Bending Moment Capacity of L-Shaped Mitered Frame Joints Constructed of MDF and Particleboard

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The impact of fastener type (glued and unglued butterfly dovetail keys, glued and unglued H-shaped dovetail keys, one-pin dowel, two-pin dowels, and plywood spline) and wood composite material type on the bending moment capacity of L-shaped mitered frame joints under diagonal tension and compression loads was investigated. Specimens were constructed of laminated medium-density fiberboard (LamMDF) and laminated particleboard (LamPB). The glued joint specimens were constructed with polyvinyl acetate (PVAc) adhesive. In both tests, joints reinforced with two dowels had the highest bending moment capacity, whereas unglued joints fastened with H-shaped dovetail keys had the lowest capacity. Splined joints were characterized by the second highest bending moment capacity. Two-pin dowel joints had, on average, 47% greater capacity than one-pin dowel joints. The glued dovetail joints were 31% stronger than the unglued joints. There was no statistically significant difference between the bending moment capacities of butterfly and H-shaped dovetail keys. The LamMDF joints exhibited 7.8% greater capacity than joints constructed of LamPB. Overall, the bending moment capacity of joints loaded in compression was 22% higher than that of joints loaded in tension—when the moment arm in the compression specimens was taken at the inside corner of the joint.

Keywords: Dovetail keys; Dowel; Frame joints; Load-carrying capacity; Wood composite; Plywood spline

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INTRODUCTION

Mitered joints are a popular type of L-shaped connection used in the construction of door and window frames, cabinets, boxes, moldings, *etc*. This joint is visually attractive and, at the same time, capable of withstanding heavier loads than comparable butt joints (Atar *et al.* 2009; Maleki *et al.* 2012b). These characteristics have led to its continued use in the furniture industry. Depending on the material type and strength requirements, different fasteners may be used in the construction of a mitered joint. For example, plastic dovetail keys, used with or without glue, are best suited for case-type mitered joints constructed of wood-based composite panels such as medium-density fiberboard (MDF) and particleboard (Taghiyari 2013), whereas in solid-wood frames, mitered joints with glued fasteners such as dowel pins, wood biscuits, and wood splines provide the highest capacities (Jivkov and Marinova 2006; Maleki *et al.* 2012b; Dalvand *et al.* 2013a). Kilic *et al.* (2009) investigated the effect of adhesive type on the bending moment capacity of solid-wood mitered joints reinforced with a single dovetail fitting under both compression and tension loads. They demonstrated that the highest bending moment capacities are obtained in joints made with polyvinyl acetate (PVAc) adhesive and lowest in joints without adhesive (unglued joints). The bond performance of PVAc adhesive is a function of the spread rate of this adhesive. The bond strength is improved as the PVAc spread rate is increased (Raftery *et al.* 2008); hence, the impact of gluing on the mechanical properties of wood joints would be even more significant when an increased PVAc spread rate is used. Dalvand *et al.* (2013b) reported that, under both diagonal tension and compression loads, mitered corner joints made of fir wood (*Abies alba*) had greater strength capacity than comparable butt joints. These researchers indicated that mitered dowel joints in solid wood frames had higher load-carrying capacity than joints fastened with either glued or unglued dovetail keys.

Mitered joints are also widely used in constructing frames made of wood composite materials such as particleboard and medium density fiberboard. Information relating to the load-carrying capacity of mitered joints in frames made of these materials, however, is limited to a few specific areas; Altun *et al.* (2010), for example, studied the diagonal tension and compression capacities of mitered joints with a single butterfly dovetail key in frames made of MDF panels. They demonstrated that the bending moment capacity of the joints loaded in compression was significantly higher than that of comparable joints loaded in tension. Results also indicated that the type of adhesive had a major effect on the bending moment capacity of MDF joints with plastic dovetail fittings. The highest bending capacity under diagonal tension loading was obtained in joints glued with cyanoacrylate (CA) adhesive, whereas, under diagonal compression loading, the highest capacities were obtained with PVAc adhesive. It was also demonstrated that polyurethane (PU) adhesive does not significantly increase the bending moment capacity of MDF mitered joints with dovetail keys over joints without adhesive. Ozkaya *et al.* (2010) reported that, in an oriented-strand board (OSB) frame, mitered joints with a single dovetail key produced higher load carrying capacity than similar joints made with two dovetail keys. These researchers also demonstrated that joints bonded with PVAc adhesive were stronger than joints bonded with either polyurethane (PU) or cyanoacrylate (CA) adhesives. Maleki *et al.* (2012a) studied the load-carrying capacity of mitered dovetail joints made of MDF and particleboard panels under diagonal tension loads. Based on the results, the bending moment capacity of the joints strongly depended on the distance between the dovetail holes and the inner and outer edges of the joints. They also indicated that under a diagonal tension load, MDF joints had higher bending moment capacity than particleboard joints.

