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CONTRASTIVE ANALYSIS OF SCREW WITHDRAWAL RESISTANCE BETWEEN BAMBOO ORIENTEDSTRANDBOARD AND CONVENTIONAL PARTICLEBOARD

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ABSTRACT

Effects of screw diameter, pilot hole diameter, and material's anisotropy on the withdrawal resistance of bamboo oriented strand board (BOSB) has been evaluated and the results has been compared with conventional particleboard (CPB). Results indicate that the effects of screw diameter on the face withdrawal resistance in BOSB have significant differences, whereas the edge withdrawal resistance was not. In contrast, the effect of screw diameter on face and edge withdrawal resistance in CPB has been statistically significant difference. The effect of pilot hole diameter on the face and edge withdrawal resistance both in BOSB and CPB has significant difference, the withdrawal resistance decreased as related to increasing pilot hole diameter. Furthermore, the withdrawal resistance in BOSB is anisotropic, whereas the relative superiority is sorted by the face, edge and end in turn. In addition, the withdrawal resistance in BOSB was much higher than CPB in all directions.

KEYWORDS: Oriented bamboo particleboard, withdrawal strength, screw diameter, pilot hole diameter, anisotropy.

INTRODUCTION

Bamboo is an important non-wood forest resource, widely distributed in the world, known as "the world's second largest forest"(Wang et al. 2006). There are more than 70 genus of bamboo plants in the world, more than 1,200 species (Zehui 2007), mainly distributed in the tropical and subtropical regions of 46° latitude to 47° latitude, and few bamboo species are distributed in temperate and chill regions. The World bamboo producing areas can be divided into Asia-Pacific Bamboo region, American Bamboo region, African Bamboo region and European and North American region (Lobovikov et al. 2007). Bamboo are plants that can affect the daily life of residents and have multi-objective functions. It is of great significance in soil and water conservation, environmental protection and tourism development. Furthermore, bamboo has a short growth cycle that can be maturity in 3-5 years as compared to wood which takes almost more than 20 years (Khalil et al. 2012). In addition, the mechanical properties of maturity bamboo are comparable to wood. Therefore, bamboo is an important non-wood forest resource that can replace wood in many applications, and has become recognized as a green low-carbon industry. At present, bamboo is widely used in construction, transportation, furniture, gardens, paper, chemical industry, textiles, handicrafts and many other areas (Li et al. 2016).

Currently, the contradiction between the effective supply of forests and the growing social needs remains outstanding. Timber dependence is close to 50% in China (Data from China Forestry Database), wood safety situation is grim. Simultaneously, the fragile situation of forest ecosystem has not yet fundamentally changed, and the shortage of ecological products is still a prominent problem that restricts the sustainable development. In contrast, China is one of the world's bamboo distribution center, is the most abundant bamboo species, the most widely distributed countries (FAN et al. 2004). Bamboo's planting area more than 6million hectares and the production up to 222,439 million trees (large diameter bamboo) (Data from China Forestry Database). In recent years, the steady development of bamboo industry in China has proved the importance in ecological construction, ecological security and ecological civilization. The production of bamboo oriented strand board (BOSB) is the efficient use of bamboo resources in one aspect, which can be used in construction, packaging, furniture (including flooring, doors, and windows), and the automotive industry. It is well known that particleboard is a pillar of wood-based panel industry. China's particleboard production in the year of 2014 was 2,875,300 cubic meters, whereas non-wood particleboard production of 349,300 cubic meters (Data from China Forestry Database). It can be seen that the use of bamboo to produce particleboard is still very little, with great potential for growth, especially in BOSB. However, in order to evaluate whether a new material has a development prospect, whether it can be widely applied, but also need to test and analysis the material's performance in many aspects, such as mechanical strength, decorative, environmental friendly, security.

