Determination of the Strength of L-Type Corner Joints Obtained from Wood-Based Board Materials Using Different Joining Techniques

Hasan Ozgur Imirzi
Kadir Ozkaya
Hasan Efe

Abstract

Flat pack (ready-to-assemble, knockdown) furniture has become the most extensive furniture model produced with the development of wood-based board materials technology. It is especially preferred in the building industry as a model suitable for mass production. In this study, the resistances of dowels and screws, which are used in a widespread manner as joining material at the corners of ready-to-assemble furniture, were investigated against tensile and compression resistances in the diagonal direction. Chipboard (CB), medium-density fiberboard, and gaboon mahogany plywood (GMP), 14, 16, and 18 mm thick, were used in this study. Dowel + screw, screw, screw + polyvinyl acetate (PVAc) adhesive, and screw + polyurethane (PUR) adhesive joining were implemented for the L-type corner models obtained from wood-based board materials. According to the results obtained, the highest moment-carrying capacity values in the L-type corner joining were provided in the 18-mm GMP board joined with screw + PVAc adhesive and screw + PUR adhesive for both tests. The joining made without adhesive and the CB materials produced the lowest moment-carrying capacity values.

Furniture should be designed so that production, from economical materials, is simple and practical and done in a manner that will create interest from the perspective of aesthetics and function. Furniture endurance design and analysis is a new concept and is still not implemented seriously in many countries. Up until the middle of the 1950s, furniture was not analyzed structurally despite the fact that furniture was defined as a structural system. Instead, past experience and aesthetics were the factors considered in the determination of element measurements and joinings (Erdil 1998). It is necessary to solve problems related to security, usability, and dimensions when designing furniture. The structure or system should show resistance of materials and construction to mechanical influences (Altinok 2003).

As the demand for flat-pack furniture in the furniture sector has increased flat-pack furniture production has also increased to the same extent. Flat-pack furniture has unique design and production techniques (Yerlikaya 2013b). Generally, L- and T-type elements are used in testing the joining for flat-pack furniture systems. The connections of the system are in the direction of the flat surface axes, whereas the tensile, bending, and shearing are in the direction of the flat surface diagonals and remain under the influence of torsion loads. Flat-pack furniture should be able to display resistance during use against the probable effects of these external loads (Altinok 2003).

Wood and wood-based materials constitute an important component for the design of furniture construction. The behavior against physical and mechanical effects of the materials included in the formation of furniture products should be known in advance and provide technical, aesthetic, and economic benefits to the designer, producer, and user. For both the design and the scientific activities based on this, data are used for the physical and mechanical

The authors are, respectively, Assistant Professor, Dept. of Wood Products Industrial Engineering, Faculty of Technol., Gazi Univ., Ankara, Turkey (himirzi@gazi.edu.tr). Associate Professor, Dept. of Materials and Materials Processing Technol., Denizli Vocational School of Technical Sci., Pamukkale Univ., Denizli, Turkey (kadirozkaya@pau.edu.tr [corresponding author]); and Professor, Dept. of Wood Products Industrial Engineering, Faculty of Technol., Gazi Univ., Ankara, Turkey (hasanefe@gazi.edu.tr). This paper was received for publication in August 2014. Article no. 14-00081.

Forest Prod. J. 66(3/4):214–224.
doi:10.13073/FPJ-D-14-00081

Table 1.—Some physical and mechanical properties.[a]

Type of material	Density (g/cm^3)		Moisture content (%)		Bending strength (%)		Modulus of elasticity (%)	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
14-mm CB	0.64	2.56	5.09	5.09	10.16	15.41	2.006	10.33
16-mm CB	0.66	1.68	5.06	5.06	11.18	23.05	2.293	18.56
18-mm CB	0.61	6.36	5.06	5.06	12.31	24.75	2.379	22.37
14-mm MDF	0.75	2.81	4.64	4.64	31.24	5.72	2.821	3.74
16-mm MDF	0.79	0.98	4.86	4.86	32.09	10.71	3.129	4.76
18-mm MDF	0.70	1.16	4.98	4.98	27.67	6.13	3.436	3.78
14-mm GMP	0.50	1.70	6.73	6.73	43.49	11.48	4.905	4.77
16-mm GMP	0.57	2.06	5.90	5.90	45.37	6.81	5.790	17.17
18-mm GMP	0.47	0.89	6.48	6.48	44.71	8.57	5.048	3.37

[a] CV = coefficient of variation; CB = chipboard; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood.

attributes of the materials and the resistances of the joining (Efe 1994). Consequently, in addition to testing the joining system for flat-pack furniture, the materials constituting the furniture have been examined in many studies.

Zhang and Eckelman (1993a, 1993b) determined that as the dowel diameter and dowel length increase in chipboards produced with a single-dowel flat-pack corner joining element, their resistance increases; in cases where a different number of dowels are used, the distance between the two dowels should be 7.5 cm for the highest resistance. Efe and Kasal (2000) determined that using fiberboard was superior to using chipboard in flat-surface furniture production and that of the adhesives used, polyvinyl acetate (PVAc) produced the best results. Ors et al. (2001) stated that the polyurethane-based desmodur–vinyl trie ketonol acetate adhesive was the most successful with laminated medium-density fiberboard (MDF LAM) and 4 by 50-mm screws performed the best in the tensile resistance tests conducted on furniture corner joining. Efe and Imirzi (2008) determined that adhesive-screw experimental specimens produced from plywood and MDF materials in flat-pack furniture had a higher moment-carrying capacity against the diagonal tensile force. Tankut and Tankut (2010) stated that the side-band thickness in flat-pack furniture was effective and that 0.4-mm melamine side-band MDF LAM boards provided the best diagonal tensile resistance. Altinok et al. (2009) discovered that the dowel plus foreign strip of wood joining implemented together in flat-pack furniture produced from chipboards covered with melamine showed a better diagonal tensile and pressure resistance than when the joinings were made separately. Simek et al. (2010) determined that minifixed joinings strengthened the dowels to a significant extent without adhesive in flat-pack furniture. Yerlikaya (2013b) studied the resistance effects of a different number of dowels and minifixes in flat-pack furniture and showed that the highest bending moment value was in the joinings with two minifixes plus two dowels. Tankut (2006) carried out a study to determine the bending moment resistance of corner joints connected with different types of ready-to-assemble (flat-pack) fasteners so that the structure can safely resist the loads imposed on them in service. The fastener types included minifix cam-tightened mechanical connectors, rafix cam-tightened mechanical connectors, a corner fitting, a pipe-type fitting, a trapez connector with metal parts, and a trapez connector with plastic parts (known as corner block connectors). In both tension and compression tests, results also indicate that the joints constructed with MDF and the trapez connector with metal parts produced the highest resistance values; the rafix joints constructed with particleboard were the weakest joints evaluated.