Overall, information is lacking concerning the strength characteristics of mitered joints constructed of wood composite materials. In addition, no comprehensive study has to date been conducted to determine the impact of fastener type on the load-carrying capacity of mitered joints in frames made of these materials. Most available information is related to the effect of adhesive type and dovetail key type on the load carrying capacity of mitered joints. The strength characteristics of these joints with other commonly employed fasteners in wood composite frames (such as dowel pins and wooden splines) have not been documented—although these fasteners are widely used in the construction of panel furniture. Such information provides appropriate and necessary tools for both designers and manufacturers, better enabling them to engineer their products. Hence, additional studies are needed to find ways to optimize the rational design of the joint to meet its maximum load capacity. Therefore, the goal of this study was to examine the impact of the joining method, connector type, and wood composite material type on the bending moment capacity of L-shaped mitered joints under diagonal loading. Specific objectives were: a) to determine the bending moment capacity of mitered corner joints connected with different fasteners (connectors) including H-shaped and butterfly dovetail keys, dowel pins, and a plywood spline; b) to determine the effect of the number of dowel pins on joint capacity; c) to determine the bending moment capacity of glued versus unglued mitered corner joints fastened with dovetail keys; d) to determine the bending moment capacity of joints made of laminated medium density fiberboard and laminated particleboard composite panels; and e) to compare the bending moment capacities of these joints under tension and compression loads.

EXPERIMENTAL

Materials

Specimens were constructed of 16 mm-thick medium-density laminated fiberboard (LamMDF) and particleboard (LamPB). Specific gravity (SG), internal bond strength (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) of the panels are listed in Table 1. Measurements were carried out in accordance with EN 310 (British Standard Institution 1993a) and EN 319 (British Standard Institution 1993b).

Table 1. Major Physical and Mechanical Properties of the Wood Composite Panels Used in the Study

Panel type	SG	IB (MPa)	MOE (MPa)	MOR (MPa)
LamPB	0.66 ± 0.026	0.59 ± 0.042	3781 ± 311.82	18.29 ± 1.06
LamMDF	0.73 ± 0.017	0.76 ± 0.036	3844 ± 253.50	23.41 ± 0.78

10 replicates were tested for each treatment in the table

Commercially available butterfly and H-shaped dovetail keys made of polyvinyl chloride (PVC), multi-groove dowel pins fabricated of poplar wood (*Populus deltoides*), and splines made of 3 mm thick plywood (three-ply) were used as fasteners (Fig. 1).

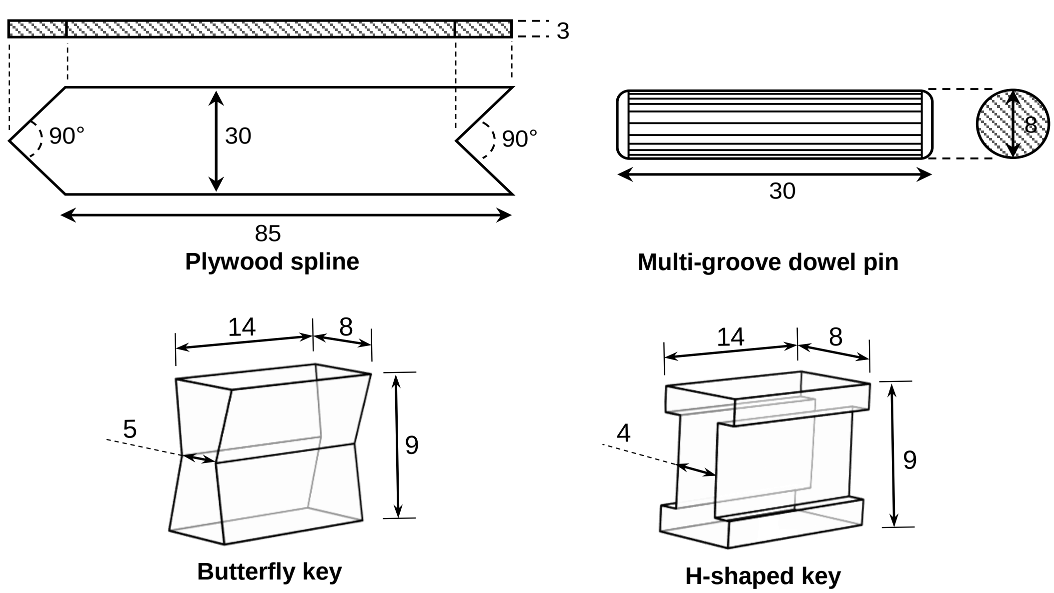

Fig. 1. Geometry of fasteners used in the study (measurements in mm)

The multi-groove dowel pins measured 8 mm in diameter by 30 mm in length. Width, length, and thickness of the plywood splines were 30 mm, 85 mm, and 3 mm, respectively. The PVAc adhesive had a solids content of 55%.

Specimen Preparation

The configurations of the specimens are given in Fig. 2. The dovetailed joints that were not glued are referred to as unglued joints with butterfly keys and unglued joints with H-shaped keys. For the dovetailed joints, the dovetail slots on the faces of both members of the frames were drilled using a pneumatic dovetail routing machine at a speed of 34,000 rpm. A T-shaped router bit was employed for this purpose to route the slots in which the H-shaped keys were inserted. A dovetail router bit was employed to route the slots in which the butterfly keys were inserted. The routing machine was set in such a way that the slots were made on each member of the frame to a depth of 14 mm.

