

INVESTIGATION INTO THE EFFECT OF SOME FACTORS ON THE FAILURE LOAD OF CORNER JOINTS REINFORCED WITH GLASS-FIBER FABRIC IN CASE- TYPE FURNITURE

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(RECEIVED SEPTEMBER 2012)

ABSTRACT

In this study the effects of material type, test method, joint type, and reinforcement on the failure load of L-type corner joints, which are reinforced with glass-fiber fabric in case-type furniture have been analyzed experimentally and statistically in laminated medium-density fiberboard (LMDF) and laminated particleboard (LPB) material. The failure loads of corner joints have been analyzed experimentally under compression and tension loads. Dowels (D), dowel + glass fiber composite layer from the outside (DCO), dowel + glass fiber composite layer from the inside (DCI), dowel + glass fiber composite layer from the outside and inside (DCOI) and dowel + glass fiber composite layer from the edge (DCE) are used as joint methods. Tests were carried out according to ASTM Standards. The test results were analyzed statistically by variance analysis. The results show that the failure load takes its highest value for DCOI joints in both tension and compression and lowest value for D joints in tension and for D and DCI joints in compression. The LMDF corner joints were stronger than the LPB corner joints. The tension failure load values were greater than the compression failure load of L-type reinforced corner joints except for DCO joints. The reinforced corner joints were considerably greater than the unreinforced joints.

KEYWORDS: Case-type furniture, glass-fiber fabric, dowel, corner joints, failure load.

INTRODUCTION

Production of furniture adequate to meet (even) the basic needs of an ever-increasing world population in the face of an ever-shrinking traditional resource base as well as increase its quality of life requires better product engineering, more efficient use of composite materials and better

“proofing” of the furniture to ensure its durability (Eckelman and Erdil 1999).

The mechanical property tests of wood-based composite boards do not necessarily evaluate those characteristics of the board that are most important to its use in furniture. Tests indicate that at least three other characteristics govern the performance of composite-based constructions, namely, edge splitting strength, edge breaking strength, and edge pull out strength. Edge splitting strength is an important characteristic of composites used in furniture. Tests indicate that when a case fails owing to racking forces, either the end of one panel splits, or, the edge of the mating panel breaks (Eckelman and Erdil 1999). In furniture construction technology too, the weakest points against heavy weights are indicated as the corner joints of the furniture. Therefore, to strengthen furniture corner joints have a great deal of importance. For this purpose, many researchers tested strength of many fasteners in the furniture corner joints. Recently, many engineering fields have used glass-fiber fabrics to improve the resistance of the material. In this study, therefore, the joint method of glass fiber composite which is different from the joint methods which have been tested by many researchers up to now is tested.

Fiber reinforced polymer (FRP) composites have the potential to replace some conventional construction materials in both new construction and retrofitting applications Bakis et al. (2002). The composite materials consist of unidirectional fibers embedded in a matrix resin. The fibers provide the strength and stiffness, while the resin holds the fibers and transfers stresses between the fibers. Two major advantages of FRP composites are the high strength-to-weight ratio and non-corrosive characteristics (Fam et al. 2005, Kim and Hefferman 2008).

Acceptable reinforcement systems and processes would also permit structural use of poorer quality wood including short lengths. Additional advantages and savings could be realized by reinforcing and thereby strengthening mechanical fasteners, regions of stress concentration, and finger and butt joints Rowlands (Rowlands et al. 1986).

