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INVESTIGATION OF OPTIMUM DOWEL SPACING FOR CORNER JOINTS, WHICH ARE REINFORCED WITH GLASS-FIBER FABRIC IN CASE-TYPE FURNITURE

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ABSTRACT

Optimum dowel spacing for corner joints, which are reinforced with glass-fiber fabric in case-type furniture, was investigated in this study. In addition, the effect of dowel spacing, and the number of dowels on the bending moment was examined. Laminated medium-density fiberboard (LMDF) and laminated particleboard (LPB) L-type corner joints were tested under compression load. Dowels and glass-fiber composite layers (glass-fiber fabric) were used as fastener components. This test was carried out on 96, 128, 196, 256, and 320 mm wide specimens that were constructed with 2 and 3 dowels. Tests were carried out according to ASTM D1037, 2006 Standard. The test results were analyzed statistically by a multi variance analysis to examine the effect of the main factors (number of dowel and dowel spacing) and their interactions on the bending moment of the joints. The results show that the optimum dowel spacing is 96 mm in LMDF, and 128 mm in LPB. The stronger joint is obtained when more dowels are used in the joint. The joints with 32- and 64 mm dowel spacings had less strength than the joints with 96- and 128 mm dowel spacing.

KEYWORDS: Case-type furniture, corner joint, glass-fiber fabric, dowel, dowel spacing.

INTRODUCTION

Tankut and Tankut (2009) stated that it is necessary to understand fastening and improvements in joinery and to develop construction techniques best suited for use with composites such as the use of local reinforcements of the composite itself. For this purpose, to reinforce the joint area of corner joints, glass-fiber fabrics can be used in the corner of case-type furniture. Studies on glass fiber fabric, has shown a significant increase in resistance. In recent years, glass fiber fabric has been used to provide increased resistance in many engineering fields. For example, concrete, plastic pipes and hollow wood wrapped around it began to be used. At the same time, the idea of, increasing the resistance of glass fiber fabric in furniture corner joints, was put forward by Yerlikaya and Aktas (2012) and was applied also by Yerlikaya and Aktas (2012).

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. The two major advantages of FRP composites are the high strength-to-weight ratio and its non-corrosive characteristics (Fam et al. 2005, Kim and Heffernan 2008).

A basic understanding of the influence of dowel spacing on corner joint strength performance in case-type furniture is necessary to assist furniture manufacturers as they engineer their products (Tankut 2005). Several studies have been conducted regarding fastener spacing, e.g. dowel, and screw. However, no researcher to date has examined the dowel spacing of corner joints, which are reinforced with glass-fiber fabric.

Zhang and Eckelman (1993) analyzed the rational design of multi-dowel corner joints and optimum dowel spacing in 18 mm thick particleboard (PB) case-type construction. They constructed a bending strength test that was carried out on 172, 229, 279, and 256 mm wide specimens that were constructed with 2 to 5 dowels. They found that the maximum strength per dowel was obtained when the dowels were spaced at least 76 mm apart. Norvydas et al. (2005) investigated the influence of the dowel spacing on the joint strength carried out using joints produced from PB of 16 and 18 mm in thickness connected with the dowels diameter of 8 and 10 mm. They expressed the view that the strength of dowel joint depends on the dowel spacing and the distance between the dowel and the edge of a detail. They indicated that the dowel spacing should be the multiple of the drilling module m = 32 mm, but not less than 96 mm. Tankut (2005) evaluated the effect of dowel spacing on the bending moment capacity of corner joints in 32-mm case construction which were prepared from laminated particleboard (LPB) and laminated medium-density fiberboard (LMDF) materials. He concluded that the optimum dowel spacing was 96 mm in both these materials. He showed that LMDF corner joints were stronger than PB corner joints. Wan-Qıan and Eckelman (1998) determined the bending strength of 457 mm wide corner joints constructed with multiple fasteners. They concluded that the bending strength per fastener began to drop as the spacing between the fasteners decreased to less than approximately 57 mm.