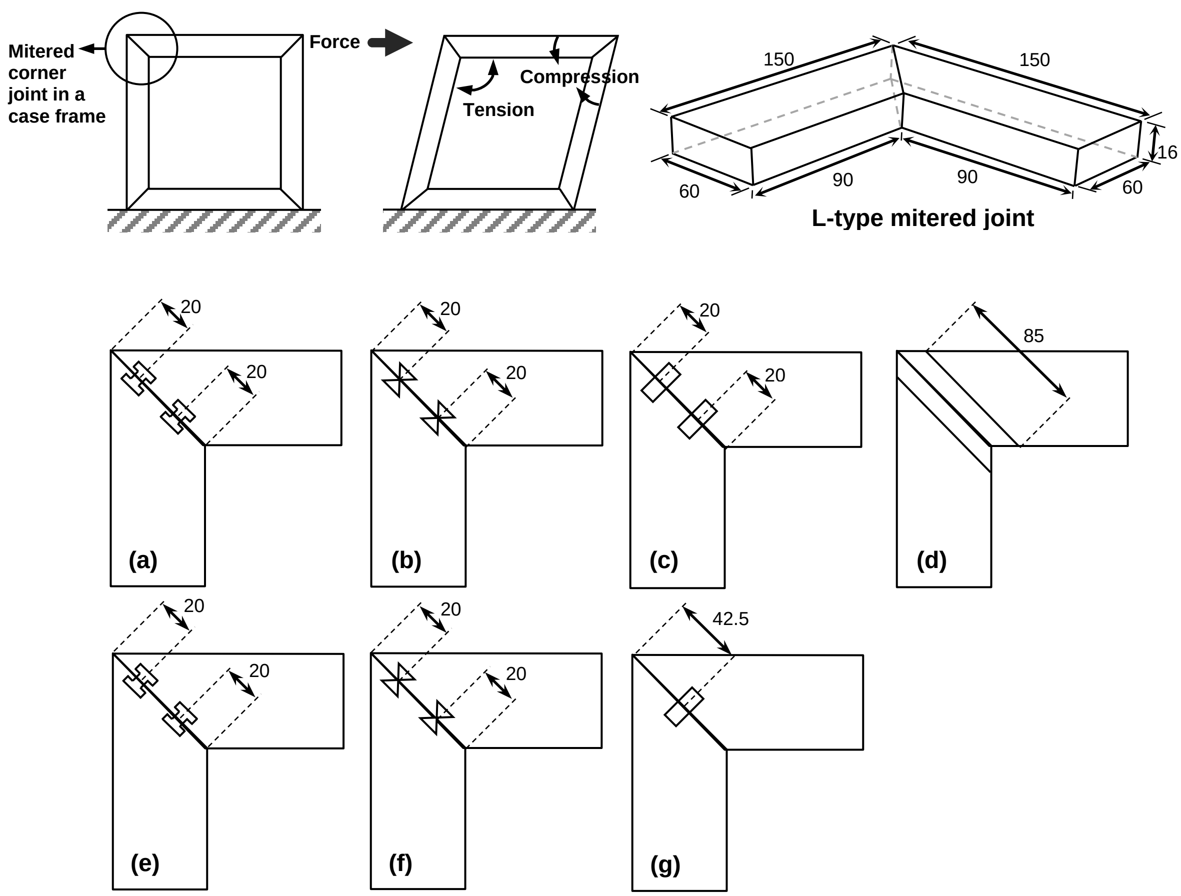

Fig. 2. Dimensions (mm) and configurations of L-type mitered joints with different fasteners; (a): glued joint with H-shaped dovetail keys; (b): glued joint with butterfly dovetail keys, (c): two-pin dowel joint; (d): plywood spline joint; (e): unglued joint with H-shaped keys; (f): unglued joint with butterfly keys; (g): one-pin dowel joint

Grooves for the splines were cut in the faces of the mitered surfaces with a table saw. The depth of penetration of the spline in both members was 15 mm. The dowel holes in the two-pin and one-pin dowel joints were drilled to a depth of 15 mm by means of a drill press. In the case of the glued joints, PVAc adhesive was applied to the fastener and mitered faces of the two members, as well as to the fastener hole/slot walls. Following the application of adhesive, the joints were assembled immediately—the open time of the PVAc adhesive was 5 min. The two members of the joints were then clamped together for 3 h. Finally, the joints were seasoned in a climatic chamber at a temperature of 20 ± 2 °C and an air humidity of 65 ± 5% for a week.

Experimental Design and Data Evaluation

Using a full factorial experimental design, 3 factors were considered to study the bending moment capacity of mitered joints; namely, fastener type (7 levels, including glued and unglued fasteners), panel type (2 levels, LamMDF and LamPB), and loading direction (2 levels, tension and compression). With 5 replicates for each of 28 combinations shown in Table 2, overall, 140 specimens were constructed and tested.

Table 2. Combinations of Test Variables in the Study

Exp. No	Fastener Type (7 levels)	Panel Type (2 levels)	Type of Loading (2 levels)	Replicates
1	Glued one dowel	LamMDF	Compression	5
	Glued one dowel	LamMDF	Tension	5
	Glued one dowel	LamPB	Compression	5
	Glued one dowel	LamPB	Tension	5
2	Glued two dowel	LamMDF	Compression	5
	Glued two dowel	LamMDF	Tension	5
	Glued two dowel	LamPB	Compression	5
	Glued two dowel	LamPB	Tension	5
3	Glued plywood spline	LamMDF	Compression	5
	Glued plywood spline	LamMDF	Tension	5
	Glued plywood spline	LamPB	Compression	5
	Glued plywood spline	LamPB	Tension	5
4	Glued two H-shaped keys	LamMDF	Compression	5
	Glued two H-shaped keys	LamMDF	Tension	5
	Glued two H-shaped keys	LamPB	Compression	5
	Glued two H-shaped keys	LamPB	Tension	5
5	Unglued two H-shaped keys	LamMDF	Compression	5
	Unglued two H-shaped keys	LamMDF	Tension	5
	Unglued two H-shaped keys	LamPB	Compression	5
	Unglued two H-shaped keys	LamPB	Tension	5
6	Glued two butterfly keys	LamMDF	Compression	5
	Glued two butterfly keys	LamMDF	Tension	5
	Glued two butterfly keys	LamPB	Compression	5
	Glued two butterfly keys	LamPB	Tension	5
7	Unglued two butterfly keys	LamMDF	Compression	5
	Unglued two butterfly keys	LamMDF	Tension	5
	Unglued two butterfly keys	LamPB	Compression	5
	Unglued two butterfly keys	LamPB	Tension	5
			Total	140 specimens