Researchers have conducted several studies related to glass fiber. Ghassan (2011) determined the effect of FRP on the structural properties of a single piece of wood identified as southern pine wood. He concluded that addition of FRP has significant impact on strength and behavior of structural wooden elements. He also concluded that testing results revealed a 14 % increase in compression, 18 % increase in bending, and 10 % increase in tension. Stevens and Criner (2000) determined that the FRP-reinforced beams are stronger than non-reinforced glulam beams because the reinforcement absorbs some of the most damaging tension stresses endured by conventional wooden glulam beams. In the study by Rowlands et al. (1986) the technical feasibility of producing internally reinforced laminated wood was evaluated experimentally. They concluded that glass-fiber reinforced Douglas fir (18 % glass by volume) produced a 40 % stiffness enhancement and doubled the strength over similar unreinforced wood. Windorski et al. (1997) investigated the use of fiberglass reinforcement to enhance the load-carrying capacity of bolted wood connections. They concluded that the ultimate strength of a three-layer reinforced connection was 33 % greater than the unreinforced connection for parallel-to-grain loading and more than 100 % for perpendicular-to-grain loading. Heiduschke and Haller (2010a) discussed the load carrying behavior of lightweight columns with circular hollow cross sections. They concluded that when compared to unreinforced tubes, the ultimate load of FRP reinforced tubes is increased by about 60 %. Cabrero et al. (2010a) investigated the outcomes of a parametric study on the performance of reinforced wood tubes submitted to axial compression. They explained that the failure response stress for the corresponding unreinforced tube was also depicted; a clear improvement of the performance of the tube in the material controlled area was noticed; and the strength of the unreinforced material was about 2/3 of the reinforced. Heiduschke et al. (2008) investigated to provide engineered wood products on the basis of formed wood profiles being

optionally reinforced with technical fibers and textiles for structural purposes. They concluded that when compared to the unreinforced columns, the load-carrying capacity of the reinforced columns increased by factors of 1.46 and 1.22, respectively.

Heiduschke and Haller (2010b) investigated work dealing with the analysis and testing of wooden tubes reinforced with fiber reinforced plastic (FRP) composites. Cabrero et al. (2010b) worked dealing with the development of an analytical model to obtain the axial strength for the design of wooden tubes reinforced with glass-fiber-epoxy composite subjected to simple axial compression loading. Fam et al. (2010) investigated the behavior of cantilevered glass-fiber-reinforced polymer (GFRP) hollow tubular poles subjected to both lateral and axial loads. Han et al. (2007) evaluated the elastic buckling strength of a GFRP (Glass Fiber Reinforced Plastic) pipe reinforced with ribs. Fam and Mandal (2006) carried out an experimental investigation on pre-stressed, concrete-filled, fiber-reinforced polymer tubes (PCFFTs). Shin et al. (2002) investigated the axial crushing and energy absorption behavior of an Al/glass fiber reinforced epoxy square composite hybrid tube through ply orientations of 0° , 90° , $0^\circ/90^\circ$ and $\pm 45^\circ$.

Researchers have conducted several studies related to the dowel joints. Tankut (2005) examined optimum dowel spacing for corner joints in 32 mm cabinet construction. He determined that maximum moment is obtained in joints when the spacing between dowels is at least 96 mm. Liu and Eckelman (1998) carried out study in order to determine the bending strength of case joints constructed with multiple fasteners in 19 mm thick particleboard (PB) and 22 mm thick MDF. They tested both dowels and screw joints under compression load. They concluded that probably because of the adhesive added to the joint area, corner joints constructed with dowels could exceed the bending strength of the board itself. Altinok et al. (2009) analyzed the effects of using dowel joints, spline joints, and combined use of the two methods, on the diagonal pressure and tension strength in corner joints of case-type furniture constructions for melamine-faced chipboard sheet material. They found that specimens prepared using the two joint types together (combined) provided higher pressure and tension strength values than the widely used dowel joint type.

Tankut and Tankut (2010) have carried a study out to determine the effects of the edge banding material, namely polyvinyl chloride (PVC), melamine and wood veneer, thickness of edge banding material, and wood composite panel type on the diagonal compression and tension strength properties of LPB and LMDF. They found that samples with edge banding gave higher diagonal tension and compression strength than control samples. In compression tests of control specimens, they concluded that the edge of the face member split within its thickness and the split was continuous, parallel and very close to the glue line throughout the length of the specimens. In the tension test, they concluded that butt members split inside the corner of the joints near the glue line and linearly continuously throughout the length of specimens.

Norvydas et al. (2005) determined that the weakest place of doweled joints in case of furniture is the edge member, thus 98 % of all joints fail due to its fracture. In addition, they concluded that distance between the centers of dowel holes should be the multiple of drilling module $m = 32$ mm, but not less than 96 mm. They concluded that there are three characteristic schemes of joint failure: I- fracture zones of the joint are overlapping, II- fracture zones of the joint are not overlapping, III- expanded fracture zones of the joint reach the edge of a face member.

