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EFFECTS OF NUMBER AND DISTANCE BETWEEN DOWELS OF READY-TO-ASSEMBLE FURNITURE ON BENDING MOMENT RESISTANCE OF CORNER JOINTS

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ABSTRACT

In this paper, the effects of number and distance between the dowels of ready-to-assemble (RTA) on bending moment resistance of corner joints in cabinet type furniture made of different boards types were investigated. Melamine-coated particleboards (MCP) and melamine-coated fiberboards (MCF) with five different lengths were utilized as test materials. Four different distances between the first drilling hole center and the front edge, referred to as stop, were applied for each test specimen. Small cam fasteners and wooden dowels, together with boards, were used for specimen construction. It was found that the bending moment resistance of MCP and MCF increased when the wooden dowel number increased. It was also determined that the moment resistance increased for both MCP and MCF when the dowel spacing increased up to 160 mm. However, the moment resistance decreased with the increasing dowel spacing from 160 to 192. Additionally, the results showed that the bending moment resistance of MCF was 40 % higher than that of MCP.

KEYWORDS: Ready-to-assemble (RTA) furniture, bending moment resistance, corner joints, dowel number, dowel spacing.

INTRODUCTION

Furniture has been produced in various forms for centuries; however the structural features of furniture have not had the attention they deserve. Generally, designs of furniture is developed as a result trial and error. According to Eckelman (2003), traditional understanding based on previous experiences and information has been transferred from generation to generation unless very radical designs or changes occur.

Joints are the weakest parts of furniture and thus, their designs are very important. Even though furniture components have enough strength to carry the loads which the furniture bears, a failure of joints can affect the whole furniture structure negatively. In this respect, it is vitally important to make safe scientific designs in order to carry the loads on each component that constitute furniture construction (Eckelman 2003).

Several investigations have been realized on the corner joints which have yielded valuable design information for cabinet type furniture. In related tests with a number of dowels and screws, board types, and fasteners, Bachmann and Hessler (1975) carried out tests with joints constructed with dowels diameter 8 mm. They found that the moment capacities of joints increased regularly when was constructed with 1 to 4 dowels. Rajak and Eckelman (1996) reported that the bending strength of corner joints was directly proportional to the number of fasteners. The bending strength of a two-fastener joint was twice as strong as a single-fastener joint. Moreover, the authors suggested that the most appropriate screw spacing was 102 mm for a board of 19 mm in thickness. According to Efe (1998), an increase in the number of dowel was a reason for an increase in tension strength, but a decrease in compression strength. Also, fiberboard tented to have 60 % higher results than particleboard. Nicholls and Crisan (2000) determined that the stiffness values increased by increasing the number of the joint components and the thickness of the board. Additionally, higher values were acquired from the dowel joint than the minifix joints. Eren and Eckelman (1998) figured out that joint strength and the number of the joint components had a correlation. They explained that significant differences in strength exist from board to board. Kasal at al. (2008) claimed that the joint strength was enhanced when any features (the number, the diameter or the length) of the screws was increased.

In other studies about the distances of various fasteners (dowels, screws and small cam), Zhang and Eckelman (1993) analyzed the rational design of multi-dowel corner joints in 19 mm-thickness particleboard case construction; their results indicated that maximum strength was obtained when the distance between the dowels was at least 76 mm. Liu and Eckelman (1998) mentioned that strength usually weakened when the distance between the joint components was lower than approximately 57 mm. Ho and Eckelman (1994) claimed that the most appropriate screw spacing was approximately 76 mm. In addition, and similar to be aforementioned research, Liu and Eckelman's (1998) study on corner joints clearly demonstrated that for either glued dowels or screws, the bending moment capacity of the joints decreased as the spacing between the fasteners decreased below 60 mm. In the similar pattern, Tankut (2005) claimed that the maximum moment capacity per dowel is obtained in the joints when the spacing between the dowels was at least 96 mm. Also, it was determined that three dowel joints yielded better results compared to two dowel joints, and the results regarding the corner joints of MDF were three times better than that.