Test results were evaluated by means of analysis of variance (ANOVA) techniques. Important differences in bending moment capacities between joint type groups were determined by means of the Duncan's test.

Test Methods

Specimens were tested in tension or compression as shown in Fig. 3. All tests were conducted in an INSTRON (USA) testing machine at a feed rate of 5 mm·min^{-1}.

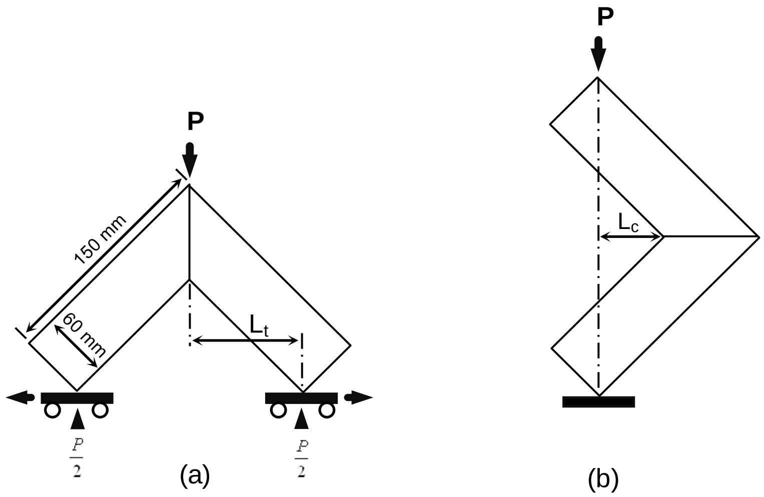

Fig. 3. Method of loading of L-shaped joints specimens; (a): tension test, (b): compression test

Ultimate loads were recorded as the highest load was reached, just before a sudden non-recoverable loss in load occurred. The bending moment capacities of the joints loaded in tension (M_t), or compression (M_c), were calculated as follows (Eqs. 1 and 2),

$$M_t = \frac{P}{2} \times L_t \tag{1}$$

$$M_C = P \times L_C \tag{2}$$

where P is the ultimate load (N), L_t (tension moment arm) is the distance from the center line of the joints to the line of action of either of the reaction tension forces (63.6 mm), and L_c (compression moment arm) is the distance from the inner corner of a joint to the line of action of the compression load (21.2 mm)—in keeping with procedures of Kilic *et al.* (2009) and Altun *et al.* (2010).

RESULTS AND DISCUSSION

Failure Modes of Joints

Regardless of the type of loading, deep cracks and splits occurred on the edges of the wood composite panels in: a) all of the dovetailed joints (both glued and unglued joints) (Fig. 4), b) in 3 out of 20 joints fastened with one dowel, c) in 17 out of 20 joints reinforced with two dowels, and d) in 9 out of 20 joints constructed with plywood spline. The fractures of the panels were greater in the LamPB joints than in the joints constructed of LamMDF, which could be related to the lower internal bond strength and specific gravity of LamPB panels. In the case of mitered spline joints, most failures occurred due to glue line failure between the spline and the internal wall surfaces of the corresponding slot. No failures of the splines themselves occurred. No important deformations/failures were observed in the butterfly or H-shaped keys as well. In 17 out of 20 one-pin dowel joints, the dowel withdrew from its respective hole along with a considerable amount of LamMDF or LamPB fibers attached to its surface. This was also observed in 3 out of 20 two-pin dowel joints. In the case of joints fastened with two dowels, lower dowel failure combined with panel fracture occurred in 4 out of 10 joints loaded in tension, whereas failures occurred on the edge of the panels at the outer corner of the joints when the joints were loaded in compression.