Glass-fiber fabric has been examined by many researchers. On the other hand, many fastener components were examined for effect of corner joints in case-type furniture by many researchers. But the effects of reinforcing available corner joining methods with glass-fiber fabric in terms of the strengthening of case-type furniture products are not known for wood-based materials. Reinforcement with fabric of corner joints in case-type furniture is a new research topic. The

study by Yerlikaya and Aktas 2012 in this topic, the failure loads of L-type corner joints in case-type furniture have been analyzed experimentally and statistically in laminated medium-density fiberboard material. For this purpose, they used dowel, minifix and glass-fiber fabric were used as fastener components. They concluded that the failure load takes its highest value in the dowel+minifix+composite layer (DMC) case for both average values of the test results and for 95 % reliability under Weibull distribution, while it takes its lowest value in the dowel (D) case.

The presented research work deals with investigation of the effect of material type, test method, joint type, and reinforced on failure loads of L-type corner joints reinforced with a glass-fiber composite layer (fabric) in laminated particleboard (LPB) and laminated medium density fiberboard (LMDF). The current study addresses the following research objectives: (1) to determine the effects of materials, (2) to determine the effects of glass-fiber composite layer (fabric), (3) to determine the effects of the joint type, namely dowels (D), dowel + fabric from the outside (DCO), dowel + fabric from the inside (DCI), dowel + fabric from the outside and inside (DCOI), dowel + fabric from the edge (DCE) on failure loads in L-type corner joints in case-type furniture, (4) to determine the effects of diagonal compression and tension failure load behavior in different joints, which are reinforced with glass-fiber composite layer (fabric), and (5) to statistically analyze, using variance analysis, the effects of the fastener type and material type on failure loads in L-type furniture corner joints.

MATERIAL AND METHODS

Specimens were constructed from 18 mm thick LPB and LMDF, which is a common utilization by most manufacturers. The LMDF panels were tested for specific gravity (SG), moisture content (MC), and modulus of elasticity (MOE) in accordance with ASTM D1037-6a 2006. The result of these tests is given in Tab. 1.

Tab. 1: Average MC and mechanical properties of the LPB and LMDF used in the test.

Material	MC (%)	SG	MOE (N.mm ⁻²)
LMDF	7.56 (3)	0.75	3522
LPB	8.32	0.65	2838

MC: Moisture content, SG: Specific gravity, MOE: Modulus of elasticity

In this study, dowels and glass fiber composite layers (fabrics) were used as fastener components (Fig. 1). Glass-fiber fabrics having 400 g.m⁻² and multi-groove beech dowels 8 mm in diameter and 34 mm in length were used (Fig. 1a, b). Dowels were assembled with the polyvinyl acetate (PVAc) adhesive. Fabrics were fastened with epoxy resin and hardener. The type of epoxy resin used in the matrix material was Bisphenol ACY-225 and the hardener was Anhydride HY-225. In general, each specimen consisted of two principal structural members, a face member and a butt member.

In order to investigate failure load of L-type corner joints reinforced with glass-fiber fabric, D, DCO, DCI, DCOI and DCE corner joint methods were used (Fig. 2). Five specimens were prepared and tested for every configuration. Specimens were drilled according to drilling plans with a drilling machine (Three Lines Multi-Boring Machine BJK65) at the speed of 500 rpm as shown Fig. 3.

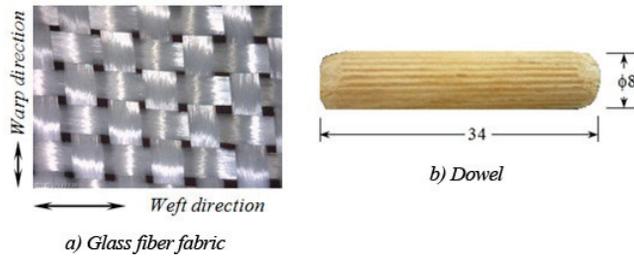


Fig. 1: Fastener materials (dimensions in mm).