In recent studies, different materials were tested for their ability to increase the diagonal resistances of flat-pack furniture. Yerlikaya (2013a) attempted to use glass-fiber fabric as a support in dowel joinings. It was found that dowel joinings supported with glass-fiber fabric implemented together in the internal and external parts of L-type corner joinings had a better diagonal tensile resistance compared with the unsupported, plain dowel joinings.

With the data obtained from this technological study, it will be possible to determine more reliably which material should be used where and which connection technique should be implemented on which material. In this study, the moment-carrying capacities were determined against the tensile resistances and the compression resistances of experimental specimens joined with different screw techniques that were prepared from wood-based board materials commonly used in the production of furniture. Thus, suggestions are made for the most suitable variety of material and joining form for tensile and compression resistances in the production of flat-pack construction furniture, which is the most suitable furniture production type for mass production.

Experimental

Materials

Boards.—The wood-based board materials used in the experiments included chipboard (CB), MDF, and gaboon mahogany plywood (GMP; *Aucoumea klaineana*) with thicknesses of 14, 16, and 18 mm according to TS 64-5 (EN 622-5; Turkish Standards Institution [TSE] 1999) and TS 4645 (EN 636; TSE 2005). Some physical and mechanical properties of wood-based materials are given in Table 1.

Adhesive.—PVAc and polyurethane (PUR) adhesives were used in the formation of the test specimens. PVAc is preferred because of its widespread use in the production of armchair frameworks and its attributes, which permit use in the cold and include facilitating spreading, rapid hardening, lack of odor, and fire resistance. PUR is used because of its good cohesion resistance; its elastic structure; its resistance against hot water, oil, and chemical substances; and its ability to enter into a reaction at room temperature (Burdurlu 1994).

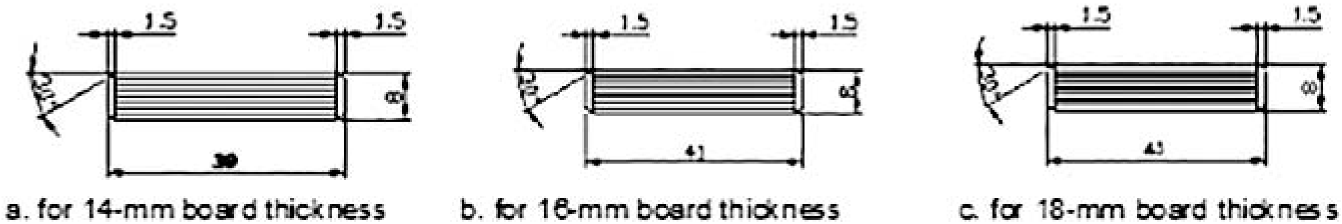


Figure 1.—The dowel examples (measurements in millimeters) used in the tests for the boards with different thicknesses: (a) 14 mm; (b) 16 mm; (c) 18 mm.

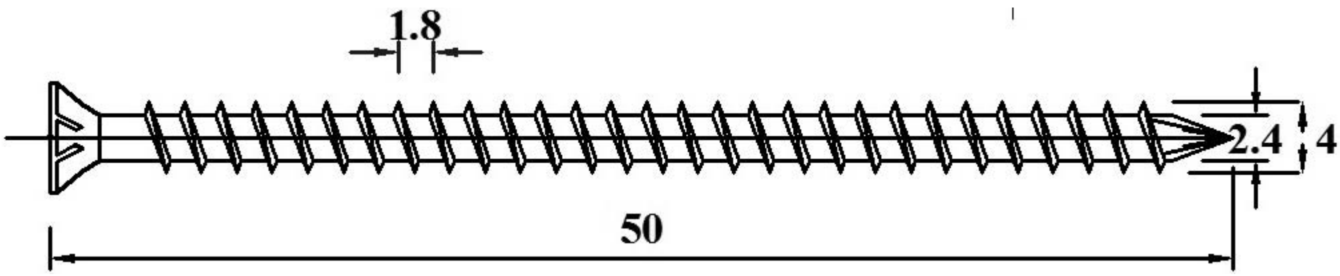


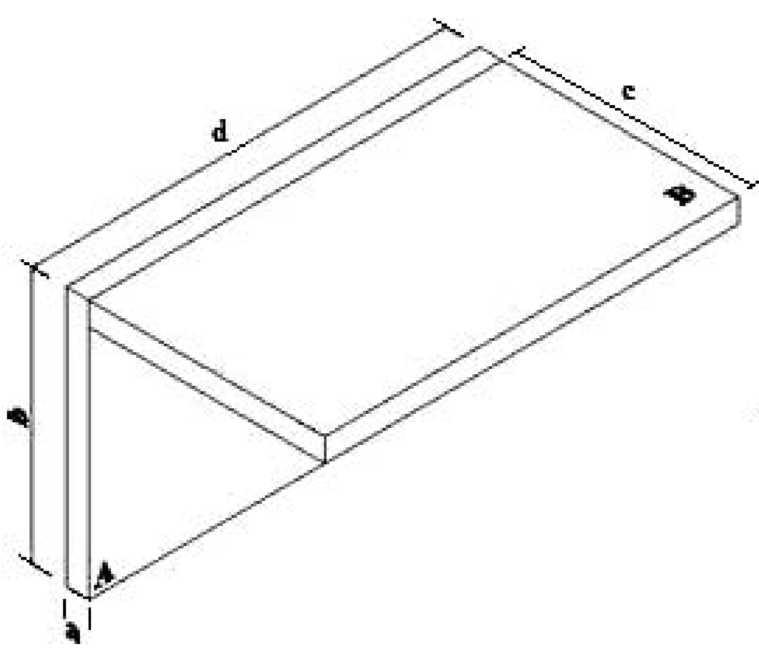
Figure 2.—The 4 by 50-mm screw example (measurements in millimeters) used in the tests.

Dowels and screws.—Dowels with threaded bodies having a diameter of 8 mm and lengths of 39, 41, and 43 mm were used in the experiments. Dowels were prepared from beechwood with the characteristics stated in the TS 4539 standard (TSE 1983; Fig. 1).

It is stated in the literature that the entrance depth of the dowel from the edge should be a minimum of 3.5 times the diameter of the dowel while not exceeding 90 percent of the thickness of the board on the surface (Norvydas 2004). Accordingly, it was calculated that the depth of entering from the surface was 11 mm for the 14-mm-thick board, 13 mm for the 16-mm-thick board, and 15 mm for the 18-mm-thick board and that the depth of entering from the edge for all three board thicknesses was 28 mm.

Four-millimeter-diameter, 50-mm-long Phillips screws were used in the experiments in accordance with the TS 61 standards (TSE 1978); these screws are used especially as connection elements in furniture joining produced from wood composite boards. The bottom diameter (root) of the thread of the Phillips screw used was 2.4 mm, and the pitch screw thread was 1.8 mm (Fig. 2).