Further, Simek at al. (2010) investigated the effect of the end distance of cam-lock RTA fasteners and non-glued wooden dowels on the splitting and bending moment resistance and dowel number, of RTA corner joints. The results showed that for a joint length of 760 mm, the dowels significantly supported the cam connectors. It was suggested that with two or more dowels, stresses arising as the joint was loaded into compression were distributed more evenly over the joint length. Additionally, two cam fasteners and three, four or five un-glued dowels increased the bending moment capacity when the number of unglued dowels increased. Norvydays at al. (2005) observed that the strength increased whereas the dowel spacing and edge were amplified. They figured that the weakest part of cabinet type furniture was the edge components of the its dowel joints, and that the dowel spacing should not be smaller than 96 mm. Moreover, they found that the strength increased when the dowel spacing was changed from 96 to 128 mm, and the strength lowered at 160 mm.

There are other investigations on the strength of corner joints in RTA furniture construction concerning types of fasteners, composite materials, and glues. Smardzewski and Prerad (2002) investigated stress distribution in disconnected furniture joints. They showed that trapezoid temporary joints with metal construction had the most advantageous rigidity-strength properties, while wood dowels were found to play a significant role in supporting their strength. Guntekin (2002; 2003) reported that the metal fastener are generally not as strong or rigid as adhesive dowels, and MDFs are 21 % more rigid and 31 % stronger than particleboards. In respect of joints strength, the highest strength was shown by dowel joints, and in order of following seniority was trapez, blum, Type III minifix and Type II. However, there was not much difference observed between Type III and Type II's strength levels. Tankut (2006) carried out moment resistance of corner joints connected with different RTA fasteners in cabinet construction, and found that materials type, loading type and fastener type have a significant effect on the strength of RTA connected joints. Takut and Tankut (2009) investigated the effects of fastener, glue, and composite material types on the strength of corner joints in case-type furniture construction. As a result, they emphasized that on the strength of corner joint, the type of fastener, glue, and composite material are affected.

The purpose of this study is to investigate the effects of dowel numbers, the distance between the dowels, and board type on bending moment resistance of L - type corner joints for furniture. The data from the experiments was also evaluated by means of variance analysis (ANOVA).

MATERIAL AND METHODS

Test materials and joints design

The general configuration of the tested specimens is shown in Fig. 1. Each specimen, consisting of two principal structural members (a face member and a butt member) are jointed together by dowels and small (minifix) cam fasteners according to TS 4539 (1985). The face and butt members are 185 x 18 mm and 140 x 18 mm in the cross section. They were joined along their length. The member lengths are 320, 390, 460, 530 and 600 mm, which are also referred to the depth measure of cabinet type furniture.

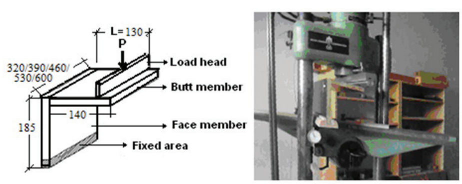

Fig. 1: Test specimen (mm) and loading type.

MCP and MCF, with a 18 mm thickness, were used in this study because of their common use by cabinet manufacturers. Face and butt members for the experiments were prepared from boards (1880 x 3660 mm) according to the cutting plans. Multi-groove beech dowels (8 mm diameter and 34 mm length) and small cam fasteners (Fig. 2) were used for assembling the specimens, as shown in Fig. 3.

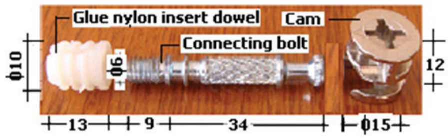

Fig. 2. Small cam fastener and its parts (mm) used in tests.