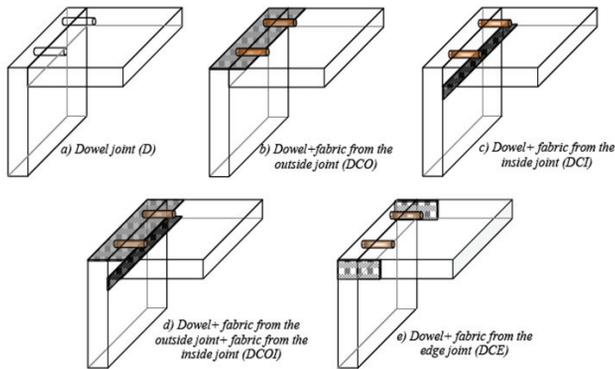


Fig. 2: The configuration of L-type corner joints.

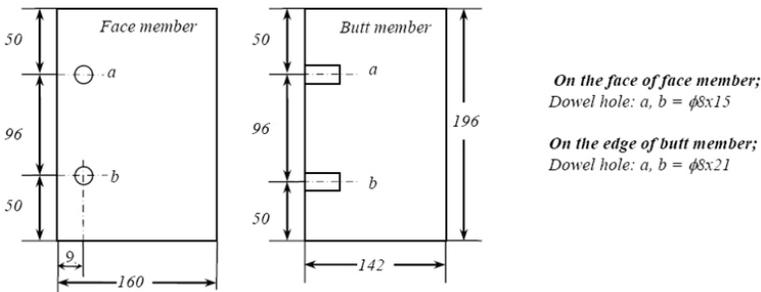


Fig. 3: Drilling plans of specimen (dimensions in mm).

Typical configuration of the specimens used in the tests is given in Fig. 4. In all the specimens, after only the dowel holes on both the butt and face member were glued with PVAc adhesive, dowels were driven into this glued hole for the butt member by a mold (Fig. 4a). Then, face and butt members were placed in conjunction. For the specimen using fabric joints, areas where the fabrics were to be placed were glued with a mixture of epoxy resin and hardener. Two layers of fabric were placed on these areas and epoxy applied (Fig. 4b, c, d and e). These specimens were left to dry for two days.

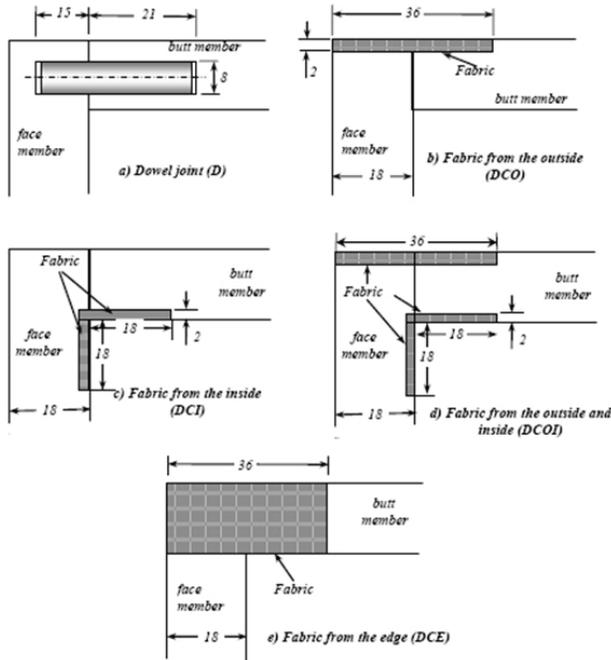


Fig. 4: Typical configuration of the specimens used in the test (dimensions in mm).

A vertical force is applied to a typical case-type construction. When a vertical force is applied, one corner of the construction is subjected to a moment trying to open the joint (Fig. 5 point a), and the other corner is subjected to a moment trying to close the joint (Fig. 5 point b). In order to simulate these forces, two tests were developed. One is a corner joint subjected to compression force causing a moment tending to open the joint (Fig. 6a), and the other is a corner joint subjected to tension force causing a moment tending to close the joint (Fig. 6b). In the tension test setup, each of the supports was placed on metal plates with four bearings so that the two joint members were free to move sideways. Load was applied to each specimen until some separation occurred between face and butt members. The load and displacement graphs were plotted by a computer for all tests. The tests were carried out at room temperature of $\sim 20^{\circ}\text{C}$ with a 10 kN loading capacity Universal testing machine at a speed of $1.5\text{ mm}\cdot\text{min}^{-1}$.