Cai and Wang (1993) determined that the stiffness of corner joints increased with the use of a greater number of dowels. As an example, when the number of dowels rises from two to four or from four to eight in corner joints, the displacement of every node point in the case furniture was reduced by 5–15. Rajak and Eckelman (1996) determined the effect of screw diameter, screw length, the number of screws used, and the length of the specimen on the bending strength of the joints. They reported that the bending strength of a two-fastener joint was twice as strong as that of a single-fastener joint. Kasal et al. (2008) investigated the effects of the number of screws and screw sizes on the bending moment resistance of L-type furniture corner joints constructed of LPB and LMDF. They concluded that the ultimate moment resistance was obtained with the medium-density fiberboard (MDF) specimens when the number of screws was four in the joints. They concluded that the moment resistance increased significantly as the number of screws increased from 2 to 4 in increments of 1. In addition, they showed that MDF corner joints showed a higher moment resistance than PB corner joints for both compression and tension tests.

These studies provide design information on the optimum dowel, screw, and fastener spacing. However, researchers have yet to examine the optimum dowel spacing of joints, which are reinforced with a glass-fiber fabric. Thus, the purpose of this study is (1) to determine the optimum dowel spacing for the joints which are reinforced with glass-fiber fabric, (2) to determine the effects of number of dowels, and the length of the specimen used in the joints on the bending moment of the reinforced dowel corner joints, (3) to compare the bending moment of the dowel corner joints which are reinforced with the glass-fiber fabric, which are constructed of different panel materials, namely LMDF and LPB, (4) to statistically analyze, using a multiple variance analysis, the effects of the number of dowel and dowel spacing on the bending moment in L-type furniture corner joints.

MATERIAL AND METHODS

In this study, the test material included eighteen-mm thick LMDF and LPB. Dowels and glass-fiber composite layers (glass-fiber fabric) were used as fastener components (Fig. 1). Multi-groove beech dowels 8 mm in diameter and 34 mm in length were used (Fig. 1a). Glass-fiber woven fabrics having 400g.m^{-2} were used (Fig. 1b). The dowels were assembled with PVAc adhesive in this study. The glass-fiber fabrics were fastened with epoxy adhesive and hardener. The type of epoxy resin used in the matrix material was Bisphenol ACY-225 and the hardener was Anhydride HY-225.

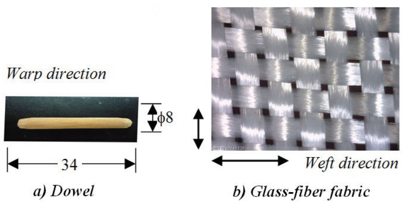

Fig. 1: Fastener materials used in the study (dimensions in mm).

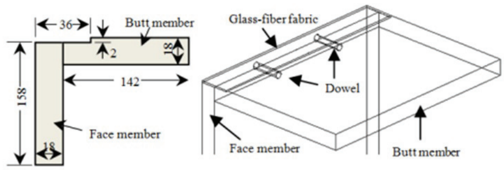

Fig. 2: The general configuration of specimens (dimensions in mm).

The general configuration of the specimens is given in Fig. 2. Five duplicates of each joint configuration were constructed. Each specimen consisted of two principal structural members, a face and butt member. These members had the same width, but the length of the butt member was 16 mm less than the face member in order to maintain joint symmetry. The members were joined together by dowels along the joint area, and then, a fabric 2 mm in thickness and 36 mm in width was glued along the outer surface of the joint.

The placements of the dowels in the joint area for the specimens are given in Fig. 3. The specimens were drilled with a drilling machine (Three Lines Multi-Boring Machine BJK65) at a speed of 500 rpm. The dowel holes were drilled into the centerline of the thickness of the butt member. The corresponding dowel holes were drilled from the 7 mm inside of the edge of the face member (Fig. 4). As shown in Fig. 4, the nominal hole depth was 15 mm in the face member and 21 mm in the butt member. In order to be placed in the fabric, the butt members were cut to 2 mm in thickness and 18 mm in width along the joint area from the outer surface of their joining areas.