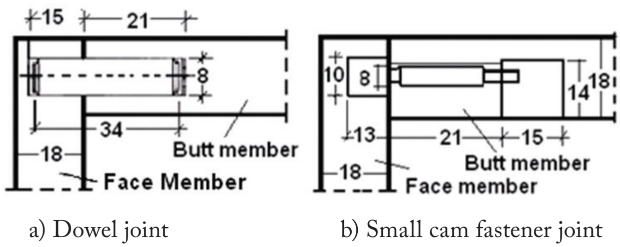

Fig. 3: Typical configuration of the specimens used in the test (mm).

Tab. 1: Description of the specimens used in the tests.

Length of specimen (mm)	Stop (mm)	Back stop (mm)	Dowel spacing (mm)	Dowel number
320	50	46	160	2
	60	36	160	2
	70	58	128	2
	80	80	96	2
390	50	20	128-128	3
	60	42	128-96	3
	70	64	192	2
	80	54	192	2
460	50	26	160-160	3
	60	48	160-128	3
	70	70	128-128	3
	80	60	128-128	3
530	50	32	192-192	3
	60	54	192-160	3
	70	44	192-160	3
	80	66	160-160	3
600	50	38	160-160-128	4
	60	60	160-128-128	4
	70	50	160-128-128	4
	80	72	192-192	3

In this study, five different lengths of MCP and MCF test specimens were prepared. For each of the specimens, four different stops (distances between first drilling hole center and front edge) were applied. They were selected as 50, 60, 70 and 80 mm and thus, twenty different drilling plans were prepared for five different lengths and four different stops. Experiments were replicated ten times for each drilling plan. The length of the specimens, stops, the dowel number and dowel spacing are shown in Tab. 1. Drilling plans were prepared according to a 32 mm manufacturing system widely used for case-type furniture. In each experiment, two cam fasteners were used, and dowel numbers were selected as 2, 3, and 4 depending on specimen length. These dowels were placed between the cam fasteners. When the distance between two dowels exceeded 180 mm, one more dowel was placed between of them. In this case, if the dowel's hole center was not in the middle of the distance between the dowels, an additional drill center, closest to the back of the specimen was selected for the drilling plan.

Dowel holes were drilled on the surfaces of the face member and on the edge of the butt member, face to edge. The drilling patterns are given in Fig. 2 and 3. Nominal hole depth in the face member was 15 mm. Nominal hole depth in the butt member was 21 mm. The parts of the cam fastener can be listed as cam, connecting bolt, and glue nylon insert dowel. Insert dowel holes were opened especially on the surface of the face member. Additionally, bolt holes were opened on the edge of the butt member ensuring they were facing one another. However, cam fastener holes were opened especially on the surface of the butt member. The places and measurements of the assembling components in each specimen pieces (Fig. 4) were made by a drilling machine according to the drilling plans mentioned earlier.

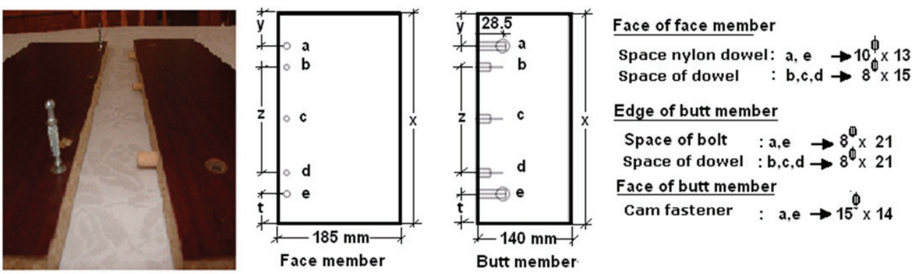

Fig. 4: Experiment specimens' drilling plans and measures (mm).

All of the butt members of the test specimens were assembled dowels with polyvinyl acetate (PVAc) as adhesive. About 150–200 $g.m^{-2}$ of adhesive was applied in dowel spaces of butt members. Wooden dowels were installed down to adhesived holes by means of a mould. These butt members with the wood dowels were laid down to dry for a day, and cams were installed in the empty places on the surface. Insert dowels were positioned on surfaces of face members by hammer, and then bolts were placed. The butt and face members on joint components, were properly positioned by cam fasteners and each specimen were installed by this method.