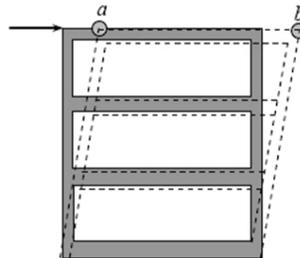


Fig. 5: A typical case-type construction applied by a vertical force.

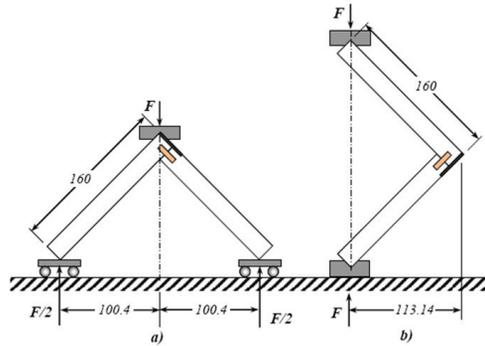


Fig. 6: Loading forms of specimen subjected to tension and compression loads (measurements in mm.)

The variance analysis was carried out on the data at the 0.05 significance level for the individual data to examine the main factors (material type and joint type) and their interactions on the failure load of the joints. It was to be determined by the Duncan test whether there was a meaningful difference between the groups.

RESULTS AND DISCUSSION

Failure load

The results obtained from the experiments in the present work are given in Tab. 2. All the results obtained from the experiments were analyzed statistically using SPSS 15 statistical analysis software. The results of the variance analysis are given in Tabs. 3 and 4. For tension, the results show that there were significant differences at the 0.1 percent significance in the failure load in terms of the joint type, and the interacting effects of material and joint type factors, but, there was no significant difference at the 5 percent significance in the failure load in terms of the material type. For compression, the results show that there was significant difference at the 0.1 percent significance level in the failure load in terms of the joint type, at the 1 percent significance level in the failure load in terms of the material type, and at the 1-5 percent significance level in the failure load in terms of the interacting effects of material and joint type factors.

Tab. 2: Failure load values (N).

Joint type	Tension				Compression			
	LMDF		LPB		LMDF		LPB	
	Failure load	HG	Failure load	HG	Failure load	HG	Failure load	HG
D	923	D	895	D	229	D	210	B
DCO	1462	C	1155	C, D	1587	A	1260	A
DCI	2212	B	2140	B	252	D	250	B
DCOI	2746	A	4236	A	1210	B	1298	A
DCE	1735	C	1300	C	608	C	408	B

Tab. 3: Results of variance analysis (for tension).

Source of variance	Sum of squares	df	Mean square	F ratio	Level of significance ^a
Main factors					
Ab = Material type	210470.720	1	210470.720	3.868	NS
Bc = Joint type	40837967.320	4	10209491.830	187.607	***
Interactions					
A * B	6063247.880	4	1515811.970	27.854	***
Error	2176786.400	40	54419.660		
Corrected total	49288472.320	49			

a *** : Highly significant with probability < 0.001,

b Material type (LMDF, LPB),

a NS : Non significant

c Joint type (D, DCO, DCI, DCOI, and DCE).

Tab. 4: Results of variance analysis (for compression).

Source of variance	Sum of squares	df	Mean square	F ratio	Level of significance ^a
Main factors					
A ^b = Material type	105708.020	1	105708.020	5.877	*
B ^c = Joint type	12951068.00	4	3237767.00	180.020	***
Interactions					
A * B	280953.680	4	70238.420	3.905	**
Error	719423.600	40	17985.590		
Corrected total	14057153.30	49			

a *** : Highly significant with probability < 0.001,

a * : Less significant with probability 0.01- 0.05,

c : Joint type (D, DCO, DCI, DCOI, and DCE).

a ** : Moderately significant with probability < 0.01,

b : Material type (LMDF, LPB),

The difference between the groups regarding the effect of the joint type on the failure load is meaningful regarding 5 % of probability. The Duncan test results conducted to determine the importance of the differences between the groups are given in Tab. 5. According to Tab. 5, the highest failure load was obtained in the DCOI for the tension, and in the DCO for the compression, the lowest in the D for the tension, and in the D and DCI for the compression.

