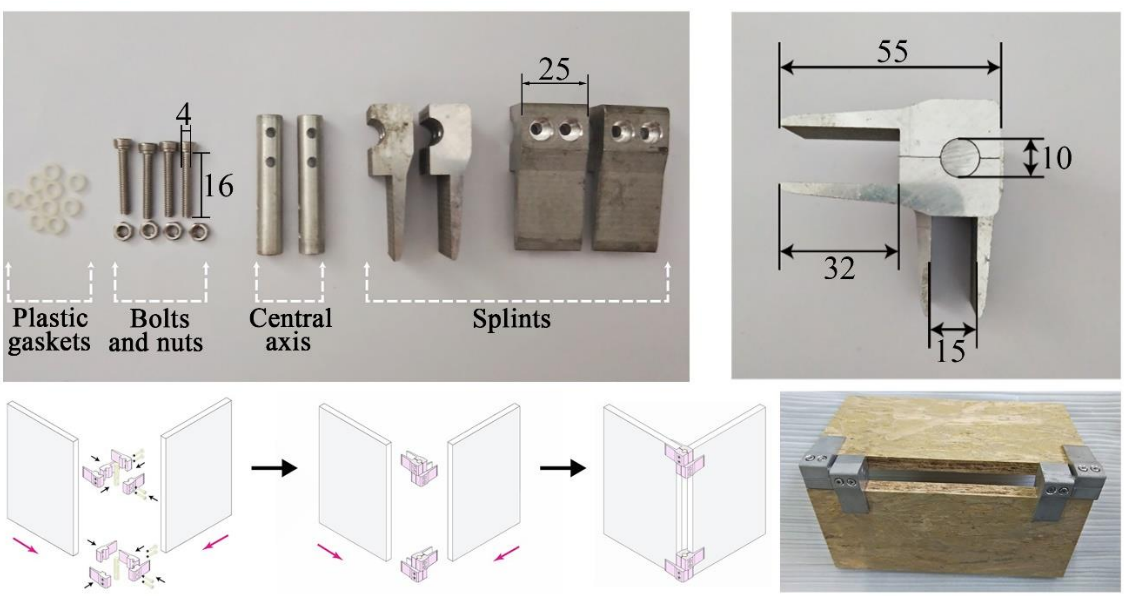

Fig. 2. Splint-type connector dimensions (mm) and installation modes

Common connectors

Six common connectors on the market were selected: a plastic buckle, three-in-one connector, transparent butterfly corner connector, two-in-one connector, wooden dowel pins, and a white corner connector. Figure 3 shows their dimensions.

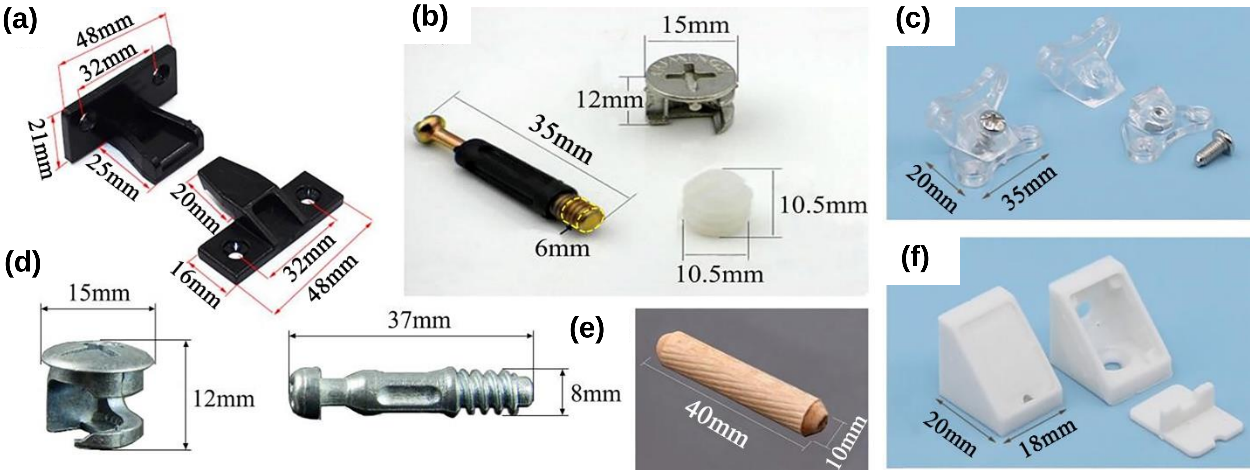

Fig. 3. Common L-type connectors: (a) plastic buckles; (b)three-in-one connectors; (c) transparent butterfly corner connectors; (d) two-in-one connectors; (e) wooden dowel pins; and (f) white corner connectors

Material properties

In this experiment, BOSB and WOSB were selected and provided by Yunnan Yonglifa Forestry Co., Ltd. (Dehong, China) and Beixin International Wood Industry Co., Ltd. (Beijing, China), respectively. Studies of elastic properties and moisture content of wood-based composites were carried out in accordance with standard requirements [EN-322 1993; EN-323 1993; ASTM D 1037 1993]. Table 1 lists the basic physical and mechanical indexes of BOSB and WOSB.