Method of loading and testing

Specific gravity (SG) values were calculated following the ASTM Standard D 2395-93 Method A (1997). Moisture contents (MCs) were determined on the same specimens according to the ASTM Standard D 4442-92 Method A (1997). The tests for bending moment capacity of MCP and MCF were performed following the procedures given in the ASTM Standards D 1037-96a (1997). All tests were carried out on the Universal testing machine with a constant loading rate 6 mm.min^{-1}. Specimens were attached on the test machine by a mould (Fig. 1). The load was applied on the edge, which was 130 mm away from the assembling side of the butt member's. The loading process was continued until the strength of the joints decreased significantly. The applied force was measured with ± 1 kg sensitivity.

The strength of joints was characterized by the bending moment value at which the joint was destroyed. The bending moments are calculated according to the following formulation:

$$M = P \times 1 \ (N.m)$$

where: M - joint bending moment (N.m),
P - an applied load (N),
L - arm lenght (m), as shown in Fig. 1.

RESULTS AND DISCUSSION

Tab. 2 shows the average MC, specific gravity SG, modulus of elasticity (MOE), and the modulus of rupture (MOR) values of the MCP and MCF used in the test.

Tab. 2: Average MC and mechanical properties of the MCP and MCF.

Material	MC (%)	SG	MOR	MOE
			(N.mm^2)	
MCP	8.34 (8)	0.65	15.55	2826
MCF	7.56 (3)	0.75	27.67	3522

Effect of number of dowels

The moment values of the test samples are shown in Fig. 5 as a function of the dowel number. The results indicated that when the dowel number increased from 2 to 3, 3 to 4 with an increment 1 and 2 to 4 with an increment 2, the strength of the joints increased 40, 59 and 120 % for the MCP, and 20, 63 and 100 % for the MCF, respectively. The analysis of variance (ANOVA) was carried out on the data at the 0.01 significance level as shown in Tab. 3. The results of this analysis showed that there was a significant difference in the bending strength in terms of the dowel number. Duncan's test results determining the groups of homogeneity of the dowel number are given in Tab. 4.

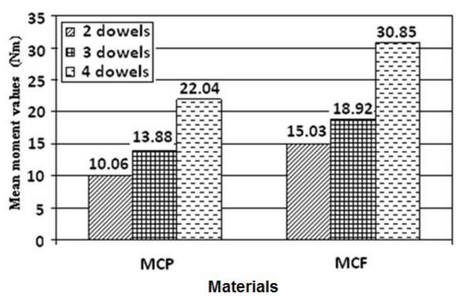

Fig. 5: Moment values of dowel number.

Tab. 3: ANOVA results of dowel numbers.

Material	Source of variation	Sum of squares	df	Mean square	F ratio	Level of significance [a]
MCP	Between groups	2872.575	2	1436.288	430.053	***
	Within groups	657.939	197	3.340		
	Total	3530.514	199			
MCF	Between groups	5102.393	2	2551.196	374.706	***
	Within groups	1341.281	197	6.809		
	Total	6443.674	199			

a *** : Highly significant with probability<0.001

Tab. 4: Groups of homogeneity of dowel number.

Dowel number	MCP		MCF	
	Moment value (Nm)	Groups of homogeneity	Moment value (Nm)	Groups of homogeneity
2	10.06	C	15.03	C
3	13.88	B	18.92	B
4	22.04	A	30.85	A

Effect of distance between dowels

Fig. 6 shows moment values as a function of space between the wooden dowels. According to the outcomes, when the distance increased from 96 to 128 mm and from 128 to 160 mm, the bending moment capacity increased 30 and 16 % for MCP, respectively and 23 and 16 % for MCF. Conversely, when the distance between wooden dowels increased from 160 to 192 mm, the bending moment capacity decreased 29 % for MCP and 21 % for MCF. ANOVA was carried out on data at the 0.01 significance level, as shown in Tab. 5. The results of this analysis indicated that there were significant differences in bending strength in terms of distances between dowels. The results of Duncan's test conducted to determine groups of homogeneity of dowel spacing are shown in Tab. 6.