During construction only the dowel holes were glued with PVAc. After the dowel holes on the face member were glued, the dowels, to be 14 mm inside, were driven into this glued hole by a mould (Fig. 4). In all of the samples, wax paper was added between the two members to prevent the face from adhering to the butt member. Then, the dowel holes on the butt member were glued; and, the face and butt members were placed in conjunction. All the specimens were left to dry for two days. Then, the areas where the glass-fiber 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. 4). These specimens were left to dry for two days.

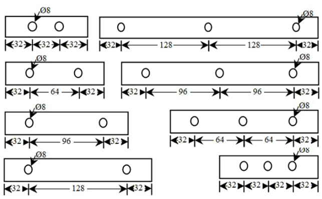

Fig. 3: Placements of the dowels in the joint area for each joint configuration (dimensions in mm).

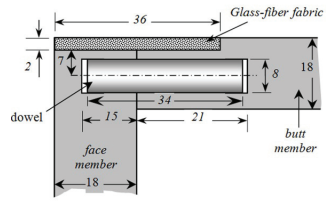

Fig. 4: The configuration of the dowel and glass-fiber fabric used in the tests (dimensions in mm).

The LMDF and LPB materials were tested for specific gravity, moisture content and modulus of elasticity in accordance with ASTM D1037, 2006.

The specimens were located in the compression only as shown in Fig. 5. In a study by Yerlikaya and Aktas (2012) it was stated that the failure loads for dowel + fabric joints and dowel joints are approximately the same in tension tests. In these cases, they stated that the fabric is subjected to compression and bending. They explained that since the flexural rigidity of the fabric is low, its effect on the failure loads is also low. Therefore, in this study, the specimens were not located in tension. All failure load tests were carried out on a 10 kN loading capacity Universal testing machine. A rate of loading at 1.5 mm per minute was used in all the tests. The maximum load was used to represent the failure load of the corner joints of the case-type furniture. The load was applied to each specimen until a failure and some separation occurred between the face and butt members. The load and displacement graphs were plotted by a computer for all the tests.

Then, ultimate failure load values were calculated to a corresponding bending moment values (M) by the expression: M=Rxd where: R= reaction against the applied load, d= moment arm that is defined as shown in Fig. 5.

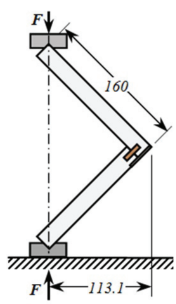

Fig. 5: Loading forms of specimen subjected to compression loads (measurements in mm).

The multiple variance analysis was carried out on the data at the 0.05 significance level for the individual data to examine the main factors (number of dowel and dowel spacing) and their interactions on the bending moment of the joints. It was to be determined by the Duncan test whether there was a meaningful difference between the groups.

RESULTS AND DISCUSSION

The specific gravity, moisture content and modulus of the elasticity values of the LMDF and LPB used in the tests is given in Tab. 1. The average bending moment of the corner joints under the compression tests are given in Tab. 2.

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

	MC (%)	SG	MOE ($N.mm^{-2}$)
LMDF	7.56 (3)	0.75	3522
LPB	8.34	0.5	2826

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

Tab. 2: Average bending moment of LMDF and LPB corner joints according to length of specimen, dowel spacing, and number of dowel.

Length of specimen	Dowel spacing	Number of dowel	Bending moment (Nm)	
			LMDF	LPB
96	32	2	63.0	51.3
128	32	3	82.5	69.6
128	64	2	85.1	78.3
192	64	3	97.7	114.1
160	96	2	123.6	99.0
256	96	3	190.1	141.2
192	128	2	110.1	113.7
320	128	3	172.3	198.7