Table 1. Basic Physical and Mechanical Indexes of BOSB and WOSB

Type	Density (g/cm^3)	Water Content (%)	Elastic Modulus (MPa)	Static Bending Strength (MPa)
BOSB	0.8	12.71	12811	107.56
WOSB	0.55	7.2	1624.12	12.85

Preparation of L-type test samples

Table 2 lists the size and quantity of the test samples.

Table 2. Size and Quantity of the Test Samples

Connector Types	L-type Cantilever Bending Test Samples		Corner Tension and Compression Test Samples	
	Size/mm	Quantity	Size/mm	Quantity
Six Common Connectors	150 × 270 × 15	60	150 × 270 × 15	120
Splint-type Connectors	157.3 × 270 × 15	10	127.3 × 270 × 15	20
V-type Connectors	156.5 × 270 × 15	10	126.5 × 270 × 15	20
Note: Five groups of repeated samples were used in this experiment; BOSB and WOSB panels were used in this experiment; and the same size and quantity of the test samples were utilized in the corner tension and corner compression tests.				

In relation to the different connectors, the drilling position of the test samples and installation position of the connectors were different. Figure 4 shows the installation hole position and size of the wooden dowel pins. The wooden dowel pins had to be coated with white latex in the hole during installation. The connectors were installed at room temperature, and had to be placed at room temperature for 1 week after installation.

