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INVESTIGATION ON WITHDRAWAL RESISTANCE OF SCREWS IN RECONSTITUTED BAMBOO LUMBER

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ABSTRACT

The objective of this study was to evaluate the effects of screw diameter, pilot hole diameter, screw type and loading rate on the withdrawal resistance of some screws in reconstituted bamboo lumber (RBL) and comparison of screw withdrawal resistance in RBL with MDF and Particleboard. Results indicate that there were no significant differences among withdrawal resistance with screw diameter, screw type and loading rate. Significant differences were found between withdrawal resistance with pilot hole diameter. Screw withdrawal resistance decreased with increasing pilot hole diameter. Suggested size of pilot hole is 60-85 % of the nominal screw diameter. The withdrawal resistances in the face and edge of RBL are greater than the end direction. This reveled RBL is anisotropic. Face and edge withdrawal resistances of screws in RBL were higher as compared with those of MDF and particleboard. This indicates that withdrawal resistance of RBL meets the requirements of furniture structure design.

KEYWORDS: Reconstituted bamboo lumber; withdrawal strength; screw types and diameter; pilot hole diameter; loading rate; furniture structure design.

INTRODUCTION

Reconstituted bamboo lumber (RBL) is a kind of plate or timber use long and mutual crosslinking loose reticular bamboo fiber bundles as the composition unit. The unit arranged according to the original mode of bamboo fiber. Then drying, sizing, assembling and hot pressing (or cold pressing). Its material and color are similar to hard wood. Currently, RBL is considered to be one of the most potential new-type bamboo-based composites because the material has advantages in terms of high strength, high density, and high utilization ratio of raw materials, processing and surface decorative well. At present, is still in the initial stage of RBL's development, the products obtained approaches 100 ten thousand m^3 per year (in China), the main target market positioning in the indoor floor. However, as the shortage of wood resources and forest protection consciousness enhancement, RBL will expand the application scope into the traditional furniture manufacturing industry because of its excellent physical and mechanical performance. In addition, it will developed the products with water resistance, mechanical properties and anti-corrosion properties, which based on the adjustment of material density, the doping content of phenolic resin, the impressafining of bamboo chips, and the manufacturing process. Such as furniture, wind blades, construction materials, container/platform flooring, construction formwork and outdoor landscape engineering.

The corner joint design is an important factor in furniture structure design. Components of furniture except itself must have certain strength and stiffness, also must satisfy certain corner joint strength. Screw joint, as an important corner joint of modern furniture especially for panel-type furniture, often with the withdrawal resistance to evaluate the strength of the screw combination. RBL is supposed to function as replacement material for wood, study of the connectivity and the withdrawal resistance is essential. As the connection of wood elements written on APA (Williamson 2002), and its importance states that 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 connections are the guarantee of firm structure, 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. What's more, it is significant to have information about withdrawal resistance of screws and nails so as to achieve the efficient use of materials in the building system (Celebi and Kilic 2007). Similarly, connection is just as important as the structure design of RBL furniture, which has an important guiding significance for its proper furniture structure design, and provide important theoretical basis for its application in the furniture manufacturing industry.

Currently, research on RBL withdrawal resistance performance is rarely reported. However, a few achievements have been acquired about the withdrawal resistance of wood, particleboard, medium density fiberboard (MDF), wood plastic composite (WPC) panels. This can provide reference for the study of withdrawal resistance on RBL. Based on the literature review (Özçifçi 2009; Tankut 2006; Eckelman 1974; 1975; 1988; 2003; Eckelman and Martin 1980; Eckelman and Erdil 1999; Semple and Smith 2007), it was found that the screw type, pilot hole, penetration depth, loading rate and material type all are the most important parameter for the evaluation of withdrawal resistance of screws in materials. In addition, as internal bond strength (IB) to MDF and particleboard, shear strength parallel to the grain in solid wood will also impact the withdrawal resistance of the material. For instance, Eckelman (1975) analyzed the screwholding performance in hardwoods and particleboard; it was found that shear strength parallel to grain is a better predictor of holding strength in solid wood than specific gravity. However, the specific gravity is a good indicator of holding strength in particleboard. It is reported in a same study, 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). In other studies, it was found that the glue applied in pilot hole increased the withdrawal strength for screws in some wood and composite materials, and there was no relationship between screw length and withdrawal strength while the diameter of screw had a linear relationship (Yalçın et al. 1998; Doganay et al. 1997).