Screw withdrawal resistance as an evaluation index of the mechanical properties of BOSB, has an important guiding significance so as to achieve the efficient use of BOSB in many fields. The relative superiority of screw withdrawal resistance determines the connection performance of the BOSB. As written in APA (Williamson 2002), a chain is only as strong as its weakest link, and connections are the critical link between elements of a structure. Properly design and detailed connectionsare the guarantee of structural integrity, and provide the load path continuity. The designer needs to understand some fundamental principles associated with connections for wood structures. While ignoring the importance of proper connection details, structure failure occurs (Celebi and Kilic 2007). In fact, studies have shown that there are many parameters that affect the screw withdrawal resistance of the material, including material type, screw type, screw diameter, pilot hole diameter and depth, and the penetration depth (Eckelman 1974, Eckelman and Martin 1980, Eckelman 1975, 1988, 2003, Eckelman and Erdil 2000, Özçifçi 2009, Semple and Smith 2007, Tankut 2006). The withdrawal resistance of various screws in wood plastic composites (WPC) increases as screw diameter, loading rate and penetration depth increase, and there were no significant differences between different types of screw (Haftkhani et al. 2011a). In addition, for a given diameter of screw, the lateral resistance of joint increases with the increase in end distance, joint member's thickness, pilot hole diameter and loading rate (Haftkhani et al. 2011b). As reported, the use of pilot holes of the proper diameter significantly increases the holding strength of large-diameter sheet metal screws in the face and edge surfaces of medium density fiberboard and particleboard. In general, pilot holes should be equal to about 80%-85% of the root diameter of the screw (Eckelman 1988, Özçifçi 2009, Rajak and Eckelman 1993). Screwed comer joint became stronger as either screw diameter or screw length or number of screws was increased, whereas screw length has a larger influence on bending moment resistance than screw diameter (Kasal et al. 2008). In another interesting study (Smardzewski et al. 2015), the authors found that the strength of screw joints depended on the total area of pressure and shear, which depended on the screw thread diameter, number of coils as well as coil inclination angle in turn. In addition, as the density, internal bond strength (IB), and fiber orientation to particleboard, shear strength parallel to the grain in solid wood will also impact the withdrawal resistance of the material. The shear strength parallel to grain is a better predictor of holding strength in solid wood than specific gravity, whereas the specific gravity is a good indicator of holding strength in particleboard (Eckelman 1975). In addition, there was a linear relationship between withdrawal strength of nails and the specific gravity, and the withdrawal resistance increased with increasing specific gravity values (Cassens and Eckelman 1985).

Screw connection as an important part of the joints in furniture and structure, whereas joints are the weakest parts of furniture and structure. Therefore, the design and determination of screw withdrawal resistance in wood-based materials is held to be of especially importance because the fasteners are inserted in the middle layer of panels where the holding strength of the boards is presumably the lowest and the most variable strength (Rajak and Eckelman 1993). Consequently, the effect of screw type, screw diameter, and material's anisotropy on screw withdrawal resistance in BOSB has been investigated. Simultaneously, the screw withdrawal resistance of BOSB and CPB was compared and analyzed statistically with the 19.0 SPSS software. In fact, it is imperative to execute the experiment to evaluate the effects of various factors on connection strength, which present great significance to using BOSB in furniture and structure design.

MATERIAL AND METHODS

Material

The BOSB used in the experiments was supplied by Yunnan Yonglifa Forestry Co., Ltd (Yunan, China), which raw materials for the dendrocalamus yunnanica (*Dendrocalamus giganteus* Munro). The sample with the thickness of 15 mm, the corresponding density is 0.94 $g·cm^{-3}$. The conventional particleboard used in the experiments was commercially available (Ningguo Southeast Wood Co., Ltd, Ningguo, China) with the thickness of 15 mm, density of 0.83 $g·cm^{-3}$. Two types of screws (self-tapping screw and drywall screw) used in this study can be found in our previous study (Chen et al. 2016).

Methods

Specimen preparation and processing

The nominal dimensions of specimens used to test the face and edge withdrawal resistance were 100×60×15mm (length, width and height), which according to ASTM D1037-12-2012. For the withdrawal resistance test at various directions, the nominal dimensions of these sets of specimens were 75×75×15 mm (length, width and height) according to EN 320 standard (Union 1993). Before the test, using a bench drill (MOBEL Z4120) for pilot-hole drilling, the pilot hole diameter for each screw was 1mm less than the nominal diameter of corresponding screws except for the test at various pilot hole diameters. The depth of the penetrated part of the screw is 10 mm and the pilot hole depth for each screw was 2 mm less than the penetrate depth of corresponding screws. T he tests were conducted by making use of a computer-controlled universal test machine with the loading crosshead speed was set at 5 mm·min^{-1} (WDW-100E, Jinan Shidai Shijin Testing Machine Group Co., Ltd., Jinan, China) (As Fig. 1 presents)

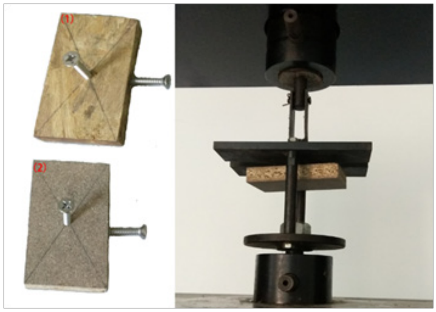

Fig. 1: Withdrawal resistance test, (1) BOSB; (2) CPB.