Two screws were used for each test specimen. Pilot holes were opened on the opposite element with a diameter of 3 mm and a depth of 32 mm in the screwing processes. In the joinings with screws, it was proposed that pilot holes be opened to provide better joining (Forest Products Laboratory 1999).



A and B Piece Measurements

a	b	c	d
14 mm	200 mm	186 mm	320 mm
16 mm	200 mm	184 mm	320 mm
18 mm	200 mm	182 mm	320 mm

Figure 3.—The perspective appearance and measurements of the L-type joining test specimens.

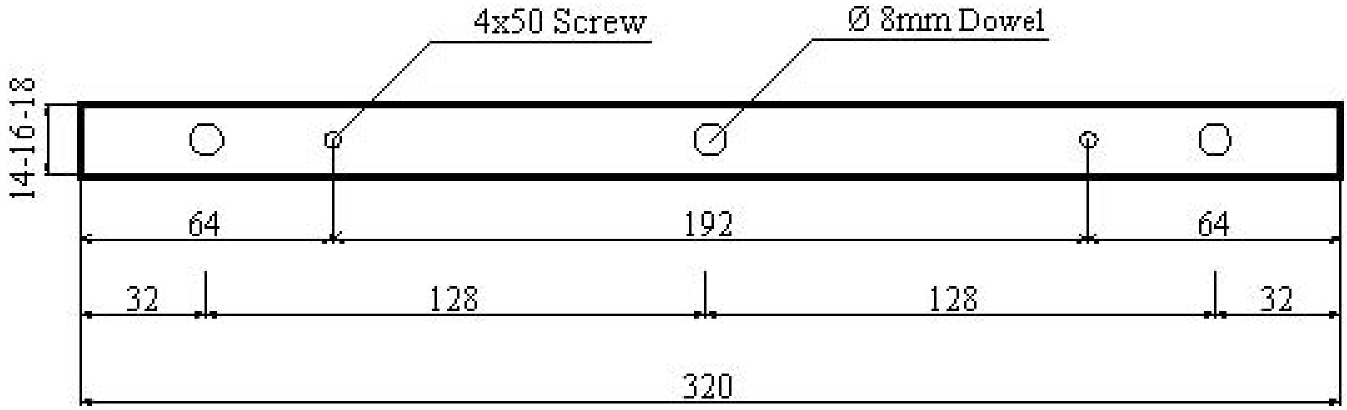


Figure 4.—Dowel and screw hole centers (measurements in millimeters) of the test specimens.

Methods

Preparation of the test specimens.—Every test specimen was composed of two elements, labeled A and B. The perspective appearance and the measurements of the test specimens prepared are shown in Figure 3. All of the specimens obtained were conditioned at 20°C ± 2°C and 65 ± 5 percent relative humidity so that they could reach the equilibrium moisture content.

In the test specimens, the centers of the dowel holes were arranged symmetrically and exactly at the center in a manner that would be 32 mm in from the edges in the broadness direction of the piece's cross section and in a manner that would be exactly at the center axis in the thickness direction. The centers of the screw holes are shown in Figure 4.

Test methods and moment calculation.—The force-carrying form, the moment arm distances, and the test specimen measurements for the diagonal tensile and compression resistance tests are shown in Figure 5. Diagonal resistance tests were carried out with a 4-ton universal test device according to the ASTM D1037 (ASTM Internatioanl 2002) method (Fig. 6).

The moment force in the diagonal tensile tests (M_t) was calculated with Equation 1:

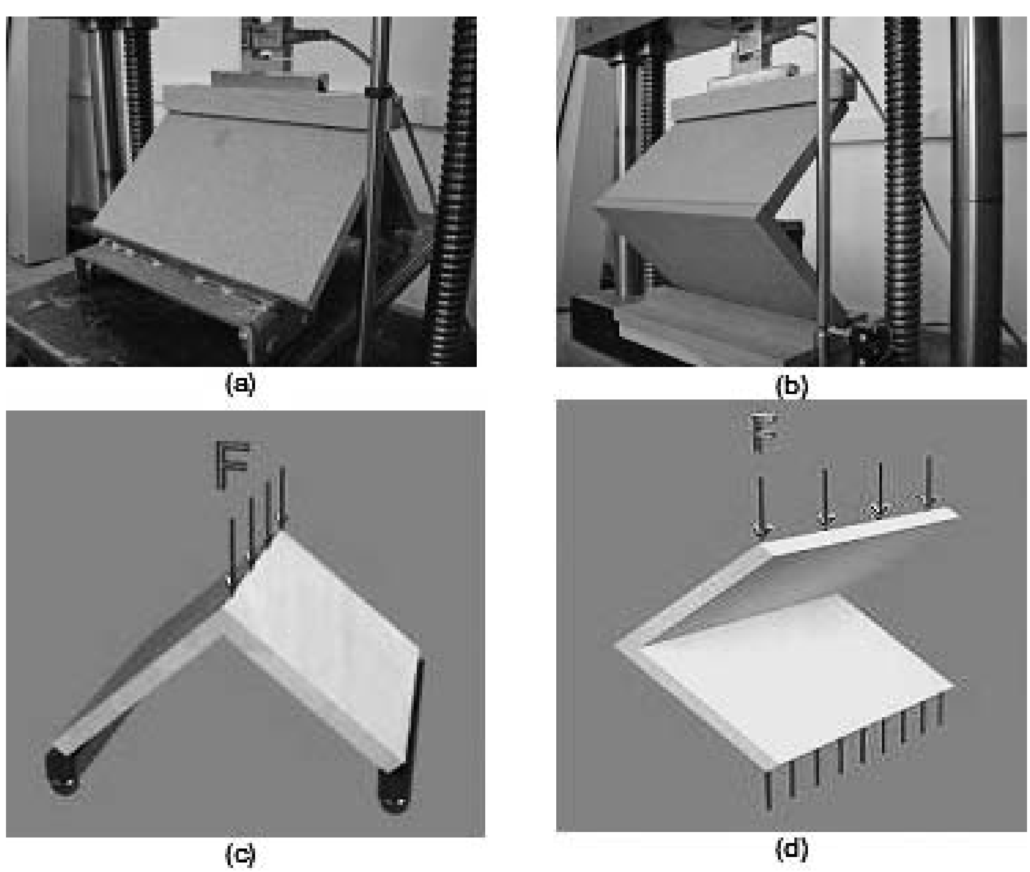


Figure 5.—The test configurations (a and b) and models (c and d).