In addition, Rajak and Eckelman (1993) studied the holding strength of large-diameter sheet metal screws in the face and edge surfaces of medium density fiberboard and particleboard. Results indicated that the use of pilot holes of the proper diameter significantly increases the holding strength of the screws in the material. In general, pilot holes should be equal to about 80-85 % of the root diameter of the screw. It was also stated in other studies (Özçifçi 2009; Eckelman 1988). Study conducted on various screws in face and edge of wood-plastic composite panel has revealed that withdrawal resistance in both directions increased as screw diameter, pilot hole diameter close to root diameter of screw, penetration depth of screw into panel and loading rate increase. There were no significant differences between different types of screw. In addition, face and edge withdrawal resistance of screws in WPC is higher than those of MDF and particleboard (Haftkhani et al. 2011a). As literature (Rajak and Eckelman 1993) has pointed out, the determination of screw holding strength in face or edge of 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. Therefore, the determination of withdrawal resistance in RBL can consult these literatures. However, it is worth noting that the physical and mechanical properties of RBL are different from the general woodiness material. It is imperative to conduct the test to evaluate the effects of various factors on connection strength; which present great significance to furniture structure design of RBL.

MATERIAL AND METHODS

Material

The RBL used in the experiments was supplied by Anhui Hongyu Bamboo Products Co., Ltd (Xuancheng, China). The sample with the thickness of 15mm and 30mm, the corresponding density is 1.27 and 1.04 g.cm^{-3}, respectively. The MDF and particleboard used in the experiments was commercially available (Ningguo Southeast Wood Co., Ltd, Ningguo, China) with the thickness of 18 mm, density of 0.69 and 0.83 g.cm^{-3}, respectively. Four types of screws (supplied by Xinghua Pingfan Stainless Steel Standard Fastener Factory, Xinghua, China) were used, including self-tapping screws (A2-70 stainless steel screw, diameter of 4, 5, and 6 mm, respectively.) with the length of 40 mm, chipboard screws (carbon steel of property class 4.8, diameter of 5 mm) with the length of 50 mm, wood screws (carbon steel of property class 8.8, diameter of 4 mm) with the length of 40 mm, and drywall screws (carbon steel of property class 8.8, diameter of 3.5 mm) with the length of 40 mm. Screws used in this study are shown in Fig.1.

Fig.1: Screws used in this study (from left to right in the order of self-tapping screws (diameter of 6, 5 and 4 mm), chipboard screw, wood screw, and drywall screw).

Methods

Specimen preparation and processing

RBL specimens with a thickness of 30 mm were cut according to ASTM D1037-99 standard (ASTM International 2006); the nominal dimensions of specimens were 100×60×30 mm (length, width and height). In order to investigate withdrawal resistance of RBL, MDF and particleboard, corresponding specimens were cut according to EN 320 standard (EN 320 1993-08). The nominal dimensions of these sets of specimens were 75×75×15 mm (length, width and height) for RBL and 75×75×18 mm (length, width and height) for both MDF and particleboard. Before the test, using a bench drill (MOBEL Z4120) for pilot-hole drilling. The pilot hole depth for each screw was 2 mm less than the penetrate depth of corresponding screws.

Withdrawal resistance test of various screw diameters

The screws in the face and edge of RBL specimens (100×60×30) were self-tapping type, with the diameter of 4, 5 and 6 mm. In addition, the depth of the penetrated part of the screw is 10 mm, the pilot hole diameter for each screw was 1 mm less than the nominal diameter of corresponding screws. The speed of the loading crosshead was set at 5 $mm.min^{-1}$.

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) and 100 % (4 mm) the diameter of the screw. The screws in the face of RBL specimens (100×60×30 mm) were self-tapping type, with the diameter of 4 mm. In addition, the depth of the penetrated part of the screw is 10 mm; the speed of the loading crosshead was set at 5 $mm.min^{-1}$.