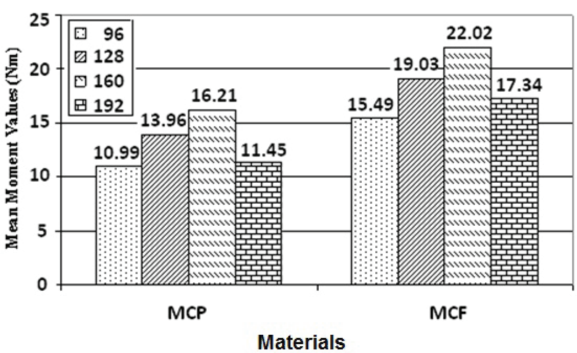

Fig. 6: Moment values of dowel spacing.

Tab. 5: ANOVA results of dowel spacing.

Material	Source of variation	Sum of squares	df	Mean square	F ratio	Level of significance a
MCP	Between groups	871.879	3	290.626	21.426	***
	Within groups	2658.635	196	13.564		
	Total	3530.514	199			
MCF	Between groups	957.726	3	319.242	11.406	***
	Within groups	5485.948	196	27.990		
	Total	6443.674	199			

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

Tab. 6: Homogeinity groups of dowel spacing.

Distance between dowels	MCP		MCF	
	Moment value (Nm)	Groups of homogeneity	Moment value (Nm)	Groups of homogeneity
96	10.99	C	15.49	C
128	13.96	B	19.03	B
160	16.21	A	22.02	A
192	11.45	C	17.34	B, C

The previous studies conducted on joint components shows diversity about the dowel spacing. For instances, Zhang and Eckelman (1993) claimed that the dowel spacing must be at least 76 mm whereas Tankut (2005), and Norvydas et al. (2005) mentioned that the distance must be at least 96 mm. In addition, Liu and Eckelman (1998), claimed if the dowel spacing is smaller than approximately 57 mm, the strength decreases. Liu and Eckelman (1998) demonstrated that for either glued dowels or screws, bending moment capacity of the joints decreased as the spacing between the fasteners decreased below 60 mm. Norvydays et al. (2005), found that when the dowel spacing increased from 96 to 128 mm the strength of the joints increased. They also showed that when the dowel spacing was increased to 160 mm, then the strength decreased. The most appropriate screw spacing is suggested as 76 mm by Ho and Eckelman (1994), however, it was suggested as 102 mm by Rajak and Eckelman (1996). In the present study, it was observed that the bending moment capacity became stronger when the dowel spacing was increased to 160 mm. Additionally, the strength became weaker when the dowel spacing was increased from 160 to 192 mm.

The average moment resistances are: MCP = 13.96 and MCF = 19.54. As can be seen in the bending moment resistance of the MCF is 40 % higher than the one of MCP. This result is supported by the results given in Tab. 2. That can be attributed to a greater adhesive area of dowel in the MCF due to a less rough and porous structure and thus, a stronger adhesion force exists between the dowel and the MCF compared with the MCP (Tankut 2005; Güntekin 2003).

In the present study, the bending moment resistances were different than in the literature. The moment resistance of the MDF was recorded at 14 % higher than the PB (Güntekin 2002; 2003) whereas it was found to be 60 % higher in a study by Efe et al. (1998). Both tension and compression values of the corner joints of the laminated MDF were found to be approximately

22 % higher than the corner joints of the laminated PB (Tankut and Tankut 2009). Additionally, the corner joint of the MCF was recorded at three times higher than the MCP (Tankut 2005).