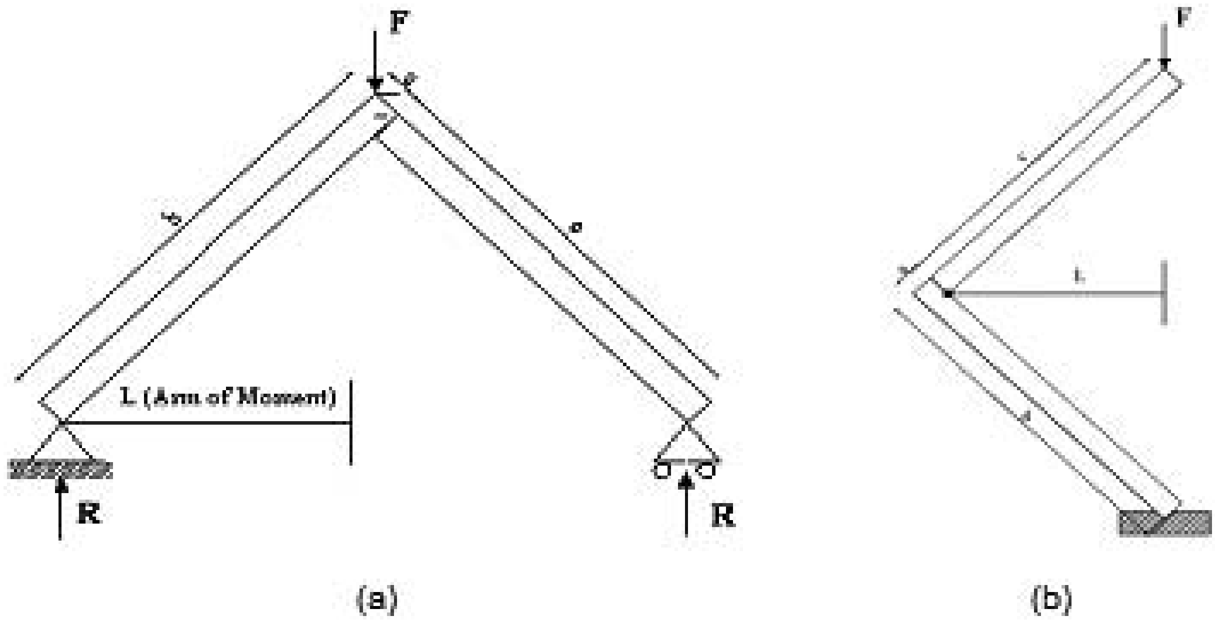


Figure 6.—The test model sections for the diagonal tensile (a) and diagonal compression (b) resistance tests.

$$M_t = \frac{F_{max}}{2} \times L_t \,(\text{Nm}) \qquad (1)$$

The moment force in the diagonal compression tests (M_c) was calculated with Equation 2:

$$M_c = F_{max} \times L_c \,(Nm) \qquad (2)$$

where

M_t and M_c = moment (Nm),
F_{max} = maximum force at the moment of breaking (N), and
L = arm of moment (m).

Test configuration.—In the tests, three different wood-based board materials (CB, MDF, and GMP), three different board thicknesses (14, 16, and 18 mm), four different joining techniques (dowel + screw, screw, screw + PVAc adhesive, and screw + PUR adhesive), and five specimens from every combination were prepared for a total of 180 ($3 \times 3 \times 4 \times 5 = 180$) diagonal tensile specimens and a total of 180 diagonal compression specimens.

Evaluation of the data.—The effects of board type, board thickness, and construction type and the dual and triple interactions of these factors on the moment-carrying

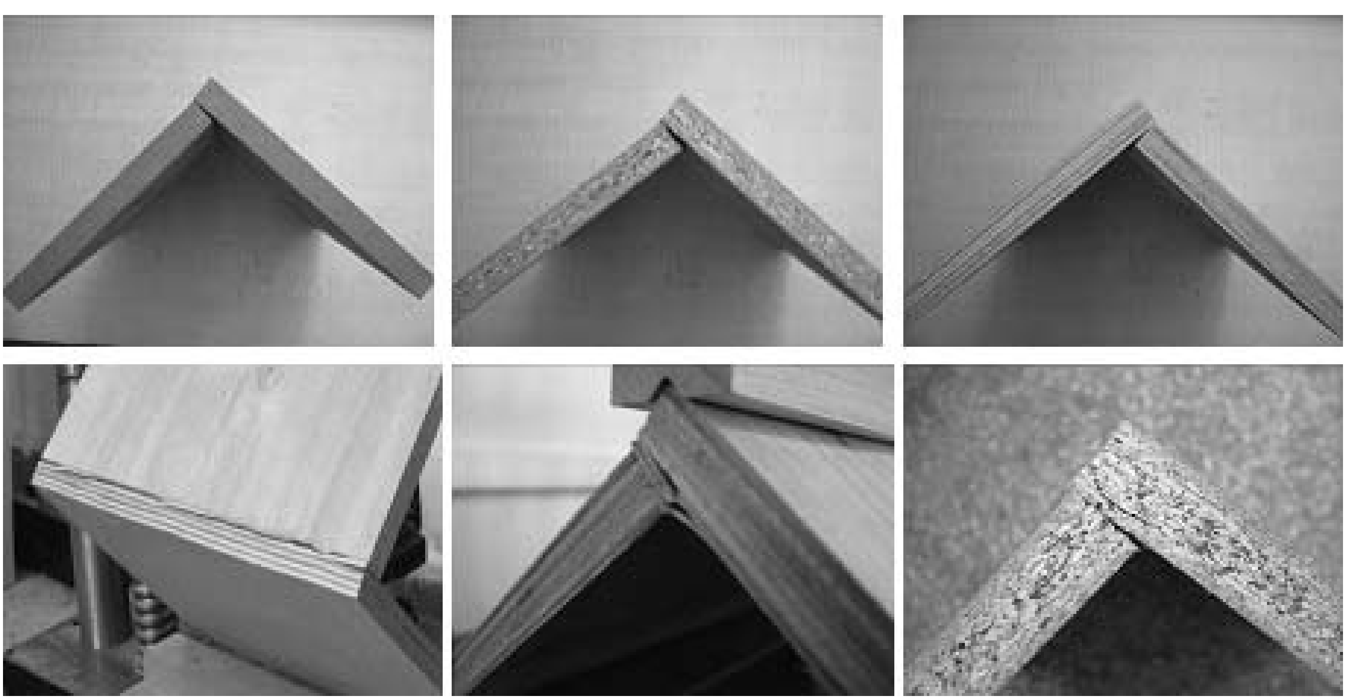


Figure 7.—Failure modes of test specimens.