Withdrawal resistance test of various screw types

The screws in the face of RBL specimens (100×60×30 mm) were self-tapping and wood type. Both diameters of the screw are 4 mm. The pilot hole diameter for each screw was 1 mm less than the nominal diameter of corresponding screws. In addition, the depth of the penetrated part of the screw is 10 mm; the speed of the loading crosshead was set at 5 $mm.min^{-1}$.

Withdrawal resistance test at different loading rate

The screws in the face of RBL specimens (100×60×30 mm) were self-tapping type (4 mm), chipboard type (5 mm) and drywall type (3.5 mm), and the depth of the penetrated part of the screw is 10, 20 and 20 mm, respectively. In addition, the pilot hole diameter for each screw was 1 mm less than the nominal diameter of corresponding screws. The speed of the loading crosshead was set at 55, 105 and 205 $mm.min^{-1}$, respectively.

Anisotropic test of RBL'S withdrawal resistance

The screws in the face, edge and end of RBL specimens (75×75×15 mm) were drywall type (3.5 mm). In addition, the depth of the penetrated part of the screw is 10 mm, the pilot hole diameter for each screw was 1 mm less than the nominal diameter of corresponding screws. The speed of the loading crosshead was set at 20 $mm.min^{-1}$.

Comparison of screw withdrawal resistance in RBL with MDF and Particleboard

The screws in this test were drywall type, with the diameter of 3.5 mm. The dimension of RBL, MDF and particleboard specimen is 75×75×15, 75×75×18 and 75×75×18 mm, respectively. In addition, the depth of the penetrated part of the screw is 10mm, the pilot hole diameter for each screw was 1mm less than the nominal diameter of corresponding screws. The speed of the loading crosshead was set at 5 $mm.min^{-1}$.

Data processing

Screw withdrawal resistance was determined using the following Eq.

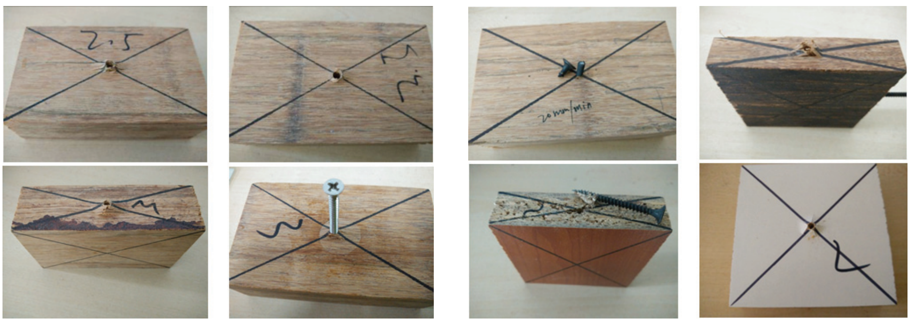
$$WR = F_{max}/L$$

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

Five replicates for each treatment were tested. The collected data were statistically normalized, and the 19.0 SPSS software was used for analysis; the chief statistical indexes were tested by Levene Statistic to confirm homogeneity of variance between groups.

The tests were conducted by making use of a computer-controlled universal test machine (WDW-100E, Jinan Shidai Shijin Testing Machine Group Co., Ltd., Jinan, China; Fig. 2). Fig. 3 shows failure modes of some screws used in this study.

Fig. 2: Withdrawal strength test.



a) Self-tapping screw (4 mm). b) Drywall screw (3.5 mm).

Fig. 3: Failure modes in some of the studied screws.

RESULTS AND DISCUSSION

Effect of screw diameter on withdrawal resistance

Tab. 1 shows the withdrawal resistance in face and edge of RBL specimens relative to the screw diameter. It can be seen that face direction withdrawal resistance increased with increase in screw diameter, and achieve the maximum (211.25 N.mm^{-1}) when the screw diameter is 5 mm. Then, it decreases to 203.2 N.mm^{-1} when the screw diameter is 6 mm. This may be attributed to the significant effect of pilot hole diameter. These results are in agreement with the literature (Haftkhani et al. 2011a), which the withdrawal resistance in WPC increased with increase in screw diameter. The edge direction withdrawal resistance increased with increasing screw diameter. This mainly because shearing increased with the increasing contact area of screw and specimen after screw diameter increased. Thus, withdrawal strength increased.