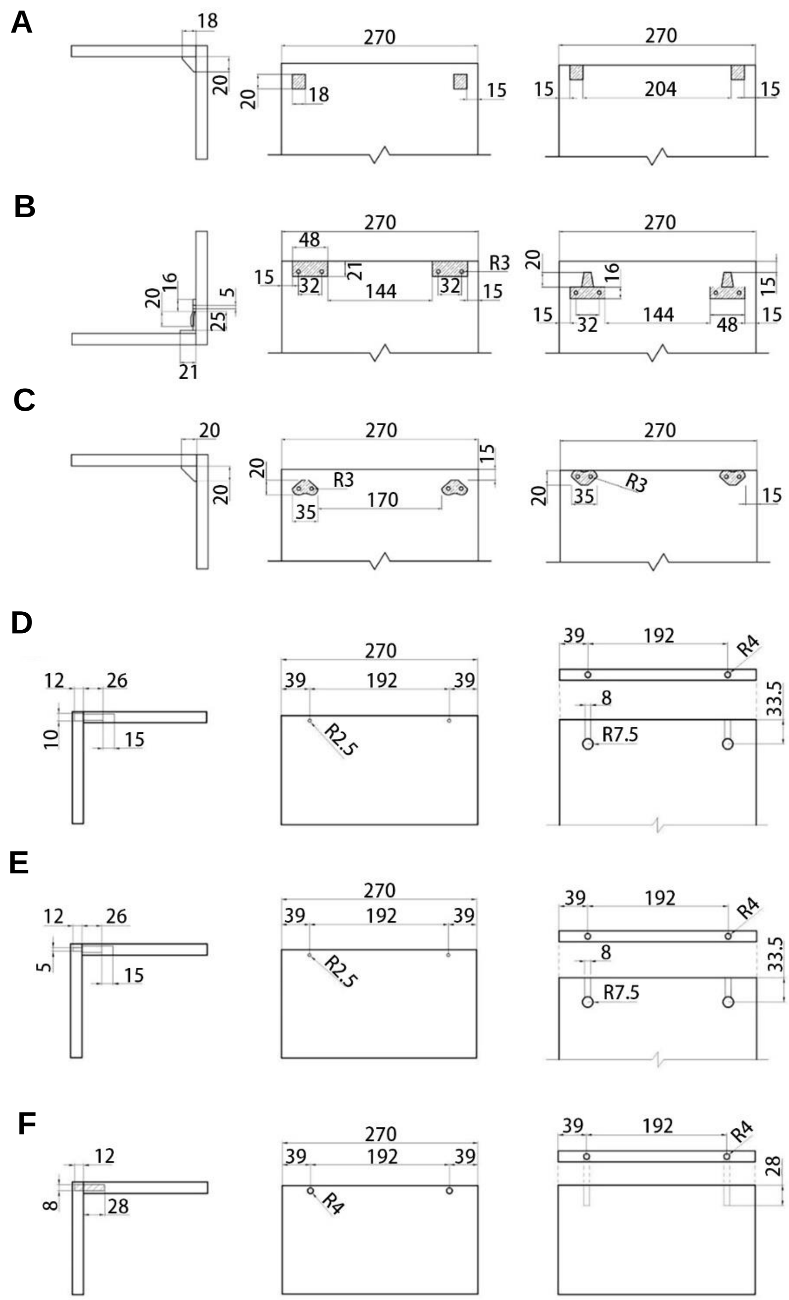

Fig. 4. Common connectors position and size (mm): A-white corner connectors; B-plastic buckles; C-transparent butterfly corner connectors; D-three-in-one connectors; E-two-in-one connectors; and F-wooden dowel pins

Methods

Cantilever bending test

The universal strength testing machine (Model WDW-100E, Jinan Chenda Testing Machine Manufacture Co., Ltd., Jinan, China) was employed to perform cantilever bending tests at a loading speed of 5 mm/min to obtain the maximum load (Derikvand and Ebrahimi 2014; Yildirim *et al*. 2015) (Fig. 5). The load measurement accuracy was 0.01 N, while the displacement measurement accuracy was 0.01 mm, respectively. The room temperature and relative humidity were 25 to 30 °C and 35 to 45%, respectively. The cantilever ultimate bending moment was calculated in Eq. 1,

$$M = P_{max} \times L \tag{1}$$

where M represents the ultimate bending moment (N·m), P_{max} is the ultimate load (N), and L is the cantilever length (m).

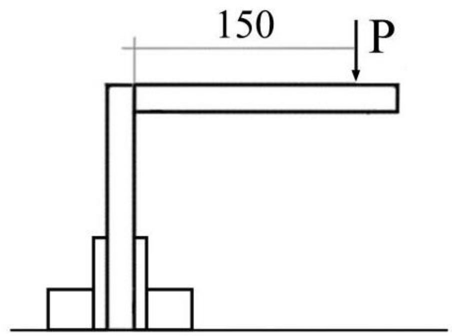

Fig. 5. Loading mode of the samples (mm)

Corner tension and compression tests

A mechanical testing machine (model: WDW-100E, Jinan Chenda Testing Machine Manufacture Co., Ltd., Jinan, China) was employed for loading at a speed of 5 mm/min (Fig. 6).

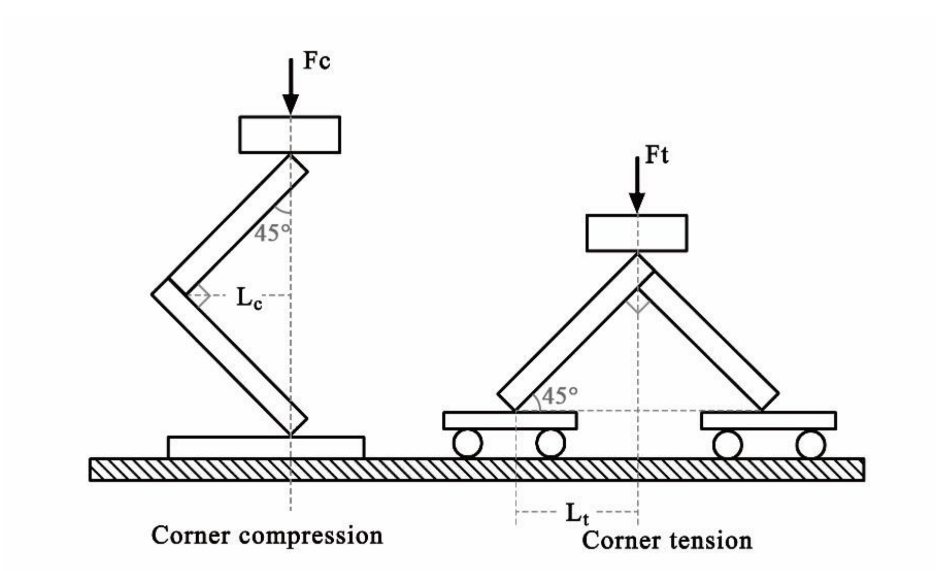

Fig. 6. Loading mode of the samples: (a) corner compression and (b) corner tension

After the load reached the peak value, the machine continued to press down until the load decreased to 80% of the maximum load, and the test stopped (Šimek and Koňas 2012; Smardzewski *et al.* 2017; Podskarbi and Smardzewski 2019). The bending moment was calculated in Eqs. 2 and 3;

$$M_c = F_c L_c \quad (2)$$

$$M_T = 0.5 F_t L_t \quad (3)$$

where M_c is the bending moment resistance of the joint under compression loading (N·m), M_T is the bending moment resistance of the joint under tension loading (N·m), P_{max} is the maximum load in each test sample (N), L_c is the moment arm in compression (m), and L_t is moment arm in tension (m).