According to the results of the test, in comparison of the corner joints with two and three dowels for both materials, Fig. 6 clearly shows that a stronger joint is obtained when there are more dowels used in the joint. Test results of similar previous studies concerning the number of fasteners (Cai and Wang 1993, Rajak and Eckelman 1996, Kasal et al. 2008) are consistent with this study. In addition, while the optimum dowel spacing is 96 mm in LMDF (Fig. 6a), the optimum dowel spacing is 128 mm in LPB (Fig. 6b). The reason for this is the effect of the fabric in the LPB increases because the length of the specimen increases. That is, the adhesive force between the LPB and fabric is more than the adhesive force between the LMDF and fabric when the length of the specimen is 192 mm and more than 192 mm. Optimum dowel spacing was obtained at 96 mm by Tankut (2005). For LMDF, this result obtained by Tankut (2006) is compatible with this study. In addition, Norvydas et al. (2005) claimed that the dowel spacing must be at least 96 mm where as Zhang and Eckelman (1993) asserted that the distance must be at least 76 mm. In addition, Wan-Qıan and Eckelman (1998), claimed if the dowel spacing is smaller than approximately 57 mm, the strength decreases. The joints with 32- and 64 mm dowel spacings had less strength than the joints with 96- and 128 mm dowel spacing. By Tankut (2005), the reason for this can be explained by overlapping zones influenced by the neighbouring dowels.

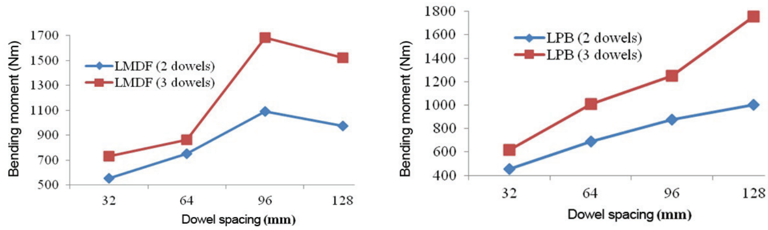

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Fig. 6: Average bending moment values as a function of number of dowels and dowel spacing.

As shown in Fig. 7a, in comparison to LMDF and LPB corner joints for the joints with two dowels, the LMDF corner joints were stronger than the LPB corner joints. According to Tankut (2005), the reason for the stronger effect when the joints were constructed of MDF was stronger than the joints constructed of PB is that MDF has higher internal bond strength than PB. However, in this study, LPB corner joints were stronger than LMDF corner joints because the length of the specimen is 192 mm when the dowel spacing is 128 mm. As explained above, in LPB corner joints, the stronger joints are obtained when the length of the specimen is 192 mm and more than 192 mm. However, for joints with three dowels as shown in Fig. 7b, the LPB corner joints were stronger than the LMDF corner joints when the length of the specimen is 192 mm and more than 192 mm. Nonetheless, the LMDF corner joints were stronger than the LPB corner joints when the length of the specimen is 256 mm, that is, the dowel spacing is 96 mm. This means that, the effect of the dowel spacing, which is 96 mm, is more than the effect of the length of specimen. This can be seen clearly in Fig. 8 also.

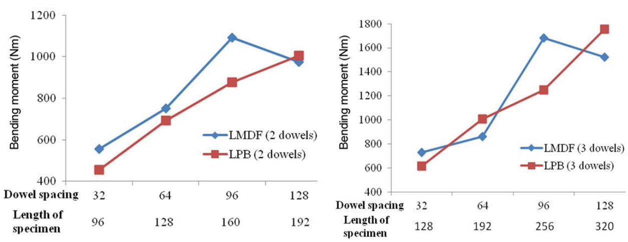

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Fig. 7: Average bending moment values as a function of material types and dowel spacings.

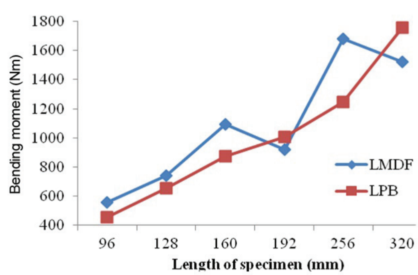

Fig. 8: Average bending moment values as a function of material types and length of specimen.