According to Levene Statistic test, both sets of data passed homogeneity test (Sig.>0.05). An analysis of Variances with a 0.05 significance level showed that there was a not significant differences among face and edge withdrawal resistance of screws with 4, 5 and 6 mm diameter (Tab. 2). However, Haftkhani's study showed that there was a significant difference among face and edge withdrawal strength of screws with 3, 4, 5 and 6 mm diameter in wood-plastic composite(WPC) panel (Haftkhani et al. 2011a).

Tab. 1: Descriptive Statistics for various screw diameters.

Direction	Screw diameter mm	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95 % confidence interval for mean	
					Lower bound	Upper bound
Face	4	200.6	43.798	19.587	146.22	254.98
	5	211.25	12.148	6.074	191.92	230.58
	6	203.2	36.711	16.418	157.62	248.78
Edge	4	203	50.754	22.698	139.98	266.02
	5	204.8	61.12	27.334	128.91	280.69
	6	208.2	44.952	20.103	152.38	264.02

Tab. 2: ANOVA (P=0.05).

Direction		F	Sig.
Face	Between groups	0.109	0.898
Edge	Between groups	0.013	0.988

Effect of pilot hole diameter on screw withdrawal resistance

Tab. 3 illustrate the effect of pilot hole diameter on face withdrawal resistance in 30mm thick RBL. The withdrawal strength in face of RBL decreased with increasing pilot hole diameter. What's more, the withdrawal resistance decreased drastically when the pilot hole is 100 % of the nominal screw diameter. As Que's study (Que et al. 2014), who revealed that the withdrawal strength would be slow down while the pilot hole diameter increased. In addition, when the vessel diameters were 2-3 mm, the withdrawal strength was stable. But as the pilot hole diameter further increased, the withdrawal strength would be sharply reduced. With the pilot hole diameter increased from 2 to 3.5 mm, withdrawal resistance changed 25.88 %. This result attributed to the decrease of screw shearing. Size of contact surface, shearing and compression of screw on the plate fiber affected screw withdrawal resistance (Li et al. 2011). As the pilot hole diameter increase, the contact area between screw and specimen decreased. Shearing and squeezing action of screw on bamboo fiber reduced due to not fully thread line. Then, withdrawal resistance decreased. This result is not fully corresponding with the literatures (Eckelman 1988; Haftkhani et al. 2011a; b), which indicated that withdrawal strength increases gradually as pilot hole increases until the pilot hole nears the root diameter of the screw. Above the point, withdrawal strength decreases, gradually at first and then drastically as the pilot hole approaches the nominal diameter of screw.

Variances analysis results are shown in Tab. 4, the significance level is 0.000. This indicated that there was a significance difference between withdrawal resistance of self-tapping screws with different pilot hole diameters.

Tab. 3: Descriptive statistics for various pilot hole diameters.

Pilot hole diameter (mm)	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95 % confidence interval for mean	
				Lower bound	Upper bound
2	236.6	23.158	10.357	207.85	265.35
2.5	211.6	11.327	5.066	197.54	225.66
3	183.5	31.257	15.629	133.76	233.24

3.5	175.4	21.893	9.791	148.22	202.58
4	7.33	0.577	0.333	5.9	8.77

Tab. 4: ANOVA (P=0.05).

	F	Sig.
Between groups	62.426	0.000

Effect of screw type on screw withdrawal resistance

In this test, compared the wood screw and self-tapping screw withdrawal resistance on the face of RBL. As shown in Tab. 5, the withdrawal resistance of self-tapping screw on the face of RBL is greater than wood screw. This is due to the screw-pitch of self-tapping screw is smaller than wood screw. Therefore, the screw number and contact area with specimens of self-tapping screw are greater than wood screw, shearing of the screw increased, withdrawal resistance increased (Li et al. 2011). Variances analysis results are shown in Tab. 6, which revealed no significant difference among withdrawal resistance of the two screws. It is contrary to the previous study (Haftkhani et al. 2011a), which indicated that there was a significant difference among withdrawal resistances of screws when the pilot hole diameter was 1 mm less than nominal diameter of the screw.