Table 2.—Moment-carrying capacity values obtained at the end of the resistance tests.[a]

Type of material	Board thickness (mm)	Joining technique	Diagonal tensile resistance (Nm) Avg. moment resistance (Nm)	SD	CV (%)	Diagonal compression resistance (Nm) Avg. moment resistance (Nm)	SD	CV (%)
CB	14	Dowel + screw	19.14	1.39	7.28	17.90	0.84	4.71
		Screw	13.55	0.46	3.37	15.51	1.69	10.88
		Screw + PVAc	26.77	0.68	2.56	20.28	1.69	8.32
		Screw + PUR	29.67	1.82	6.15	13.72	0.42	3.07
	16	Dowel + screw	24.57	0.68	2.75	20.98	4.12	19.64
		Screw	14.04	1.35	9.64	14.57	0.41	2.83
		Screw + PVAc	37.01	0.90	2.44	19.81	2.47	12.48
		Screw + PUR	41.48	1.35	3.26	22.14	3.30	14.89
	18	Dowel + screw	38.19	2.90	7.60	29.01	0.40	1.39
		Screw	24.93	0.22	0.90	23.32	0.40	1.72
		Screw + PVAc	69.43	0.89	1.29	44.93	0.40	0.90
		Screw + PUR	54.92	3.57	6.50	42.66	0.40	0.94
MDF	14	Dowel + screw	32.90	0.91	2.77	36.99	1.69	4.56
		Screw	28.71	1.14	3.97	29.23	0.42	1.44
		Screw + PVAc	44.19	0.68	1.55	34.60	0.84	2.44
		Screw + PUR	61.93	0.91	1.47	29.83	0.84	2.83
	16	Dowel + screw	53.28	3.38	6.35	44.28	2.47	5.58
		Screw	38.93	0.45	1.16	34.96	0.00	0.00
		Screw + PVAc	51.37	3.38	6.59	41.37	4.53	10.96
		Screw + PUR	101.78	2.03	1.99	46.61	4.94	10.61
	18	Dowel + screw	53.02	2.68	5.05	49.48	1.21	2.44
		Screw	30.93	1.79	5.77	31.85	1.61	5.05
		Screw + PVAc	55.86	4.24	7.59	51.19	1.61	3.14
		Screw + PUR	93.42	5.80	6.21	51.76	0.40	0.78
GMP	14	Dowel + screw	32.90	0.91	2.77	28.63	1.69	5.89
		Screw	18.71	0.91	4.88	16.70	0.84	5.05
		Screw + PVAc	62.58	1.82	2.92	60.85	0.00	0.00
		Screw + PUR	70.32	1.82	2.59	49.51	2.95	5.96
	16	Dowel + screw	51.69	2.26	4.36	44.28	1.65	3.72
		Screw	27.76	0.23	0.81	30.30	0.82	2.72
		Vida + PVAc	84.55	2.48	2.94	57.68	2.06	3.57
		Vida + PUR	78.81	0.23	0.29	48.94	5.77	11.79
	18	Dowel + screw	62.18	0.22	0.36	52.33	1.61	3.07
		Screw	26.20	2.90	11.08	30.15	1.21	4.00
		Screw + PVAc	107.62	5.58	5.18	61.43	2.41	3.93
		Screw + PUR	98.79	1.12	1.13	64.27	2.01	3.13

[a] SD = standard deviation; CV = coefficient of variation; CB = chipboard; PVAc = polyvinyl acetate; PUR = polyurethane; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood.

capacity of L-type corner joining in flat-pack furniture were determined with multiple analysis of variance (ANOVA). The least significant difference test was applied for the differences in the analysis for the level of significance among the groups that emerged as statistically significant according to a level of reliability of $P < 0.05$. Thus, the board type, thickness, and construction type from among the factors tested were determined by being separated into homogeneous groups according to the sequences of success between each other. Figure 7 shows of failure modes of test specimens for connection joints subjected to tension and compression moment.

Results and Discussion

The average diagonal tensile and compression moment resistance values obtained according to the type of material, the board thickness, and the joining techniques are given in Table 2. As can be seen from Table 2, the highest moment resistances were obtained in the specimens with 18-mm GMP boards joined with screw + PVAc adhesive in the diagonal tensile resistance tests and in the specimens with 18-mm GMP boards joined with screw + PUR adhesive in the diagonal compression resistance tests.

Using the values from Table 2, an ANOVA was made with the objective of determining whether the type of material, the board thickness, and the joining technique have a meaningful influence on both diagonal tensile and diagonal compression resistances (Table 3). According to the results of the multiple ANOVA, the effects on the moment-carrying capacity values obtained as a result of the type of material, board thickness, and joining technique for the diagonal tensile resistance tests on the L-type corner joinings were found to be statistically significant with an error probability of 0.05. In the same manner, the results of the ANOVA for the dual and triple interactions are also significant. A comparison of the effects of type of material and board thickness on the moment-carrying capacity is given in Table 4.

According to Table 4, as a result of the diagonal tensile resistance, it was determined that the test specimens produced with GMP had the highest moment-carrying capacity and 11 percent higher resistance than the

Table 3.—Multiple analysis of variance (ANOVA) results related to the moment-carrying capacity effects for the type of material, board thickness, and the joining technique.

Sources of variance	Degrees of freedom	Total of squares	Avg. of squares	F value	Probability of error ($P < 0.05$)
Results related to diagonal tensile resistance (Nm)					
Type of material (TM)	2	24,639.924	12,319.962	2,383.2795	0.0000
Thickness of board (TB)	2	15,855.557	7,927.779	1,533.6177	0.0000
TM × TB	4	2,533.245	633.311	122.5132	0.0000
Joining technique (JT)	3	54,649.616	18,216.539	3,523.9640	0.0000
TM × TB	6	13,490.031	2,248.338	434.9379	0.0000
TB × JT	6	3,373.425	562.237	108.7640	0.0000
TM × TB × JT	12	2,233.678	186.140	36.0085	0.0000
Error	144	744.384	5.169		
Total	179	117,519.860			
Results related to diagonal compression resistance (Nm)					
TM	2	15,364.762	7,682.381	1,619.3855	0.0000
TB	2	6,729.611	3,364.805	709.2745	0.0000
TM × TB	4	726.912	181.728	38.3068	0.0000
JT	3	8,963.400	2,987.800	629.8048	0.0000
TM × TB	6	3,712.474	618.746	130.4267	0.0000
TB × JT	6	1,135.363	189.227	39.8876	0.0000
TM × TB × JT	12	1,593.688	132.807	27.9947	0.0000
Error	144	683.137	4.744		
Total	179	38,909.347			

specimens produced with MDF. Furthermore, of the boards used, the 18-mm-thick test specimens had the highest values, and it was observed that they had 15 percent higher resistance than the 16-mm-thick specimens. According to the joining technique, the test specimens produced with screws + PUR showed the highest carrying capacity and produced a 17 percent better result than the specimens prepared with screws + PVAc.

Table 4.—Comparison of the moment-carrying capacities according to type of material, board thickness, and joining technique.[a]

Source	Diagonal tensile resistance (Nm) Mean	HG	Diagonal compression resistance (Nm) Mean	HG
Type of material				
CB	32.81	C	23.74	C
MDF	53.86	B	40.18	B
GMP	60.18	A	45.42	A
Board thickness (mm)				
14	36.78	C	29.48	C
16	50.44	B	35.49	B
18	59.62	A	44.37	A
	LSD ± 0.8191 Nm		LSD ± 0.7847 Nm	
Joining technique				
Dowel + screw	40.87	C	40.87	C
Screw	24.86	D	25.18	D
Screw + PVAc	59.93	B	43.57	A
Screw + PUR	70.12	A	41.05	B
	LSD ± 0.9458 Nm		LSD ± 0.9061 Nm	

[a] HG = homogeneous group; CB = chipboard; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood; LSD = least significant difference test; PVAc = polyvinyl acetate; PUR = polyurethane.