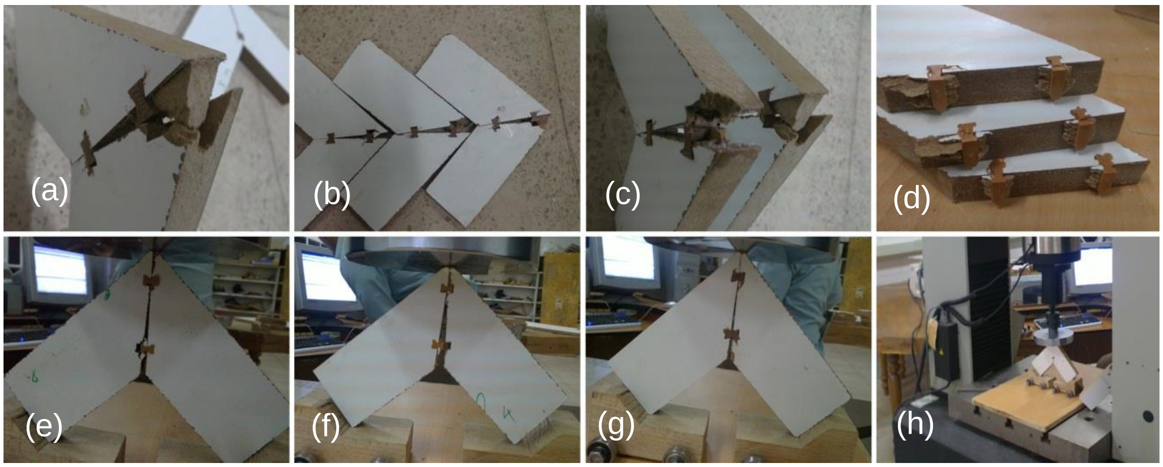

Fig. 4. Examples of panel failures in joints with dovetail keys; (a), (b), and (c) are glued mitered joints with dovetail keys tested in compression; (d), (e), (f), (g), and (h) are glued mitered joints with dovetail keys tested in tension

Bending Moment Capacity of Joints

Mean ultimate bending moment capacities of the joints are given in Table 3 and are further illustrated in Fig. 5.

Table 3. Average Bending Moment Capacities of the Mitered Corner Joints under Tension and Compression Loads

Panel type	Joint type	Bending moment capacity (Nm)			
		Tension	COV (%)	Compression	COV (%)
LamMDF	Glued butterfly key	69.6	12.1	86.2	5.3
	Glued H-shaped key	70.1	6.7	83.6	8.0
	Two dowel	83.9	10.0	97.9	9.0
	Plywood spline	74.6	3.0	96.0	7.0
	One dowel	61.2	14.0	65.2	7.6
	Unglued butterfly key	57.1	8.3	69.4	17.5
	Unglued H-shaped key	55.2	7.3	67.7	12.7
LamPB	Glued butterfly key	63.1	5.8	78.9	7.2
	Glued H-shaped key	60.6	7.9	77.6	7.0
	Two dowel	86.6	7.6	96.9	6.1
	Plywood spline	82.5	4.8	95.5	6.3
	One dowel	55.3	8.6	67.2	11.0
	Unglued butterfly key	44.6	7.2	59.8	6.3
	Unglued H-shaped key	39.0	7.7	56.7	8.2

ANOVA results are given in Table 4. The Duncan's test results for the evaluation of the important differences between joint type groups are given in Table 5. In both tests, the impacts of joint type and wood composite panel type on bending moment capacity were significant, with a 99% level of confidence. The interaction effect of the two factors was also significant.

Table 4. Results of ANOVA for Tension and Compression Tests

Test	Source of variance	Sum of squares	df	Mean square	F-value	P-value
Tension	Fastener type (A)	11601.45	6	1933.58	92.43	0.000
	Panel type (B)	571.68	1	571.68	27.33	0.000
	A × B	1064.36	6	177.39	8.48	0.000
	Total	305852.94	70			
Compression	Fastener type (A)	12886.16	6	2147.69	107.71	0.000
	Panel type (B)	399.43	1	399.43	20.03	0.000
	A × B	367.18	6	61.20	3.07	0.011
	Total	445852.77	70			

Table 5. Duncan's Test Results with Respect to the Fastener Type

Source factor	Bending moment capacity (Nm)			
Fastener type	Tension test	Duncan group	Compression test	Duncan group
Glued butterfly key	66.3	C	82.6	B
Glued H-shaped key	65.4	C	80.6	B
One dowel	58.3	D	66.2	C
Plywood spline	78.6	B	95.8	A
Two dowel	85.2	A	97.4	A
Unglued butterfly key	50.9	E	64.6	C
Unglued H-shaped key	47.1	E	62.2	C
Fastener type + Wood composite type	Tension test	Duncan group	Compression test	Duncan group
Glued butterfly key + LamMDF	69.6	B	86.2	B
Glued butterfly key + LamPB	63.1	C	78.9	CD
Glued H-shaped key + LamMDF	70.1	B	83.6	BC
Glued H-shaped key + LamPB	60.6	CD	77.6	D
One dowel + LamMDF	61.2	CD	65.2	EF
One dowel + LamPB	55.3	D	67.2	E
Plywood spline + LamMDF	74.6	B	96.0	A
Plywood spline + LamPB	82.5	A	95.5	A
Two dowel + LamMDF	83.9	A	97.9	A
Two dowel + LamPB	86.6	A	96.9	A
Unglued butterfly key+ LamMDF	57.1	CD	69.4	E
Unglued butterfly key+ LamPB	44.6	E	59.8	FG
Unglued H-shaped key + LamMDF	55.2	D	67.7	E
Unglued H-shaped key + LamPB	39.0	E	56.7	G

It is evident from Fig. 5 that the highest bending moment capacities for joints loaded in tension were obtained with two-pin dowel joints, whereas in the compression tests, both two-pin dowel and splined joints had the highest capacities. Specifically, splined joints had 92.2% of the capacity of the two-dowel joints loaded in tension and 98.3% in compression.