Tab. 5: Descriptive statistics for various screws.

Screw types	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95 % confidence interval for mean	
				Lower bound	Upper bound
Wood screw	149.75	29.792	14.896	102.34	197.16
Self-tapping screw	200.6	43.798	19.587	146.22	254.98

Tab. 6: ANOVA (P=0.05).

	F	Sig.
Between groups	3.892	0.089

Effect of loading rate on screw withdrawal resistance

Tab. 7 illustrates the effect of loading rate on face direction screw withdrawal resistances of drywall screw, chipboard screw and self-tapping screw. The withdrawal strength of drywall screw and chipboard screw increased with increasing loading rate, these results agree with study of Haftkhani et al. (2011b). The self-tapping screw withdrawal resistance increased with increases loading rate and achieved the maximum value (253.8 $N.mm^{-1}$) when the loading rate is 10 $mm.min^{-1}$, then decreased drastically. This mainly attributed to the differences of screw diameter and penetrated depth. According to Levene Statistic test, three groups of data all passed homogeneity test (Sig.>0.05). As the results of variance analysis (Tab. 8), this revealed that there was no significant difference between withdrawal resistances with the increase of loading rate. However, as the study of Haftkhani (Haftkhani et al. 2011a), loading rate had a significant effect on withdrawal resistance of sheet metal and fine thread drywall screws.

Tab. 7: Descriptive statistics for various loading rate.

Screw types	Loading rate (mm·min^{-1})	Mean in (N·mm^{-1})	Std. deviation	Std. error	95 % confidence interval for mean	
					Lower bound	Upper bound
Drywall screw	5	208	35.7	17.85	151.19	264.81
	10	214.1	35.839	16.028	169.6	258.6
	20	240.5	10.706	4.788	227.21	253.79
Chipboard screw	5	251.1	41.789	18.688	199.21	302.99
	10	266.3	64.24	28.729	186.54	346.06
	20	281.25	64.809	32.405	178.12	384.38
Self-tapping screw	5	220.75	62.249	31.124	121.7	319.8
	10	253.8	66.142	29.579	171.67	335.93
	20	201.6	61.146	27.345	125.68	277.52

Tab. 8: ANOVA (P=0.05).

Screw types		F	Sig.
Drywall screw	Between groups	1.639	0.238
Chipboard screw	Between groups	0.309	0.74
Self-tapping screw	Between groups	0.867	0.447

Effect of grip directions on screw withdrawal resistance

Tab. 9 shows the drywall screw withdrawal resistance in differences direction of RBL panel. It can be seen that the end direction withdrawal resistance is smaller than the face and edge. This mainly because penetrate direction of the screw perpendicular to bamboo fiber in the face and edge of RBL panels and shearing on bamboo fiber was perpendicular to the grain. However, the penetrate direction in the end of RBL panels is parallel to the grain of bamboo fiber; the shearing was parallel to the grain. Transfer portion of the screw and bamboo part was small and not close enough (Que et al. 2012). Therefore, the withdrawal resistances in the face and edge of RBL are larger than end withdrawal resistance. In addition, according to homogeneity test (Sig. =0.008), so the variance analysis was statistically insignificant.

Tab. 9: Descriptive Statistics for various directions.

Direction	Mean in (N·mm^{-1})	Std. deviation	Std. error	95 % confidence interval for mean	
				Lower bound	Upper bound
Face	136.4	33.261	14.875	95.1	177.7
Edge	137	11.225	5.02	123.06	150.94
End	91.75	8.655	4.328	77.98	105.52

Comparison of screw withdrawal resistance in RBL with MDF and particleboard

Fig. 4 illustrates the comparison of face and edge direction screw withdrawal resistances in RBL, MDF and particleboard. As shown in the figure, at the same pilot hole diameter and the same direction, the highest withdrawal resistance was observed for RBL, MDF, and particleboard, respectively. The results of the test show that on the whole, the withdrawal resistances of RBL were greatest among the other specimens.