RESULTS AND DISCUSSION

Bending Moment

Cantilever bending

The variance analysis results in Table 3 confirmed an important difference between the cantilever ultimate bending moments of the eight connector types. Figure 7 shows the cantilever ultimate bending moments for the eight joints. Under a cantilever bending load, the ultimate bending moment of the joints fixed by the two new connectors was considerably greater than those with the other common connectors. The ultimate bending moment of the BOSB members fixed by the V-type connectors was 133 N·m, which was greater than the BOSB members fixed by the splint-type connectors. However, the ultimate bending moment of the WOSB members fixed by the V-type connectors was less than those fixed by the splint-type connectors, indicating that the splint-type connectors were more suitable for fixing WOSB, while V-type connectors were more suitable for fixing BOSB. This result was possibly related to the larger friction and larger contact area between the splint-type connectors and WOSB. In addition, after the cantilever compressions, the joints fixed by the splint-type connectors failed due to connector deformations, and the joints fixed by the V-type connectors failed due to the panel breaking. Therefore, when V-type connectors were used for BOSB, the connection strength was greater than the splint-type connectors. This result also suggested that the strength of the V-type connectors was greater than the splint-type connectors.

Table 3. ANOVA Results of Cantilever Bending Moment of Joints

Material	Variance Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Level of Significance
BOSB	Between Groups	53500.966	7	7642.995	1107.450	0.000
	Within Groups	200.142	29	6.901		
	Total	53701.108	36			
WOSB	Between Groups	9520.889	7	1360.127	114.235	0.000
	Within Groups	357.191	30	11.906		
	Total	9878.080	37			

Among the six common connectors, the two-in-one connectors exhibited the highest cantilever ultimate bending moment, followed by the wooden dowel pins. The cantilever ultimate bending moments of the BOSB and WOSB members fixed by the two-in-one connectors were

36.3 N·m and 17.1 N·m, while those of the BOSB and WOSB members fixed by the V-type connectors were roughly 3.7 and 2.9 times the aforementioned values. Compared to the common connectors on the market, the two new connectors designed herein were more suitable for connecting BOSB and WOSB.

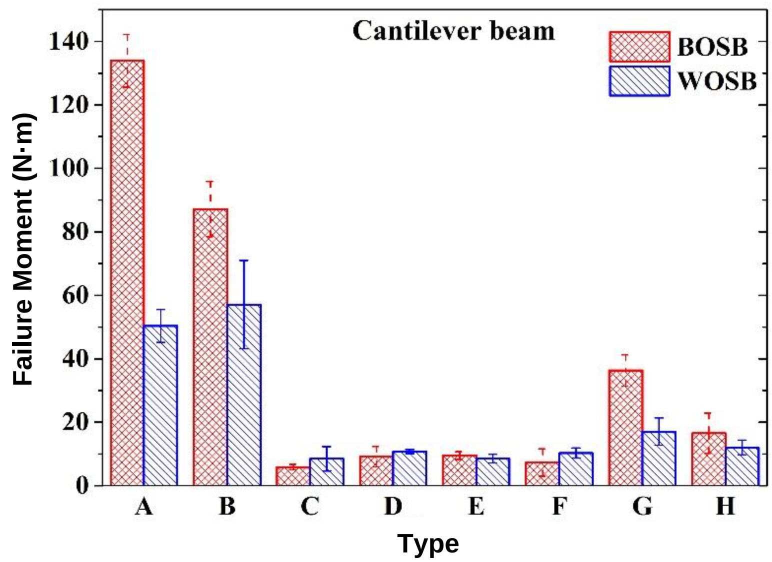

Fig. 7. Ultimate bending moment of L-type members under cantilever bending load: A-V-type connectors; B-splint-type connectors; C-plastic corner connectors; D-plastic buckles; E-butterfly corner connectors; F-three-in-one connectors; G-two-in-one connectors; and H-wooden dowel pins

Corner compression

Figure 8 shows the ultimate bending moment for OSB members subjected to inward compression.