Tab. 5: Homogeneous groups.

Joint type	Tension		Compression	
	Failure load	HG	Failure load	HG
D	909.2000	D	219.8000	D
DCO	1308.2000	C	1423.6000	A
DCI	2176.5000	B	250.6000	D
DCOI	3490.9000	A	1254.0000	B
DCE	1517.4000	C	507.9000	C

HG : Homogeneous groups

Effect of joint type

As shown in Fig. 7, for tension in both the LMDF and LPB, the failure load takes its highest value for DCOI joints and lowest value for D joints. These maximum results are obtained when the fabric from outside and inside the corner joint is used. Since the fabric is at the outer and inner surface of the corner, the fabric on the outer surface is subjected to compression and the fabric on the inner surface subjected to tension. These minimum results are obtained when the fabric is not used. Although the failure loads for D, DCO, and DCE joints are at the minimum level, for DCOI joints they are at the maximum. In addition, the failure loads for DCI joints are at the mid-level. These middle and highest results are also obtained for the composite layer from inside is used in the corner joint. Since the composite layer is at the inner surface of the corner, the composite layer is subjected to tension. The failure load values for DCI joints are higher than DCO joints. The reason for this is that the effect of the fabric from outside on the failure load is also low.

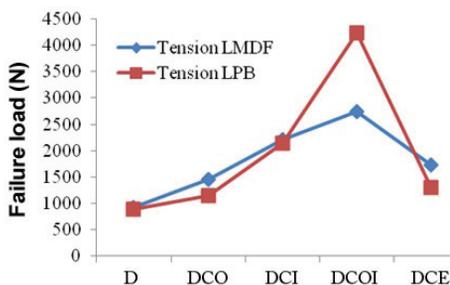


Fig. 7: Average failure load of joint types in relation to the material type in tension.

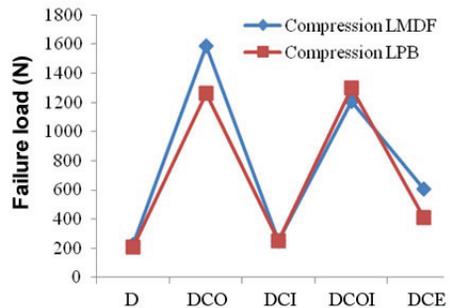


Fig. 8: Average failure load of joint types in relation to the material type in compression.

For compression in both the LMDF and LPB in the Fig. 8, it can be seen that the failure loads take their highest values for DCOI joints and lowest values for D and DCI joints. These maximum results are obtained when the fabric from outside and inside is used in the corner joint. Because of this the fabric on the outer surface is subjected to compression and the fabric on the inner surface is subjected to tension. These minimum results are obtained when the fabric is not used and the fabric from inside is used. The values for DCO joints and DCOI joints are nearly the same for LPB. In addition, the values for D joints and DCI joints are nearly the same for LPB.

Effect of material type

As shown in Figs. 7 and 8, the LMDF corner joints were stronger than the LPB corner joints. According to several researchers (Tankut 2005, Liu and Eckelman 1998, Altinok et al. 2009, Tankut 2010), the reason for the stronger effect when the joints were constructed of MDF than when the joints were constructed of PB is that MDF has a higher internal bond strength than PB.