The results of the multiple variance analysis are given in Tabs. 3 and 4. For both materials, the results show that there were significant differences in the bending moment in terms of the number of dowels, dowel spacing, and the interacting effects of these factors.

Tab. 3: Results of multiple variance analysis (for LMDF).

Source of variance	Sum of squares	df	Mean square	F ratio	Level of sig.[a]
Main factors					
A[b]	16160.1	1	16160.1	531.0	***
B[c]	47712.7	3	15904.2	522.6	***
Interactions A * B	5899.5	3	1966.5	64.6	***
Error	973.8	32	30.4		
Corrected Total	70746.1	39			

A: Number of dowel, B: Dowel spacing, a *** : Highly significant with probability < 0.001,
b: Number of dowel (2, 3), c: Dowel spacing (32, 64, 96, and 128).

Tab. 4: Results of multiple variance analysis (for LPB).

Source of variance	Sum of squares	df	Mean square	F ratio	Level of sig.[a]
Main factors					
A[b]	20519.1	1	20519.1	273.7	***
B[c]	48551.9	3	16184	215.9	***
Interactions					
A * B	6014.7	3	2004.9	26.7	***
Error	2398.9	32	75		
Corrected Total	77484.5	39			

A: Number of dowel, B: Dowel spacing, a *** : Highly significant with probability < 0.001,
b: Number of dowel (2, 3), c: Dowel spacing (32, 64, 96, and 128).

The difference between the groups regarding the effect of the dowel spacing on the bending moment 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 bending moment was obtained in the 96 mm dowel spacing for the LMDF, and in the 128 mm dowel spacing for the LPB, the lowest in the 32 mm dowel spacing for both the LMDF and LPB.

Tab. 5: Homogeneous groups.

Dowel spacing	LMDF		LPB	
	Average failure load	Homogeneous groups	Average failure load	Homogeneous groups
32.00	72.7	D	60.4	D
64.00	91.3	C	96.1	C
96.00	156.7	A	120	B
128.00	141.1	B	156	A

In LMDF materials, it can be seen from Tab. 5 that the bending moment takes its highest value for the 96 mm dowel spacing, and the minimum value for the 32 mm dowel spacing. In the LPB materials, it can be seen from Tab. 5 that the bending moment takes its highest value for the 128 mm dowel spacing and the minimum value for the 32 mm dowel spacing.

CONCLUSIONS

This study was carried out in order to obtain information relating to the optimum dowel spacing of reinforced corner joints constructed of LMDF and LPB.

The optimum dowel spacing is 96 mm in LMDF, and 128 mm in LPB. The stronger joint is obtained when more dowels are used in the joint. The joints with 32- and 64 mm dowel spacings had less strength than the joints with 96- and 128 mm dowel spacing. For the joints with two dowels, except for 128 mm dowel spacing, the LMDF corner joints were stronger than the LPB corner joints. For the joints with three dowels, except for the 256 mm dowel spacing, the LPB corner joints were stronger than the LMDF corner joints when the length of specimen is 192 mm and more than 192 mm.

For both LMDF and LPB, the multiple variance analysis results show that there were significant differences in the bending moment in terms of the number of dowels, dowel spacing, and the interacting effects of these factors. According to the Duncan test results, the highest bending moment was obtained in 96 mm dowel spacing for the LMDF, and in 128 mm dowel spacing for the LPB, the lowest in the 32 mm dowel spacing for both LMDF and LPB. The bending moment takes its highest value for 96 mm dowel spacing in the LMDF materials, and for 128 mm dowel spacing in the LPB materials, and a minimum value for 32 mm dowel spacing in both LMDF and LPB.

Additional studies are needed to determine the dowel spacing of the reinforced corner joints for massive panels, and for the different thickness of panels, e.g. 16, 22 mm, and for the different thickness or layers of glass-fiber fabric, e.g. one and three layers. In addition, to determine clearly if the corner joints which are reinforced with glass-fiber fabric, constructed of LPB is as strong as the same type corner joints constructed of LMDF, strength values of more lengths of specimen need to be investigated.

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