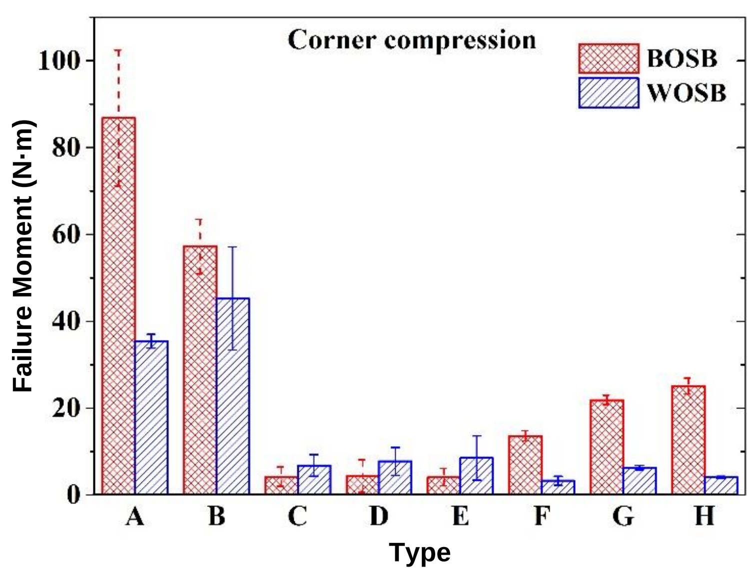

Fig. 8. Ultimate bending moments of L-type members under compression: A-V-type connectors; B-splint-type connectors; C-plastic corner connectors; D-plastic buckles; E-butterfly corner connectors; F-three-in-one connectors; G-two-in-one connectors; and H-wooden dowel pins

The comparison of Figs. 7 and 8 revealed that the inward compression moment of the member fixed by the new connectors was considerably less than the tension compression and cantilever compression. However, the change rule for the ultimate moment under inward compression was similar to that under cantilever bending. For example, the ultimate bending moments of the two new connectors were considerably greater than the common connectors, and the ultimate bending moment for the BOSB joints was greater than the WOSB joints. Moreover, the ultimate moments of the joints under inward compression for the BOSB members fixed by the two new connectors were greater than 57 N·m. This value was 2.3 to 14 times that of BOSB members fixed by common connectors.

In addition, the ultimate moments of joints under inward compression for those fixed by the six common connectors exhibited a slight difference. Among them, the ultimate moments of joints under inward compression for the WOSB members fixed by the plastic corner connectors, plastic buckles, and butterfly corner connectors were greater than the BOSB members. The ultimate moments of joints under inward compression for the WOSB members fixed by three-in-one connectors, two-in-one connectors, and wooden dowel pins were less than the BOSB members. Moreover, the variance analysis results also revealed notable differences between the ultimate moments of joints under inward compression for the different connectors (Table 4). This result suggested that different materials require different connectors and that the connector and connection strength between connectors and panels considerably affects the joint strength.

Table 4. ANOVA Results of Ultimate Moments of Joints under Inward Compression

Material	Variance Source	Sum of Squares	df	Mean Square	F	Level of Significance
BOSB	Between Groups	29042.112	7	4148.873	208.212	0.000
	Within Groups	557.934	28	19.926		
	Total	29600.046	35			
WOSB	Between Groups	10400.643	7	1485.806	73.370	0.000
	Within Groups	546.774	27	20.251		
	Total	10947.418	34			

Corner tension

Figure 9 shows the ultimate bending moment under tension for the OSB members. The ultimate moments under tension for the BOSB and WOSB members fixed by the two new connectors (except for WOSB members fixed by V-type connectors) were greater than the six common connectors. Notable differences among the eight connector types were observed (Table 5). In addition, compared to the results of inward corner compression tests, the ultimate bending moment under tension load was higher.

For BOSB, the joints fixed by V-type connectors exhibited the best load-bearing capacity, and their tension ultimate bending moment was 2.7 to 5.8 times that of the other six common connectors. The second was the splint-type connector, where the tension ultimate moment was 1.8 to 4 times those of the six common connectors. Among the six common connectors, the connection performance decreased in the order of wooden dowel pins, transparent butterfly corner connectors, white corner connectors, plastic buckles, three-in-one connectors, and two-in-one connectors. Experimental results revealed that the V-type connectors and splint-type connectors designed herein were completely suitable for the existing OSB on the market, and their load-bearing capacities under tension and cantilever loading are meaningfully better than most other common connectors. Hence, the two new connectors could better guarantee the stability and safety of the joints.