Effect of reinforced

While the failure load values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased 58, 140, 198 and 88 % for LMDF and 29, 139, 373 and 45 % for LPB more than the failure load values of unreinforced corner joints (D joints), the failure load values of reinforced joints in compression situations increased 593, 10,

428 and 166 % for LMDF and 500, 19, 518 and 94 for LPB more than the failure load values of unreinforced joints. Ghassan (2011) also concluded that testing the results of the addition of FRP revealed a 14 increase in compression, and 10 % increase in tension. Heiduschke and Haller (2010) concluded that when compared to unreinforced tubes, the ultimate load of FRP reinforced tubes is an increase of about 60 %. Rowlands et al. (1986) concluded that glass-fiber reinforced Douglas fir (18 % glass by volume) produced a 40 % stiffness enhancement and doubled the strength over similar unreinforced wood. Cabrero et al. (2010) explained that the strength of the unreinforced material was about 2/3 of the reinforced. Windorski et al. (1997) concluded that the ultimate strength of a three-layer reinforced connection was 33 % greater than the unreinforced connection for parallel-to-grain loading and more than 100 % for perpendicular-to-grain loading.

In other words, while the failure load values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased by factors of 1.58, 2.40, 2.98 and 1.88 for LMDF and 1.29, 1.2, 6.2 and 1.9 for LPB in the failure load values of unreinforced corner joints (D joints), the failure load values of reinforced joints in a compression situation are 6.93, 1.10, 5.28 and 2.66 for LMDF and 6, 1.2, 6.2 and 1.9 for LPB times as much as the failure load values of unreinforced joints. Yerlikaya and Aktas (2012) concluded that the average failure load values of dowel joints which are reinforced with glass-fiber fabric increased by factors of 2.66 (in compression), 0.13 (in tension) of the dowel joint. In addition to this they concluded that the dowel + minifix joints which are reinforced with glass-fiber fabric increased by factors of 1.58 (in compression), 0.19 (in tension) of the dowel + minifix joint. Heiduschke et al. (2008) concluded that, when compared to the unreinforced columns, the load-carrying capacity of the reinforced columns increased by factors of 1.46 and 1.22. Stevens and Criner (2000) determined that the FRP-reinforced beams are stronger than non-reinforced glulam beams because the reinforcement absorbs some of the most damaging tension stresses endured by conventional wooden glulam beams.

Effect of test method

The tension failure load values were greater than the compression failure load of L-type reinforced corner joints except for DCO joints. However, compression and tension failure loads for DCO joints were nearly the same. The tension average failure load values increased 303, 778, 127 and 185 % for LMDF and 326, 757, 226 and 219 % for LPB more than the compression average failure load values for D, DCI, DCOI, and DCE joints, respectively. For DCO joints, the tension average failure load values decreased 8 % for LMDF and 9 % for LPB more than the compression average failure load values. According to several researchers (Tankut 2005, Liu and Eckelman 1998, Tankut 2010, Norvydas et al. 2005), the reason for the phenomena in which the tension strength was greater than the compression strength is that the bending strength of joints loaded in compression is presumably related to the internal bond strength of the board, whereas the bending strength of joints loaded in tension is presumably related to the surface tensile strength parallel to the plane of the board.

CONCLUSIONS

The study questions and then rejects the assumption that the failure load of corner joints of case-type furniture is taken as an average of the experimental results.

In both the LMDF and LPB, the failure load takes its highest value for DCOI joints in both tension and compression and lowest value for D joints in tension and for D and DCI joints

in compression.

The LMDF corner joints were stronger than the LPB corner joints.

The failure load values of reinforced corner joints increased 58, 140, 198 and 88 % for LMDF and 29, 139, 373 and 45 % for LPB in tension situations and 593, 10, 428 and 166 % for LMDF and 500, 19, 518 and 94 % for LPB in compression situations more than the failure load values of unreinforced corner joints (DCO, DCI, DCOI, and DCE joints, respectively).

The tension average failure load values increased 303, 778, 127 and 185 % for LMDF and 326, 757, 226 and 219 % for LPB more than the compression average failure load values for D, DCI, DCOI, and DCE joints, respectively. For DCO joints, the tension average failure load values decreased 8 % for LMDF and 9 % for LPB more than the compression average failure load values.

Additional work is needed in order to establish the failure sensitivity of the reinforced corner joints for all wood composite materials and wood panels, e.g. MDF massive panels, and for different thickness of panels, e.g. 16, 22 mm, and different thickness or layers of glass-fiber fabric, e.g. one and three layers.

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