This attributed to the high density and internal bonding (IB) in RBL. On the other hand, it can be seen that with the increase in pilot hole diameter from 2 to 3 mm, face direction withdrawal resistances change 40.06, 52.55 and 68.62 % for MDF, particleboard and RBL, respectively while those for edge direction were 70.19, 71.09, 70.69 %, respectively. This result reveled that variation of withdrawal resistances with increases in pilot hole diameter for RBL is larger than those of MDF and particleboard, but the edge direction withdrawal resistance differences is not significant (Tab. 10).

According to Levene Statistic test, all of the data passed homogeneity test except the face withdrawal resistance in MDF. Variances analysis results are shown in Tab. 11, the significance level of withdrawal resistance in the face and edge of RBL, particleboard, and the edge of MDF was smaller than 0.05. This result suggests that there were significance differences between withdrawal resistances with different materials.

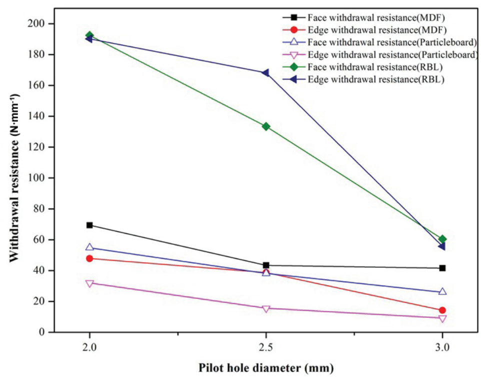


Fig. 4: Screw withdrawal resistance in RBL compared with MDF and particleboard.

Tab. 10: Descriptive statistics for various materials.

Material types	Direction	Pilot hole diameter (mm)	Mean in ($N \cdot mm^{-1}$)	Std. deviation	Std. error	95 % confidence interval for mean	
						Lower bound	Upper bound
MDF	Face	2	69.4	8.355	3.736	59.03	79.77
		2.5	43.4	3.209	1.435	39.42	47.38
		3	41.6	2.074	0.927	39.03	44.17
	Edge	2	47.8	4.919	2.2	41.69	53.91
		2.5	38.75	2.5	1.25	34.77	42.73
		3	16.33	2.082	1.202	11.16	21.5
Particleboard	Face	2	54.8	2.168	0.97	52.11	57.49
		2.5	38.2	3.962	1.772	33.28	43.12
		3	24	3.367	1.683	18.64	29.36
	Edge	2	32	3.742	1.673	27.35	36.65
		2.5	16.75	2.986	1.493	12	21.5
		3	10.67	3.055	1.764	3.08	18.26

RBL	Face	2	192.5	19.122	9.561	162.07	222.93
		2.5	131.33	21.779	12.574	77.23	185.44
		3	70.5	16.263	11.5	-75.62	216.62
	Edge	2	193.67	18.037	10.414	148.86	238.47
		2.5	165.33	17.502	10.105	121.86	208.81
		3	71	17.521	10.116	27.47	114.53

Tab. 11: ANOVA (P=0.05).

Material types	Direction		F	Sig.
MDF	Face	Between groups	43.012	0.000
	Edge	Between groups	67.987	0.000
Particleboard	Face	Between groups	101.594	0.000
	Edge	Between groups	44.083	0.000
RBL	Face	Between groups	26.863	0.001
	Edge	Between groups	39.549	0.000

CONCLUSIONS

On the basis of the performed study, the following conclusions can be drawn from the results and discussions presented:

1). Withdrawal resistance increased with increasing screw diameter in the face of RBL and achieved the maximum value when screw diameter is 5 mm, then decrease while those for edge direction were continued to grow. There was no significant difference between withdrawal resistances with various screw diameters.

2). Screw withdrawal resistance in the face of RBL decreased with increasing pilot hole diameter, and decreased drastically when the pilot hole is 100 % of the nominal screw diameter. There was a significant differences between withdrawal resistance with pilot hole diameter. However, the density of RBL is great, there need a force to drive the screws into specimens when the pilot hole diameter is small. This may be damage or splitting the specimen face and not sufficient. Therefore, the suggested proper size of pilot holes is 60-85 % to the nominal diameter of the screw.

3). There were no significant differences among withdrawal resistances with screw types and loading rate, but the penetrate depth of screws has an effect on RBL withdrawal resistance.

4). The withdrawal resistance in the end of RBL is lower than the face and edge, and avoids the end direction as far as possible when the screw connection used in RBL furniture.