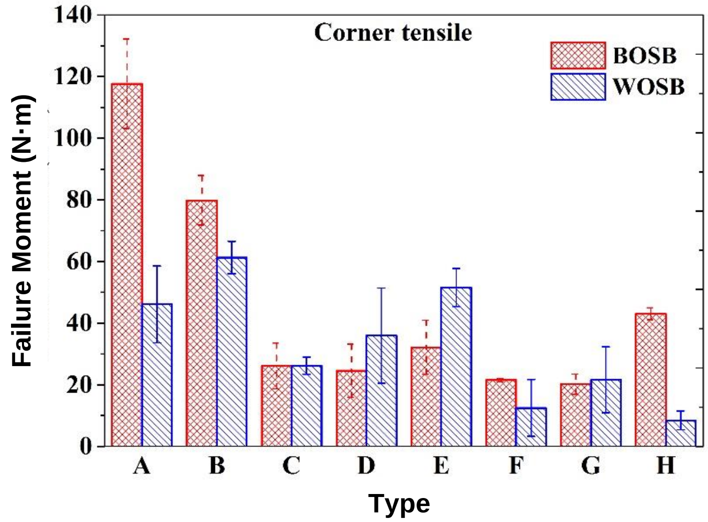

Fig. 9. Ultimate moments under tension load for L-type members: A-V-type connectors; B-splint-type connectors; C-plastic corner connectors; D-plastic buckles; E-butterfly corner connectors; F-three-in-one connectors; G-two-in-one connectors; and H-wooden dowel pins

Table 5. ANOVA Results of Tension Bending Moment of Joints

Material	Variance Source	Sum of Squares	df	Mean Square	F	Level of Significance
BOSB	Between Groups	21456.583	7	3065.226	325.771	0.000
	Within Groups	263.456	28	9.409		
	Total	21720.040	35			
WOSB	Between Groups	6065.487	7	866.498	240.823	0.000
	Within Groups	97.148	27	3.598		
	Total	6162.635	34			

Failure Modes

Figures 10 through 12 show the fracture morphology photographs of furniture joints under cantilever bending load, inward compression, and outward tension. Generally, WOSB joint deformation was clearer than BOSB mainly because the mechanical strength of WOSB was less than BOSB, and the load it could bear was smaller. The panels of WOSB members fixed by the splint-type connectors exhibited clear cracks and delamination (Figs. 10a, 11a, and 12a). The panels of BOSB members fixed by the splint-type connector were slightly deformed, as well as the connector splints, and the panel surface where the connectors were fixed was damaged due to friction (Figs. 10b, 11b, and 12b). During the loading process, the failure of WOSB members fixed by the splint-type connectors was caused by the panel fracture, and the failure of BOSB members fixed by the splint-type connectors was caused by the connector deformation. However, the splint-type connector deformation in the BOSB joints was more serious than in the WOSB joints because the BOSB joints fixed by the splint-type connectors exhibited a higher ultimate bending moment. The splint-type connector deformation was more serious, which also indicated that the strength of the panel and connector, as well as their connection strength, affect the connection performance of furniture joints. Therefore, connectors with a similar panel strength should be selected for furniture use.