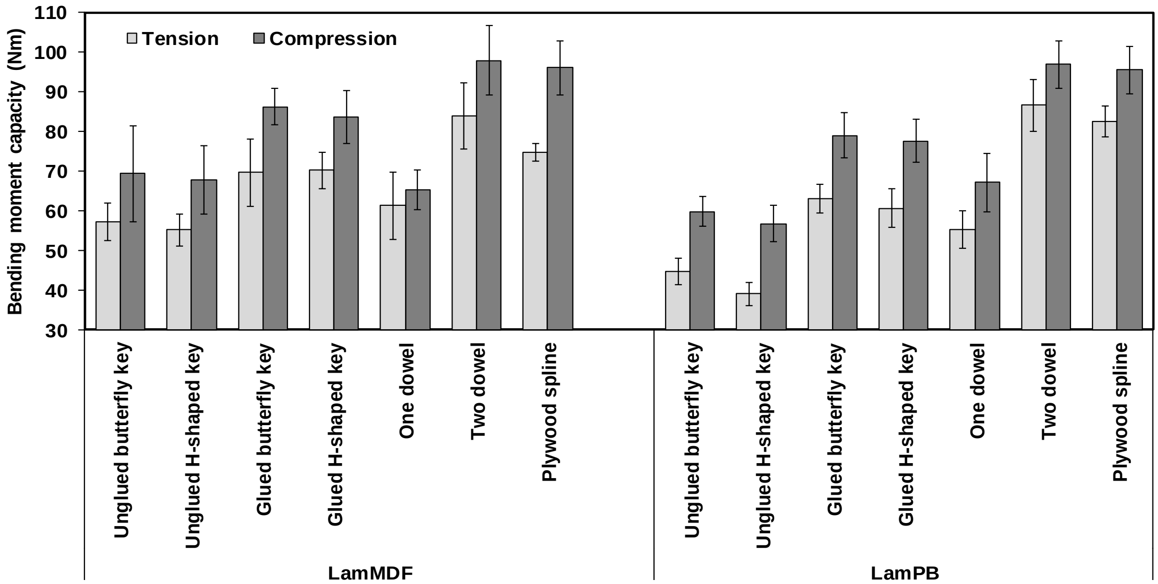

Fig. 5. Bending moment capacity of Laminated MDF and Laminated PB joints as a function of joint type

Overall, regardless of the wood composite material, one-dowel joints had 68.4% of the capacity of two-dowel joints loaded in tension and 67.9% in compression. Likewise, joints with glued butterfly keys had 77.8% of the capacity of two-dowel joints in tension and 84.8% in compression. Similarly, joints with glued H-shaped keys had 76.7% of the capacity of the two-dowel joints in tension and 82.8% in compression. Joints fabricated with unglued, H-shaped dovetail keys had the lowest bending moment capacity, namely, 55.2% of the capacity of the two-pin dowel joints in tension and 63.9% in compression. Similarly, the unglued butterfly keys had 59.7% of the capacity of the glued two-dowel joints in tension and 66.3% in compression. Likewise, the unglued H-shaped dovetail key joints had 72.0% of the capacity of identical glued joints in tension and 77.2% in compression. The unglued butterfly key joints had 76.7% of the capacity of identical glued joints in tension and 78.2% in compression. The total average difference between bending moment capacities of the glued and unglued dovetail joints was 31%. As can be seen in Fig. 5, the gluing had a more pronounced effect on the bending moment capacity of the LamPB joints, so the glued LamPB joints reinforced with dovetail keys (H-shaped and butterfly keys) had an approximately 40% (average value of combined tension and compression results) higher bending capacity than the unglued LamPB joints. This difference in the bending moment capacity for the identical joints made of LamMDF was 24%.

Overall, the combined results for joints constructed with butterfly keys were 3.6% greater than the results for joints constructed with H-shaped keys. However, Duncan's test showed no important difference between these two shapes of dovetail keys—which is in agreement with the results reported by Maleki *et al.* (2012a).

With regard to frame material, except for the spline joints and joints fastened with two dowels in the tension tests and the one-pin dowel joints in the compression, the bending moment capacity for the LamMDF joints was greater than for comparable LamPB joints—overall, the LamMDF joints had 7.8% greater capacity than the LamPB joints. In terms of loading, the mean difference between the bending capacity of the LamMDF and LamPB joints under tension was 9.3%, whereas the difference between these joints under compression was 6.3% (Table 6). The weak internal bond strength of the LamPB panel could be a reason for these differences (Maleki *et al.* 2012a, b; Yerlikaya 2013; Malkoçoglu *et al.* 2014).

Table 6. Bending Moment Capacity Values According to Wood Composite Type

Wood composite type	Bending moment capacity (Nm)			
	Tension test	HG*	Compression test	HG
LamMDF	67.4	A	80.9	A
LamPB	61.7	B	76.1	B

* HG: Homogeneity Group

As shown in Fig. 5, the compression capacities of all the joints were higher than the tension capacities. Specifically, the combined bending moment capacity of the joints loaded in compression was 22% higher than that of the joints loaded in tension, which indicates a compression-to-tension (C/T) capacity ratio of about 1.22 for the selected L_c value (moment arm in compression specimens). This ratio, however, depends on the numerical methods used for calculation of the joint bending moment capacity. In this case, although the moment arm for the tension tests is clearly defined (L_t = 63.6 mm), the moment arm for the compression tests is not. The moment arm for compression tests could be calculated from the intersection of the centerlines of the joints as done by Jivkov and Marinova (2006) and Dalvand *et al.* (2013b), for example, or from the inner corner of the joints as done by Kiliç *et al.* (2009) and Altun *et al.* (2010). For each of these moment arms, the calculated C/T ratios could be different. Since the information obtained in this study could be expected to be used in the structural design of frames, it was decided to carry out a limited set of tests on modified four-member frames in order to determine the C/T ratios for mitered two-pin dowel joints as they occur in frames. The frame specimens were constructed of LamMDF and measured 300 mm in length by 300 mm in height (Fig. 6.)