5). Withdrawal resistance of screws in RBL is higher than those of MDF and particleboard. This can be attributed to the effect of density and internal bonding. The withdrawal resistances meet the requirements of furniture structure design.

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REFERENCES

1. ASTM D1037-06 – 2006: Standard test methods for evaluating properties of wood-base fiber and particle panel materials.
2. Celebi, G., Kilic, M., 2007: Nail and screw withdrawal strength of laminated veneer lumber made up hardwood and softwood layers. Construction and Building Materials 21(4): 894-900.
3. Cassens, D.L., Eckelman, C.A., 1985: Face holding strength of threaded metal inserts in reconstituted wood products. Forest products journal 35(3): 18-22.
4. Doganay, S., Özçifçi, A., Küreli, I., 1997: The effect of edge massive on screw holding in particleboard used for furniture production. J. Nat. Appl. Sci. Gazi Univ. Turkey 10(2): 273-280.
5. Eckelman, C.A., 1974: Which screw holds best. Furniture Design and Manufacturing, magazine. Pp 25-26.
6. Eckelman, C.A., 1975: Screw holding performance in hardwoods and particleboard. Forest Products Journal 25(6): 30-35.
7. Eckelman, C.A., Martin, K., 1980: The holding strength of four types of screws in wood. Furniture Manuf. Manage 26(9): 20-24.
8. Eckelman, C.A., 1988: The withdrawal strength of screws from commercially available medium density fiberboard. Forest Prod. J. 38: 21-24.
9. Eckelman, C.A., 2003: Textbook of product engineering and strength design of furniture. Purdue University, West Lafayette, Indiana.
10. Eckelman, C.A., Erdil, Z., 1999: Joints design manual for furniture frames constructed of plywood and oriented strant board. In: 1st International Furniture Congress and Exhibition, Istanbul.
11. EN 320 1993-08- 1993: Fiberboards, determination of resistance to axial withdrawal of screws.
12. Haftkhani, A.R., Ebrahimi, G., Tajvidi, M., Layeghi, M., 2011a: Investigation on withdrawal resistance of various screws in face and edge of wood–plastic composite panel. Materials and Design 32(7): 4100-4106.
13. Haftkhani, A.R., Ebrahimi, G., Tajvidi, M., Layeghi, M., Arabi, M., 2011b: Lateral resistance of joints made with various screws in commercial wood plastic composites. Materials and Design 32(7): 4062-4068.
14. Li, J.Q., Chen, L.H., Su, T., 2011: Study on bolt joint intensity of laminated bamboo for furniture. Journal of Fujian College of Forestry, 3, 018 (in Chinese).
15. Özçifçi, A., 2009: The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber. Materials and Design 30(7): 2355-2358
16. Que, Z.L., Yang, L., Wang, F.B., Zhu, X.N., Pan, B., 2014: Effects of vessel diameter on screw withdrawal strength in dimension lumber of wood structure. Journal of Northwest Forestry University 29(5): 195-198 (in Chinese).

17. Que, Z.L., Jiang, H.D., Fu, Q., Yang, L., Sun, Y.F., 2012: Effects of vessel diameter on screw withdrawal strength in laminated veneer lumbers. China Wood-Based Panels 06: 14-16 (in Chinese).
18. Rajak, Z.I.B.H.A., Eckelman, C.A., 1993: Edge and face withdrawal strength of large screws in particleboard and medium density fiberboard. Forest products journal 43(4): 25-31.
19. Semple, K.E., Smith, G.D., 2007: Prediction of internal bond strength in particleboard from screw withdrawal resistance models. Wood and fiber science 38(2): 256-267.
20. Tankut, N., 2006: Moment resistance of corner joints connected with different RTA fasteners in cabinet construction. Forest products journal 56(4): 35-40.
21. Williamson, T., 2002: APA engineered wood handbook. McGraw Hill Professional.
22. Yalçın, Ö.R.S., Ramazan, Ö.Z.E.N., Doğanay, S., 1998: Screw holding ability (Strength) of wood materials used in furniture manufacture. Turkish Journal of Agriculture and Forestry 22(1): 29-34.

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