As a result of the diagonal compression resistance in Table 4, it was determined that the test specimens produced with GMP had the highest moment-carrying capacity and had 13 percent higher resistance than the specimens produced with MDF. The 18-mm-thick test specimens had the highest values, and they had 20 percent higher resistance than the 16-mm-thick specimens. The specimens produced with screws + PVAc had the highest values and they had 6 percent higher resistance than the specimens prepared with screw + PUR. The fixed joining produced using adhesive had a higher moment-carrying capacity than flat-pack joining produced without adhesive.

Rajak and Eckelman (1996) reported that the bending resistance of corner joints was essentially directly proportional to the number of fasteners used, i.e., the bending resistance of a two-fastener joint was twice as strong as a single-fastener joint. These results are also in agreement with the results of this study.

A comparison of the effects on the moment-carrying capacity of the joinings by the dual interaction of type of material and board thickness is given in Table 5. According to the diagonal tensile resistance in Table 5, the highest moment-carrying capacity was produced in the 18-mm-thick GMP. Also, the fact that the next best result was observed in the 16-mm-thick rather than the 18-mm-thick MDF boards is significant. The best moment-carrying capacity for the diagonal compression resistance was produced in 18-mm-thick GMP.

The results found for CB are some of the most important ones obtained in this study, as this material is used the most in the production of flat-pack furniture. Wang (1984) found that bending resistance of corner joints constructed with CB was strongly related to board density. Tankut (2006) stated that laminated MDF corner joints were an average of 22 percent stronger than laminated particleboard corner joints in both tension and compression tests. These results are also in agreement with the results of this study. In this situation,

Table 5.—Comparison of the effects on moment-carrying capacities according to the dual interaction of type of material and board thickness (14, 16, and 18 mm).[a]

	Diagonal tensile resistance (Nm)						Diagonal compression resistance (Nm)					
	14 mm		16 mm		18 mm		14 mm		16 mm		18 mm	
Type of material	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG
CB	22.28	G	29.27	F	46.87	D	16.85	H	19.37	G	34.98	E
MDF	41.93	E	61.34	B	58.31	C	32.66	F	41.81	C	46.07	B
GMP	46.13	D	60.70	B	73.70	A	38.92	D	45.30	B	52.04	A
	LSD ± 1.419 Nm						LSD ± 1.359 Nm					

[a] HG = homogeneous group; CB = chipboard; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood; LSD = least significant difference test.

it is proposed that GMP and MDF boards should be used instead of CB in the production of load-carrying flat-pack furniture.

A comparison of the effects on the moment-carrying capacities for the joinings of the dual interactions of type of material and joining technique is given in Table 6. According to the diagonal tensile resistance in Table 6, the highest moment-carrying value was observed in the MDF boards joined with screws + PUR and in the GMP boards joined with screws + PVAc. The highest moment-carrying values for the diagonal compression resistance were produced in GMP boards joined with screw + PVAc.

The joining made without adhesive and the CB materials produced the lowest moment-carrying values. A comparison of the effects of the dual interactions of thickness of board and joining technique on the moment-carrying capacities of the joinings are given in Table 7.

According to Table 5, the highest moment-carrying values for both of the diagonal resistances were obtained in the test specimens produced with a thickness of 18 mm with the screw + PUR adhesive and with the screw + PVAc adhesive.

A comparison of the effects of the triple interaction among type of material, board thickness, and joining technique on the moment-carrying capacities of the joinings is given in Table 8 and shown in Figures 8 and 9.

According to the analysis values of the triple interaction, the highest moment-carrying value for the diagonal tensile resistance was produced in the test specimens obtained with 18-mm-thick GMP boards joined with screws + PVAc. The lowest moment-carrying values were determined in the test specimens obtained from the CB material produced in thicknesses of 14 and 16 mm and joined with screws without adhesive. The results of the diagonal compression resistance tests gave similar results.

Table 6.—Comparison of the moment-carrying capacities according to the dual interaction for type of material and joining technique.[a]

	Diagonal tensile resistance (Nm)								Diagonal compression resistance (Nm)							
	Dowel + screw		Screw		Screw + PVAc		Screw + PUR		Dowel + screw		Screw		Screw + PVAc		Screw + PUR	
Type of material	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG
CB	27.30	H	17.51	J	44.40	E	42.02	F	22.63	H	17.80	I	28.34	F	26.17	G
MDF	46.40	D	32.86	G	50.47	C	85.71	A	43.58	C	32.01	E	42.39	CD	42.73	CD
GMP	48.92	C	24.22	I	84.92	A	82.64	B	41.75	D	25.72	G	59.99	A	54.24	B
	LSD ± 1.638 Nm								LSD ± 1.569 Nm							

[a] PVAc = polyvinyl acetate; PUR = polyurethane; HG = homogeneous group; CB = chipboard; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood; LSD = least significant difference test.

Table 7.—Comparison of the moment-carrying capacities according to the dual interactions of thickness of board and joining technique.[a]

	Diagonal tensile resistance (Nm)								Diagonal compression resistance (Nm)							
	Dowel + screw		Screw		Screw + PVAc		Screw + PUR		Dowel + screw		Screw		Screw + PVAc		Screw + PUR	
Board thickness (mm)	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG
14	28.31	H	20.32	I	44.51	G	53.97	E	27.84	FG	20.48	H	38.58	C	31.02	E
16	43.18	G	26.91	H	57.64	D	74.02	C	36.51	D	26.61	G	39.62	C	39.23	C
18	51.13	F	27.35	H	77.64	B	82.38	A	43.61	B	28.44	F	52.52	A	52.90	A
	LSD ± 1.638 Nm								LSD ± 1.569 Nm							

[a] PVAc = polyvinyl acetate; PUR = polyurethane; HG = homogeneous group; LSD = least significant difference test.