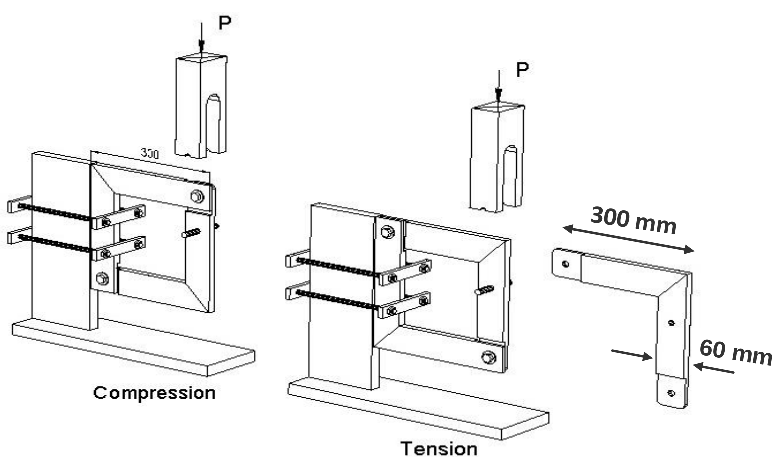

Fig. 6. Loading form of the 300 mm square frame specimens constructed with two-pin dowel joints

The thickness (60 mm) and width (16 mm) of the structural members in the frames were the same as in the L-shaped joints. Each member of the frame had a mitered joint with two glued dowels at one end and a pinned lap joint (loose bolted joint) at the other end. The bolted joints were loose and free to rotate so that they would carry zero moment under load. Five frame specimens were tested in a manner such that the joints were loaded in compression and five in a manner such that the joints were loaded in tension, Fig. 6. The loading rate was 5 mm·min^{-1}. The results indicated that the C/T ratio of the frames was 115.8/102.9, or, approximately 1.12, which demonstrates that the frames were 12% stronger in compression than in tension. The C/T ratio was then used to estimate the proper moment arm for the L-shaped two-pin dowel joints loaded in compression, as follows (Eq. 3),

$$L_c = \frac{M_t \times CT}{P} \tag{3}$$

where L_c is the estimated moment arm for the L-shaped joints in compression test (m); M_t is the tension capacity of the L-shaped joints (Nm); CT is the compression-to-tension capacity ratio obtained in frame testing (1.12); P is the ultimate failure load of the L-shaped joints in compression test (N).

Referring to the original L-shaped samples, the average tension capacity (M_t) of the two-pin dowel joint samples made of LamMDF was 83.9 Nm; based on the C/T ratio obtained in the frame testing, the comparable compression capacity (M_c) of the two-pin dowel joints would be 83.9 × 1.12 ($M_t \times CT$), or, 93.9 Nm. If this value is divided by the average failure load (P) of the L-shaped two-pin dowel joints, 93.9/4617.9, a moment arm of 0.0203 m is obtained—versus L_c = 0.0212 m, for a difference of only 4%. This result tends to indicate that the moment arm for compression joints should be L_c (*i.e.*, the moment arm for compression test should be calculated from the inner corner of the joints). Although differences would be expected from joint to joint, when the ratio obtained for the dowel joints was applied to the remainder of the L-shaped compression joints, similar results were obtained—indicating that L_c is likely the proper moment arm (Table 7).

Table 7. Estimated Moment Arms for the L-Shaped Joints Loaded in Compression Based on the Results of Frame Testing

Panel type	Joint type	Estimated moment arm * (mm)	L_c (mm)	Differ. (mm)
LamMDF	Glued butterfly key	19.2	21.2	2.0
	Glued H-shaped key	19.9	21.2	1.3
	Two dowel	20.3	21.2	0.9
	Plywood spline	18.5	21.2	2.7
	One dowel	22.3	21.2	-1.1
	Unglued butterfly key	19.5	21.2	1.7
	Unglued H-shaped key	19.4	21.2	1.8
LamPB	Glued butterfly key	19.0	21.2	2.2
	Glued H-shaped key	18.6	21.2	2.6
	Two dowel	21.2	21.2	0.0
	Plywood spline	20.5	21.2	0.7
	One dowel	19.6	21.2	1.6
	Unglued butterfly key	17.7	21.2	3.5
	Unglued H-shaped key	16.3	21.2	4.9
Average		19.5	21.2	1.7

$^{*} L_c = \frac{M_t \times CT}{P}$

Accordingly, if the results of tests on the L-shaped joint specimens are to be used in structural frame analyses, the compression capacity likely should be calculated using L_C—even though additional studies are needed in the future to fully establish this concept.

CONCLUSIONS

In this study, the bending moment capacity of L-shaped mitered frame joints, made of LamMDF and LamPB and fastened with different connectors (glued and unglued dovetail keys, dowel pins, and plywood spline), was studied under diagonal tension and compression loads.