Withdrawal resistance test of various screw diameters

The screws used to investigate the withdrawal resistance of various screw diameters in the face and edge of BOSB and CPB specimens (100×60×15 mm) were self-tapping type, with the diameter of 4, 5 and 6 mm.

Screw withdrawal resistance test at various pilot hole diameters

In this test, the pilot hole diameter is 50% (2 mm), 63% (2.5 mm), 75% (3 mm),88% (3.5 mm) and 100% (4 mm) the diameter of the screw. The screws in the face of BOSBand CPB specimens (100×60×15 mm) were self-tapping type, with the diameter of 4 mm.

Anisotropic test of BOSB and CPB withdrawal resistance

The screws in the face, edge and end of BOSB and CPB specimens (75×75×15mm) were drywall type with the diameter of 3.5mm.

Data processing

Screw withdrawal resistance was determined using the following Eq. 1.

$$WR=F_{max}/L \quad (1)$$

where: WR - withdrawal resistance (N·mm^{-1}),
F_{max} - the ultimate load required to pull out a screw from the specimen,
L - the penetrate depth of the screw in specimen(mm).

Five replicates for each treatment were tested. The experiment data were statistically and analyzed with the 19.0 SPSS software. The chief statistical indexes were tested by Levene Statistic to confirm homogeneity of variance between groups (Chen et al. 2016).

RESULTS AND DISCUSSION

Effect of screw diameter on withdrawal resistance

Tab. 1 presents the withdrawal resistance of BOSB and CPB specimens relative to the screw diameter. It can be seen that face and edge direction withdrawal resistance of BOSB achieved the maximum values of 200.80 $N \cdot mm^{-1}$ and 164.00 $N \cdot mm^{-1}$, respectively, when the screw diameter is 5 mm.

Tab. 1: Descriptive statistics for withdrawal strength of BOSB and CPB at various screw diameters.

Material types	Direction	Screw diameter (mm)	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95% confidence interval for mean	
						Lower bound	Upper bound
BOSB	Face	4	167.20	15.07	6.74	185.91	148.49
		5	200.80	30.25	13.52	238.36	162.44
		6	140.40	25.51	11.40	171.67	108.33
	Edge	4	132.40	34.93	15.62	175.78	89.02
		5	164.00	49.37	22.08	225.30	100.70
		6	128.80	28.80	12.90	167.60	90.00
CPB	Face	4	54.80	6.41	2.87	62.70	43.90
		5	48.80	4.60	2.05	54.50	43.10
		6	45.20	3.34	1.49	49.30	41.10
	Edge	4	25.40	5.36	2.40	32.00	18.80
		5	32.40	5.89	2.63	39.70	25.10
		6	20.80	6.09	2.72	27.50	13.30

Compared to the screw diameter of 4 mm and 5 mm, the surface withdrawal resistance increased by 20.10% and 43.02%, respectively; the edge withdrawal resistance increased by 23.87% and 27.33%, respectively. This result may be related to the effective net section of different diameter screws in BOSB sheet. Similar results were found in the previous work, the withdrawal resistance is smaller at low net section, which owing to the weakened shearing effect (Haftkhani et al. 2011a). In contrast, as the screw diameter increased, the face withdrawal resistance of CPB decreased; the edge withdrawal resistance of CPB first increase and then decrease. AS compared to BOSB, the maximum withdrawal resistance in face and edge direction of CPB were 54.80 $N \cdot mm^{-1}$ and 32.40 $N \cdot mm^{-1}$, respectively, were 146.00 $N \cdot mm^{-1}$ and 131.60 $N \cdot mm^{-1}$ smaller than BOSB. As literature reported (Özçifçi 2009), the withdrawal resistance depends on the density of the material, the testing specimen has a tendency to split when the screw is inserted in it, whereas the tendency was smaller for high specific gravity materials. In addition, the withdrawal resistance of screws increased with increasing specific gravity values. Therefore, the withdrawal resistance of CPB is lower than BOSB, which ascribed to their low density.