Table 8.—Comparison of the moment-carrying capacities according to the triple interactions of type of material, board thickness, and joining technique.[a]

Type of material	Board thickness (mm)	Diagonal tensile resistance (Nm)								Diagonal compression resistance (Nm)							
		Dowel + screw		Screw		Screw + PVAc		Screw + PUR		Dowel + screw		Screw		Screw + PVAc		Screw + PUR	
		Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG	Mean	HG
CB	14	19.14	U	**13.55**	**V**	26.77	RST	29.67	PQ	17.90	PQ	15.51	QRS	20.28	OP	**13.72**	**S**
	16	24.57	T	**14.04**	**V**	37.01	N	41.48	LM	20.98	NO	14.57	RS	19.81	OP	22.14	NO
	18	38.19	N	24.93	ST	69.43	G	54.92	IJ	29.01	M	23.32	N	44.93	HI	42.66	IJ
MDF	14	32.90	O	28.71	PQR	44.19	L	61.93	H	36.99	K	29.23	LM	34.60	K	29.83	LM
	16	53.28	IJK	38.93	MN	51.37	K	101.8	B	44.28	HI	34.96	K	41.37	J	46.61	GH
	18	53.02	JK	30.93	OP	55.86	I	93.42	D	49.48	EF	31.85	L	51.19	DEF	51.76	DE
GMP	14	32.90	O	18.71	U	62.58	H	70.32	G	28.63	M	16.70	QR	60.85	B	49.51	EF
	16	51.69	K	27.76	QRS	84.55	E	78.81	F	44.28	HI	30.30	LM	57.68	C	48.94	FG
	18	62.18	H	26.20	RST	**107.60**	**A**	98.79	C	52.33	D	30.15	LM	61.43	B	**64.27**	**A**
				LSD ± 2.837 Nm								LSD ± 2.718 Nm					

[a] Bold values indicate the highest and lowest values. PVAc = polyvinyl acetate; PUR = polyurethane; HG = homogeneous group; CB = chipboard; MDF = medium-density fiberboard; GMP = gaboon mahogany plywood; LSD = least significant difference test.

The highest moment-carrying value was produced in the 18-mm-thick GMP specimens joined with screws + PUR adhesive. The lowest moment-carrying value for the diagonal compression resistance was observed in the 14-mm-thick CB specimens joined with screws + PUR adhesive.

These results show that the moment resistance in both tests increased as the board thickness increased. Also, the joining made with screws + adhesive had a higher moment-carrying capacity. In Tankut's (2006) study, the joints constructed with MDF and the trapez connector with metal parts produced the highest resistance values in both tests (31.796 Nm in the diagonal compression resistance and 75.201 Nm in the diagonal tensile resistance). This connector showed weaker resistance than the screw + adhesive combination, which had the highest resistance value in our study

Conclusions

The aim of this study was to determine the most suitable joining application for fulfilling the function for a long period of time without damaging the structure against tensile and compression resistances that could emerge in

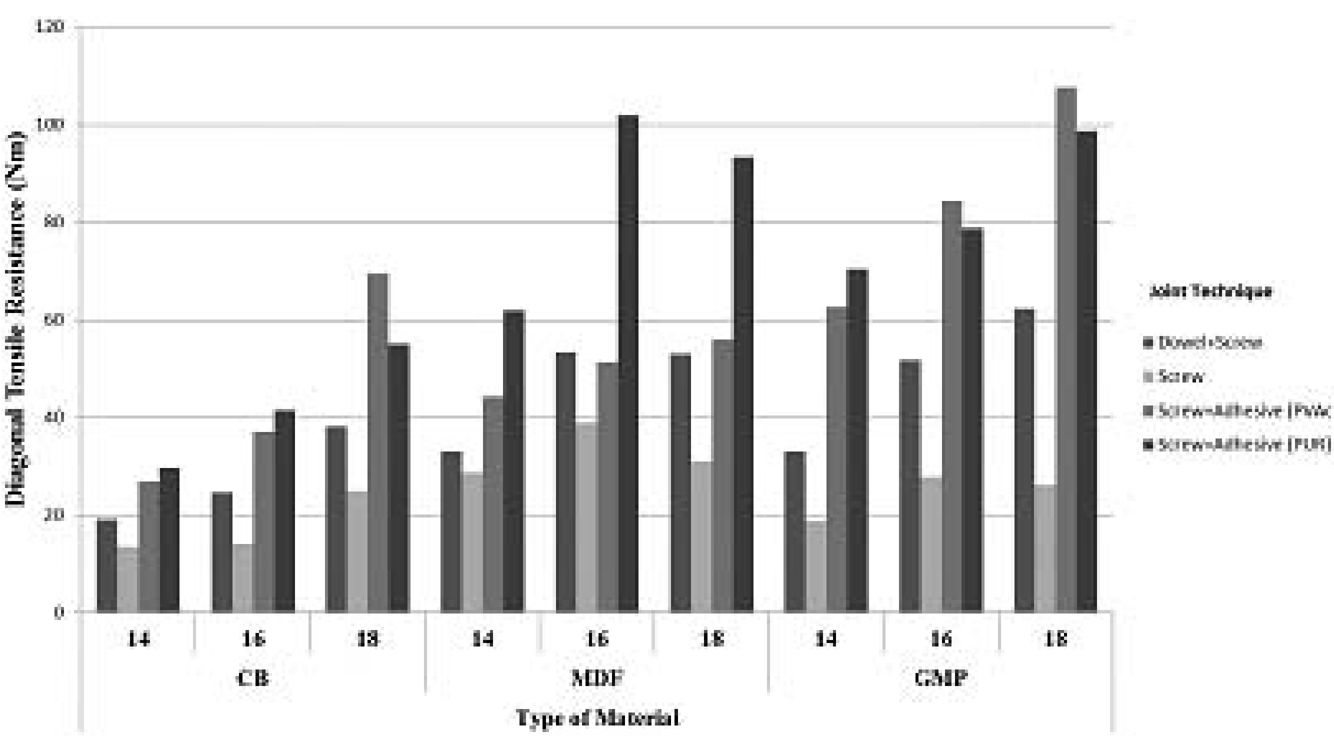


Figure 8.—Comparison of the moment-carrying capacities according to the triple interactions of type of material, board thickness, and joining technique (diagonal tensile resistance [newton meters]).