CONCLUSIONS

The results have shown that the bending moment capacity of both the MCP and MCF increases by increasing the number of the dowels. It was found that the bending moment capacity increased for both the MCP and MCF when the dowel spacing increased from 96 to 160 mm. On the other hand, the bending moment capacity decreased when the dowel spacing increased from 160 to 192 mm. The implementation of the dowel space can be recommended as 160 mm. It was determined that the MCF corner joints were stronger than the MCP corner joints. Accordingly, the MCP use can be considered to be more appropriate for the furniture manufacture which has sensitive to the resistance. It can be also recommended that particleboard can be used in furniture constructions in which resistance properties are less important. The results of the ANOVA tests showed that there are significant differences in the bending moment capacity with respect to the dowel number and dowel spacing for both the MCP and the MCF.

REFERENCES

1. ASTM D-4442-92, 1997: Standard test methods for direct moisture content measurement of wood and wood-based materials.
2. ASTM D-1037-96a., 1997: Standard test methods for evaluating properties of wood-based fiber and article panel materials.
3. ASTM-D-2395-93, 1997: Standard test methods for specific gravity of wood and wood-base materials.
4. Bachmann, G., Hassler, W., 1975: The strength of various furniture construction, their component, and fasteners. Part I. Holztechnologie 16(4): 210-221.
5. Eckelman, C.A., 2003: Textbook of product engineering and strength design of furniture. West Lafeyette, (IN), Purdue University.
6. Efe, H., 1998: Rational dowel design in the furniture corner joints for case construction. Gazi Univesity, Polytechnic Journal 1(1/2): 41-54 (in Turkish).
7. Eren, S., Eckelman, C.A., 1998: Edge breaking strength of wood composites. Holz als Roh-und Werkstoff 56(2): 115-120.
8. Güntekin, E., 2002: Experimental and theorical analysis of the performance of ready-to-assemble (RTA) furniture joints constructed with medium density fiberboard and particleboard using mechanical fasteners. PhD. Thesis. State University of New York.
9. Güntekin, E., 2003: Performance of ready-to-install furniture merges. Süleyman Demirel University, Journal of Forestry 2: 37-48 (in Turkish).
10. Ho, C.L., Eckelman, C.A., 1994: The use of performance tests in evaluation joint and fastener strength in case furniture. Forest Product Journal 44(9): 47-53.
11. Kasal, A., Erdil, Y.Z., Zhang, J., Efe, H., Avcı, E., 2008: Estimation equations for moment resistances of L-type screw corner joints in case goods furniture. Forest Product Journal 58(9): 21-27.
12. Liu, W.Q., Eckelman, C.A., 1998: Effect of number of fasteners on the strength of corner joints for cases. Forest Products Journal 48(1): 93-95.

13. Nicholls, T., Crisan, R.A., 2000: A method for determining the stiffness of corner joints used in box-type furniture. Journal of the Institute of Wood Science 15(4): 173-182.
14. Norvydas, V., Juodeikiene, L., Minelga, D., 2005: The influence of glued dowel joints construction on the bending moment resistance. Materials Science (Medziagotyra) 11(1): 36-39.
15. Rajak, Z., Eckelman, C.A., 1996: Analysis of corner joints constructed with large screw. J. of Tropical Forest Products 2(1): 80-92.
16. Simek, M., Haviarova, E., Eckelman, C.A., 2010: The effect of end distance and number of ready-to- assemble furniture fasteners on bending moment resistance of corner joints. Wood and Fiber Science 42(1): 92-98.
17. Smardzewski, J., Prekrad, S., 2002: Stress distribution in disconnected furniture joints. Electronic Journal of Polish Agricultural Univesity, Series Wood Technology 5(2): 4 pp.
18. Tankut, A.N., 2005: Optimum dowel spacing for corner joints in 32-mm cabinet construction. Forest Product Journal 55(12): 100-104.
19. Tankut, A.N., Takut, N., 2009: Investigations the effects of fastener, glue, and composite material types on the strength of corner joints in case-type furniture construction. Materials and Design 30(10): 4175-4182.
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. TS 4539, 1985: Wood joints-rules of dowel joints.
22. Zhang, J., Eckelman, C.A., 1993: Rational design of multi dowel corner joints in case construction. Forest Product Journal 43(11/12): 52-58.

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