The results of variances analysis in regard to the effects of various screw diameter on the face and edge withdrawal strength of BOSB and CPB are present in Tab. 2. According to variances analysis results, indicating the face withdrawal resistance of BOSB has a significant differences at various screw diameter, whereas the edge withdrawal resistance was not significant differences at various screw diameter (P=0.05). In contrast, the effect of screw diameter on CPB's face and edge withdrawal resistance has been statistically significant difference with a 95% confidence interval.

Tab. 2: ANOVA of withdrawal strength at various screw diameters (P=0.05).

Material types	Direction		Sum of squares	df	Mean square	F	Sig.
BOSB	Face	Between groups	9158.933	2	4579.467	7.661	0.007
		Within groups	7172.800	12	597.733		
		Total	16331.733	14			
	Edge	Between groups	3750.933	2	1875.467	1.253	0.321
		Within groups	17968.000	12	1497.333		
		Total	21718.933	14			
CPB	Face	Between groups	235.200	2	117.600	4.793	0.030
		Within groups	294.400	12	24.533		
		Total	529.600	14			
	Edge	Between groups	342.933	2	171.467	5.083	0.025
		Within groups	404.800	12	33.733		
		Total	747.733	14			

Effect of pilot hole diameter on screw withdrawal resistance

Tab. 3 present the face withdrawal resistance in BOSB and CPB at different pilot hole diameter. As the result shows, the face withdrawal strength of BOSB and CPB decreased with increasing pilot hole diameter. Furthermore, the withdrawal resistance achieved the minimum value when the pilot hole is 100% of the nominal screw diameter. As compared to the pilot hole diameter were 2 mm, the withdrawal resistance of BOSB and CPB decreased by 60.00% and 68.50%, respectively. In addition, it also can be found that in the pilot hole diameter of 2-3.5 mm, the withdrawal resistance decreased less, but the decline degree of CPB is more noticeable than BOSB. QUE et al. (Que et al. 2012, Que et al. 2014) revealed that the withdrawal strength would be slow down while the pilot hole diameter increased. The net section of screw insert in the specimen decreased with the increasing pilot hole diameter, and the thread formation is insufficient. Therefore, the shearing and squeezing action of screw on the specimen reduced, and then the withdrawal resistance decreased.

Tab. 3: Descriptive statistics for withdrawal strength of BOSB and CPB at various pilot hole diameter.

Material types	Pilot hole diameter (mm)	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95% confidence interval for mean	
					Lower bound	Upper bound
BOSB	2.0	170.00	22.67	10.13	198.10	141.90
	2.5	168.80	23.09	10.32	197.40	140.20
	3.0	165.20	22.65	10.13	193.30	136.10
	3.5	163.60	21.51	9.62	190.30	138.90
	4.0	68.00	9.16	4.09	79.30	56.70
CPB	2.0	58.40	4.56	7.32	64.00	52.80
	2.5	54.40	5.89	8.32	61.70	44.10
	3.0	49.20	4.81	9.32	54.90	43.30
	3.5	45.60	4.56	10.32	54.80	36.40
	4.0	18.40	4.77	11.32	24.30	12.50

Variances analysis results regard to the effect of pilot hole diameter are present in Tab. 4. The significance level is 0.000, indicating there was a significance difference of withdrawal resistance at various pilot hole diameter (P=0.05).

Tab. 4: ANOVA of withdrawal strength at various pilot hole diameters (P=0.05).

Material types		Sum of squares	df	Mean square	F	Sig.
BOSB	Between groups	39259.840	4	9814.960	23.289	0.000
	Within groups	8428.800	20	421.440		
	Total	47688.640	24			
CPB	Between groups	4966.400	4	1241.600	50.719	0.000
	Within groups	489.600	20	24.480		
	Total	5456.000	24			

Effect of grip directions on screw withdrawal resistance

The withdrawal resistances of drywall screw in differences direction of BOSB and CPB specimen were presents in Tab. 5. Screw failure modes in the face and edge of BOSB and CPB were present in Fig. 2.

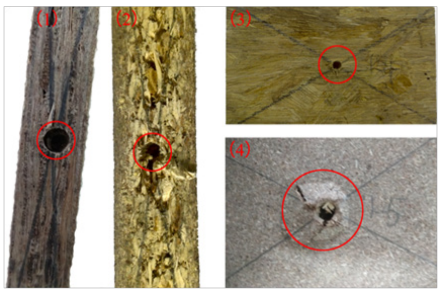

Fig. 2: Screw failure modes of in the study; (1) edge of BOSB; (2) edge of CPB; (3) face of BOSB; (4) face of CPB.