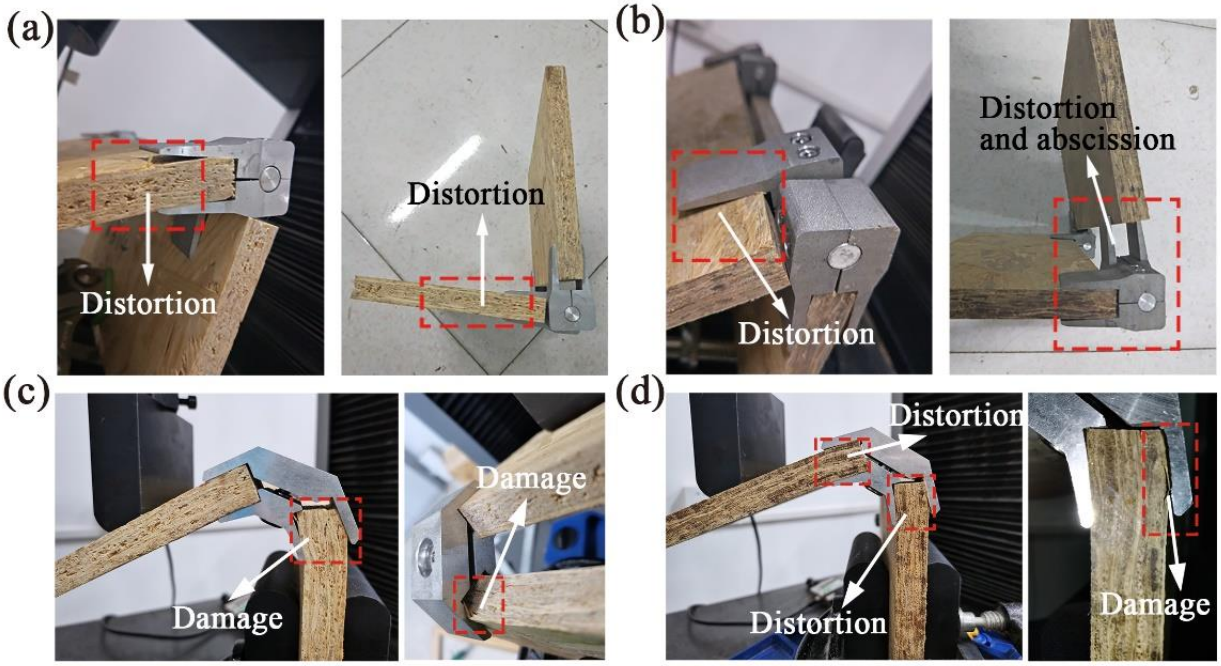

Fig. 10. Cantilever bending modes at failure for the joints fixed by new connectors : (a) WOSB members fixed by splint-type connectors; (b) BOSB members fixed by splint-type connectors; (c) WOSB members fixed by the V-type connectors; and (d) BOSB members fixed by the V-type connectors

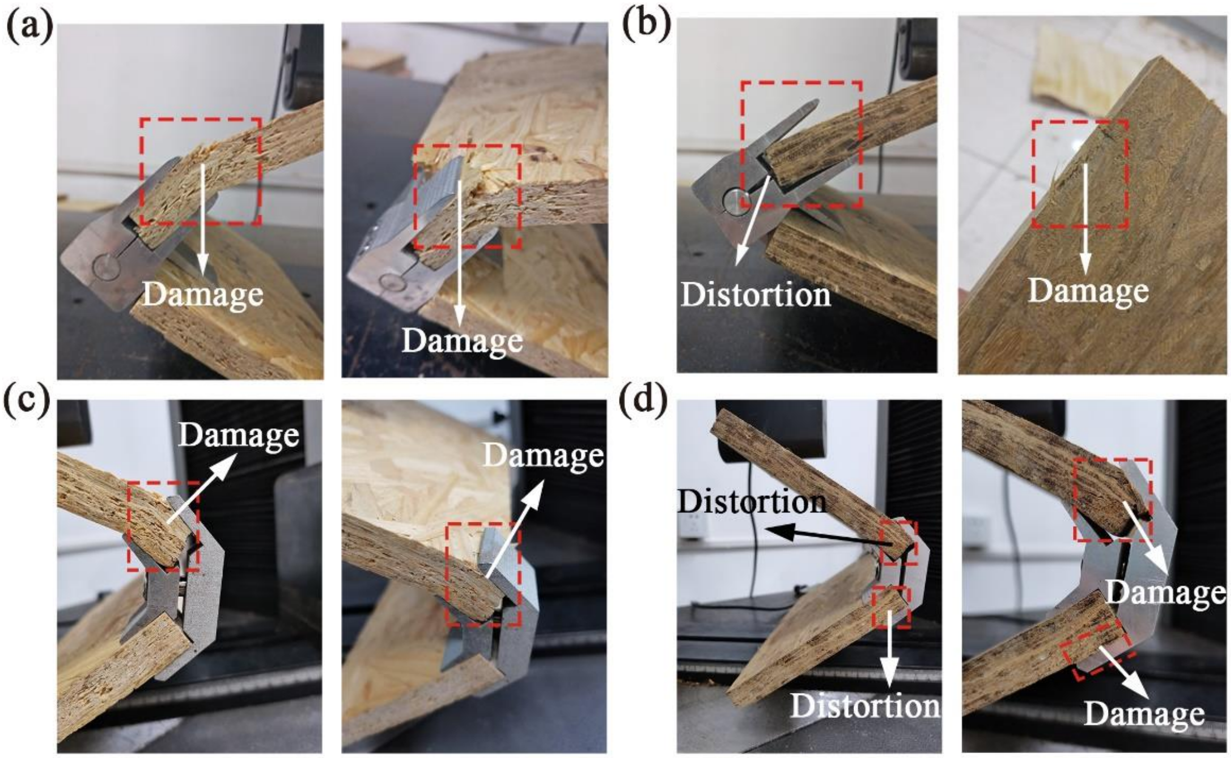

Fig. 11. Inward compression mode at failure for the joints fixed by new connectors: (a) WOSB members fixed by splint-type connectors; (b) BOSB members fixed by splint-type connectors; (c) WOSB members fixed by the V-type connectors; and (d) BOSB members fixed by the V-type connectors