1. Overall, mitered joints constructed with two dowels had slightly greater bending moment capacity than splined miter joints and a substantially greater capacity than joints constructed with a single dowel, glued, or unglued butterfly keys, or glued or unglued H-shaped keys.
2. Two-pin dowel joints and splined joints had about the same capacity in compression tests; however, statistical analysis of the results confirmed an important difference between capacities of these joints in tension tests—average differences between capacities of these joints were approximately 8.5% in tension and 1.7% in compression tests. However, both joints exhibited excellent load-carrying capacities, and, therefore, they could be used for the construction of door and window frames or any other application in case-type furniture that requires high strength capacity.
3. One-dowel joints had much less capacity than two-dowel as well as splined joints and less capacity than glued dovetail joints (both H-shaped and butterfly keys) but greater capacity than unglued dovetail joints.
4. The worst average value of bending moment capacity was obtained in unglued joints reinforced with H-shaped dovetail keys.
5. Regardless of type of wood composite material or type of loading, there was essentially no significant difference in bending moment capacity between H-shaped and butterfly dovetail keys; however, overall, butterfly keys had 3.6% greater capacity than joints with H-shaped keys.
6. The average difference between bending moment capacities of glued and unglued dovetail joints was 31%. Hence, the use of glue is strongly recommended in constructing mitered frame joints with dovetail keys when the structural members of the joints are to be subjected to heavy load stresses. Unglued dovetail keys, however, have still strength capacity enough to be used in the construction of furniture cabinet doors or photograph frames.
7. The LamMDF joints were 9.3% and 6.3% stronger than joints constructed of LamPB in tension and compression tests, respectively—for an average difference of 7.8%.
8. Overall, an average compression/tension capacity ratio of 1.22 was obtained for the L-shaped mitered joints under diagonal loadings when the moment arm is taken at the inside corner of the joint in the compression specimen.

REFERENCES CITED

Altun, S., Burdurlu, E., and Kilic, M. (2010). "Effect of adhesive type on the bending moment capacity of miter frame corner joints," *BioResources* 5(3), 1473-1483. DOI: 10.15376/biores.5.3.1473-1483

Atar, M., Ozcifci, A., Altinok, M., and Celikel, U. (2009). "Determination of diagonal compression and tension performances for case furniture joints constructed with wood biscuits," *Materials and Design* 30(3), 665-670. DOI: 10.1016/j.matdes.2008.05.023

BS EN 310. (1993a). "Wood-based panels – Determination of modulus of elasticity in bending and of bending strength," British Standards Institution, London, UK.

BS EN 319. (1993b). "Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board," British Standards Institution, London, UK.

Dalvand, M., Derikvand, M., Maleki, S., and Ebrahimi, G. (2013a). "Combined stress analysis of mitered spline furniture joints under diagonal loading," in: *The XXVIth Conference Research for Furniture Industry,* 15-22.

Dalvand, M., Ebrahimi, G., Haftkhani, A. R., and Maleki, S. (2013b). "Analysis of factors affecting diagonal tension and compression capacity of corner joints in furniture frames fabricated with dovetail key," *Journal of Forestry Research* 24(1), 155-168. DOI: 10.1007/s11676-013-0336-y

Jivkov, V., and Marinova, A. (2006). "Ultimate bending strength and stiffness under compression test of end corner miter joints constructed of solid wood," *International Symposium: "Furniture 2006,"* Technical University-Zvolen, 1-7.

Kiliç, M., Burdurlu, E., Altun, S., and Berker, U.Ö. (2009). "The bending moment capacities of miter frame corner joints with dovetail fittings," *Wood Research* 54(3), 79-88.

Maleki, S., Derikvand, M., Dalvand, M., and Ebrahimi, G. (2012a). "Load-carrying capacity of mitered furniture corner joints with dovetail keys under diagonal tension load," *Turkish Journal of Agriculture and Forestry* 36, 636-643. DOI: 10.3906/tar-1112-44

Maleki, S., Haftkhani, A.R., Dalvand, M., Faezipour, M., and Tajvidi, M. (2012b). "Bending moment resistance of corner joints constructed with spline under diagonal tension and compression," *Journal of Forestry Research* 23(3), 481-490. DOI: 10.1007/s11676-012-0288-7

Malkoçoglu, A., Yerlikaya, N. C., and Ozsahin, S. (2014). "Evaluation and optimization of bending moment capacity of corner joints with different boring plans in cabinet construction," *Wood Research* 59(1), 201-215.

Ozkaya, K., Burdurlu, E., Ilce, A. C., and Ciritciolgu, H. H. (2010). "Diagonal tensile strength of an oriented strand-board (OSB) frame with dovetail corner joint," *BioResources* 5(4), 2690-2701. DOI: 10.15376/biores.5.4.2690-2701

Raftery, G., Harte, A. and Rodd, P. (2008). "Qualification of wood adhesives for structural softwood glulam with large juvenile wood content," *Journal of the Institute of Wood Science* 18(1), 24-34. DOI: 10.1179/wsc.2008.18.1.24

Taghiyari, H. R. (2013). "Effects of nano-silver and nano-zycosil on mechanical strength of heat, vapor, and dry-ice-treated biscuit and dovetail medium-density fiberboard miter joints," *Materials and Design* 51, 695-700. DOI: 10.1016/j.matdes.2013.04.083

Yerlikaya, N. Ç. (2013). "Investigation into the effect of some factors on the failure load of corner joints reinforced with glass-fiber fabric in case-type furniture," *Wood Research* 58, 307-318.

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