Tab. 5: Descriptive Statistics for withdrawal strength of BOSB and CPB at various directions.

Material types	Direction	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95% confidence interval for mean	
					Lower bound	Upper bound
BOSB	Face	164.80	20.28	9.07	189.90	139.70
	Edge	149.00	14.42	6.45	166.90	131.10
	End	130.80	16.16	7.23	150.80	110.80
CPB	Face	46.00	7.62	3.41	55.40	36.60
	Edge	26.80	4.38	1.96	32.20	21.40
	End	24.00	3.16	1.41	27.90	20.10

The face, edge, and end withdrawal resistance of BOSB were 164.80 $N \cdot mm^{-1}$, 149.00 $N \cdot mm^{-1}$, and 130.80 N $N \cdot mm^{-1}$, respectively. For CPB, the face, edge, and end withdrawal resistance were 46.00 $N \cdot mm^{-1}$, 26.80 $N \cdot mm^{-1}$, and 24.00 $N \cdot mm^{-1}$, respectively. In fact, in the process of shaving and hot pressing of particleboard, the particleboard has a certain density gradient from the surface layer to the core layer as ascribed to the effects of temperature, drying speed and pressure transmission, and the surface density is higher than that of the core layer. Simultaneously, the internal bonding (IB) strength increased and the structure more solid as density increasing, producing the higher ultimate pull force for screw. Therefore, the face withdrawal resistance is higher than the edge and end. Furthermore, it also can be found that the CPB withdrawal resistance in all directions is much smaller than BOSB. Compared with CPB, BOSB has a large aspect ratio of shavings, which is a thin flat shaver and consistent with the direction of bamboo fiber in the length direction. Since the bamboo fiber is not damaged, the shavings themselves retain the natural mechanics of bamboo characteristic. In addition, the long shavings in BOSB arranged closely and evenly distributed, the density is larger than the CPB. Consequently, the mechanical properties of BOSB are stronger than CPB.

According to the Levene Statistic test, the data for BOSB passed homogeneity test, whereas the data for CPB did not. The variances analysis results regard to the effect of grip directions on BOSB are presents in Tab. 6. The results indicating that the effect of grip directions on screw withdrawal resistance of BOSB has a significant difference with 5% error.

Tab. 6: ANOVA of withdrawal strength at various directions (P=0.05).

Material types		Sum of squares	df	Mean square	F	Sig.
BOSB	Between groups	2894.800	2	1447.400	4.932	0.027
	Within groups	3521.600	12	293.467		
	Total	6416.400	14			

CONCLUSIONS

According to the experiment results and discussions, the following conclusions can be drawn and presented:

1. Effects of screw diameter on the face withdrawal resistance in BOSB has significant differences, whereas the edge withdrawal resistance was not. In contrast, the effect of screw diameter on face and edge withdrawal resistance in CPB has been statistically significant difference at 95% confidence interval. The face and edge withdrawal resistance of BOSB first increased and then decreases as related to the increasing screw diameter. The face withdrawal resistance of CPB decreased as increasing screw diameter, whereas the edge withdrawal resistance increased with increasing screw diameter and achieved the maximum value when screw diameter is 5mm, then decrease while screw diameter continued to grow.
2. Effect of pilot hole diameter on the face and edge withdrawal resistance in BOSB and CPB has significant difference at 95% confidence interval. The screw withdrawal resistance decreased with increasing pilot hole diameter both in BOSB and CPB, and decreased more than 60%as pilot hole is 100% of the nominal screw diameter. In fact, in order to facilitate screwing and protect products from splitting and damage, the suggested proper size of pilot holes is 50-75% to the nominal diameter of the screw for BOSB and 50%-60% for CPB.
3. The anisotropy of screw withdrawal resistance in BOSB was significant difference at 95% confidence interval. The relative superiority of the withdrawal resistance is sorted by the face, edge and end in turn. Simultaneously, it can be found that the screw withdrawal resistance in BOSB is much higher than CPB in every direction. This is results mainly ascribed to the difference of density, fiber orientation, and internal bonding strength between BOSB and CPB.

4. In fact, the screw type and diameter, pilot hole diameter and depth, and screw with glues should be considered in the application of BOSB with screws. Furthermore, it is essential to avoid using screws in edge and end direction as far as possible when the screw connection used in furniture and structure.

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