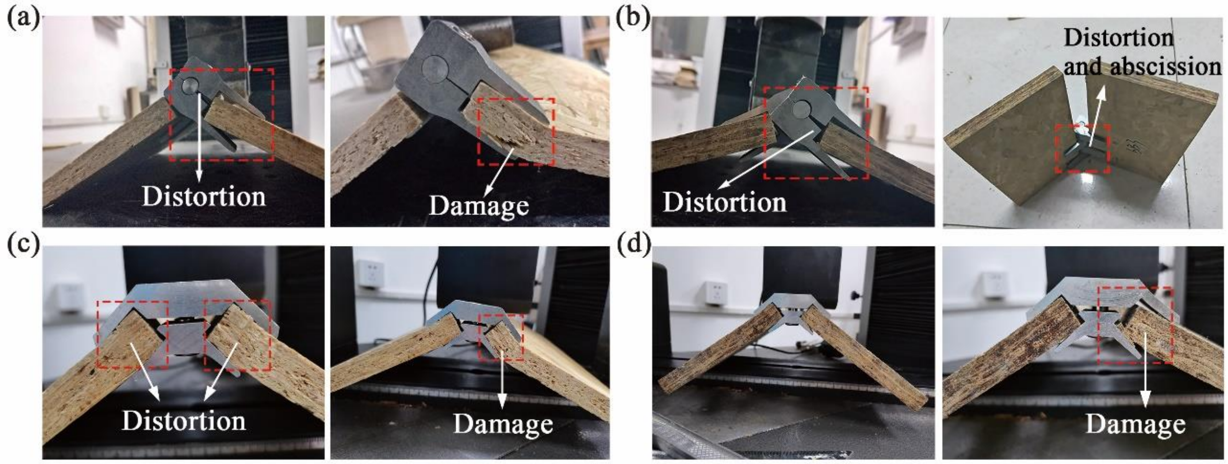

Fig. 12. Tension failure mode of the joints fixed by new connectors: (a) WOSB members fixed by splint-type connectors; (b) BOSB members fixed by splint-type connectors; (c) WOSB members fixed by the V-type connectors; and (d) BOSB members fixed by the V-type connectors

Under the bending load, the panels of the WOSB members fixed by the V-type connectors were severely deformed, and the connection was broken and led to joint failure. In addition, the end of the BOSB members fixed by the same connector was deformed, and the bamboo shavings of the panel contact part fell off due to friction and led to panel cracks (Figs. 10d, 11d, and 12d). This phenomenon further illustrated the importance of the joint strength. The panel strength itself was extremely important because a stronger panel had less damage. As shown in the above figures, BOSB exhibited low deformation, but the connector exhibited large deformation, which resulted in the panel falling off. This result indicated the importance of compatibility between panels and connectors. High-strength panels should match high-strength connectors, while low-strength panels should match low-strength connectors. Thus, joint failure caused by the interaction of connectors and panels can be avoided.

The comparison of the damage in the two panel types revealed that when fixing BOSB, compared to the V-type connectors, the splint-type connectors were more prone to deformation and that the connection strength of the V-type connectors was better than the splint-type connectors. Therefore, V-type connectors were more suitable for BOSB. In addition, the connection strength of furniture joints was affected not only by the connection strength between the connectors and panels, but also by the strength of the connectors. Therefore, during furniture design, matching connectors should be selected according to different materials to obtain the best combination, to maximize the load-bearing capacity of the joints, and to ensure stability and safety.

CONCLUSIONS

1. The connection performance for fixing bamboo oriented strandboard (BOSB) and wood oriented strandboard (WOSB) for the two developed plug-in connectors was far better than the common connectors examined. Among the six common connectors, the connection performance of the two-in-one connectors and wooden dowel pins was better than the other connectors, and the bending moment of the BOSB members was greater than the WOSB members.
2. The connection performance comparison between the two new connectors revealed that the V-type connectors were more suitable for BOSB. Their ultimate moment under cantilever

bending (133.9 N·m), inward compression (86.8 N·m), and outward tension (117.7 N·m) were greater than those of the splint-type connector, and the values were approximately 3.7 times those of the two-in-one connectors. The splint-type connector was more suitable for WOSB, and its ultimate bending moment (57.1 N·m, 45.3 N·m, 61.3 N·m) was considerably greater than the V-type connectors (50.1 N·m, 35.4 N·m, 46.1 N·m, respectfully).

3. Simple bending failure modes of BOSB and WOSB joints fixed by the two new connectors were observed. Failure of the WOSB joints was mostly caused by panel failure, while failure of the BOSB joints was caused by connector deformation, panel bending deformation, and separation of surface shavings. Moreover, the deformation resistance of V-type connectors was greater than the splint-type connectors.
4. The connection strength of the furniture joints was affected not only by panel strength, but also by the connector type and its own strength. For manufacturing furniture, suitable connectors should be selected according to material properties to improve furniture stability.

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