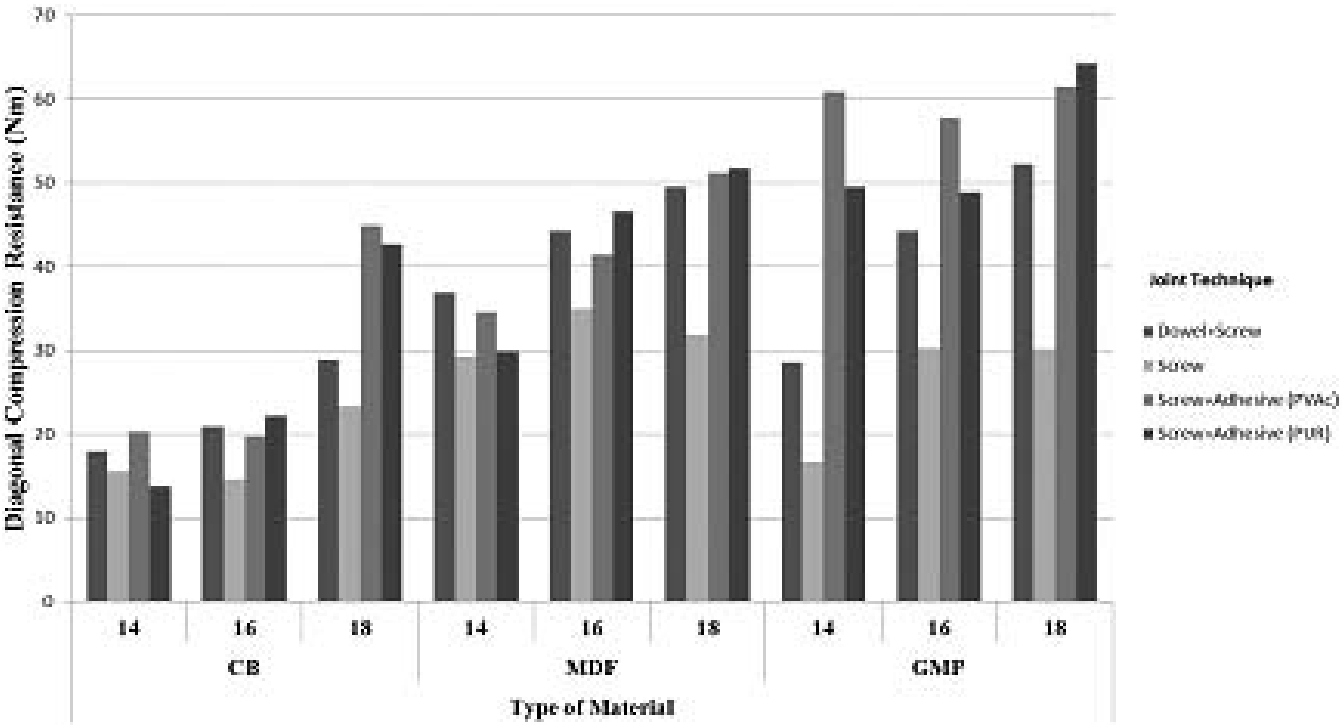


Figure 9.—Comparison of the moment-carrying capacities according to the triple interactions of type of material, board thickness, and joining technique (diagonal compression resistance [newton meters]).

response to the effect of loads that could be encountered for flat-pack furniture.

The 18-mm GMP boards showed the best resistance against the diagonal tensile and compression resistances. In production where tensile and compression resistances are important, the 18-mm board thickness should be preferred. Because the 18-mm-thick test specimens had the highest values, it was established that they had 15 percent higher resistance than the 16-mm-thick specimens.

CB, which is the most preferred material for mass production in the furniture industry, has shown weaker resistance than GMP and MDF boards in both of the diagonal resistances. Consequently, the use of CB cannot be proposed in the production of furniture for use in places where it could be subjected to tensile and compression resistances under the effect of a load.

The fixed joinings produced using adhesive showed higher tensile and compression resistances compared with the flat-pack joining produced without adhesive. Especially if strong joints against a load are desired, flat-pack joining rather than an adhesive should be used. Even if a statistically significant difference emerged between the screw + PVAc and the screw + PUR joining techniques, the diagonal tensile and compression resistance values were similar to each other. Consequently, no proposal can be made regarding the two adhesives.

The study should be further developed to determine the behaviors that could be encountered in response to the probable load effects of different materials and joinings on furniture. Finally, with the data obtained through different research, it will be possible to determine more reliably which material should be used where and which connection technique should be implemented on which material.

Literature Cited

Altinok, M. 2003. Mobilya mukavemeti [Strength of furniture]. Bachelor's degree class notes. Gazi Üniversitesi Mobilya ve Dekorasyon Eğitimi, Ankara, Turkey.

Altinok, M., H. H. Tas, and M. Cimen. 2009. Effects of combined usage of traditional glue joint methods in box construction on strength of furniture. *Mater. Des*. 30(8):3313–3317.

ASTM International. 2002. Standard test method for evaluating properties of wood-base fiber and particle panel materials. ASTM D1037. ASTM International, West Conshohocken, Pennsylvania.

Burdurlu, E. 1994. Ahsap kokenli kaplama ve levha uretim—Kullanim teknolojisi [Wood-sourced veneer and board production-use technology]. Hacettepe University, Ankara, Turkey.

Efe, H. 1994. Modern mobilya cerceve konstruksiyon tasariminda geleneksel ve alternatif baglanti tekniklerinin mekanik davranis ozellikleri [The mechanical behavior attributes of traditional and alternative joining techniques in the design of modern furniture framework construction]. PhD dissertation. Karadeniz Technical University, Trabzon, Turkey.

Efe, H. and H. O. Imirzi. 2008. Farkli birlestirme teknikleri ve degisik kalinliklardaki levhalarla uretilmis kutu-tipi mobilya kose birlestirmelerinin moment tasima kapasitesi [The moment-carrying capacity of box-type furniture corner joinings produced with boards of different thicknesses and with different joining techniques]. *J. Polytech*. 11(1):66–75.

Efe, H. and A. Kasal. 2000. Tabla tipi kavelalı kose birlestirmelerde tutkal cesidinin cekme direncine etkileri [The effects on tensile resistance of the type of adhesive in flat surface–type dowel corner joinings]. *J. Polytech*. 3(4):67–72.

Erdil, Y. Z. 1998. Strength analysis and design of joints of furniture frames constructed of plywood and oriented strand board. MS thesis. Purdue University Graduate School, West Lafayette, Indiana.

Forest Products Laboratory. 1999. Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-113. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. pp. 7–10.

Norvydas, V. 2004. Research and evaluation of strength and fracture of

the doweled furniture joint. PhD dissertation. Kaunas University of Technology, Kaunas, Lithuania.
Ors, Y., H. Efe, and A. Kasal. 2001. Kutu konstruksiyonlu vidalı mobilya kose birlestirmelerinde cekme direnci [Tensile resistance in the box construction furniture corner joinings with screws]. *J. Polytech*. 4(4):1–9.
Rajak, Z. and C. A. Eckelman. 1996. Analysis of corner joints constructed with large screws. *J. Trop. Forest Prod*. 2(1):80–92.
Simek, M., E. Haviarova, and C. A. Eckelman. 2010. The effect of end distance and number of ready-to-assemble furniture fasteners on bending moment resistance of corner joints. *Wood Fiber Sci*. 42(1):92–98.
Tankut, A. N. and N. Tankut. 2010. Evaluation the effects of edge banding type and thickness on the strength of corner joints in case-type furniture. *Mater. Des*. 31(6):2956–2963.
Tankut, N. 2006. Moment resistance of corner joints connected with different RTA fasteners in cabinet construction. *Forest Prod. J*. 56(4):35–40.
Turkish Standards Institution (TSE). 1978. Agac vidalari [Wood screws]. TS 61. TSE, Ankara.
Turkish Standards Institution (TSE). 1983. Ahsap birlestirmeler—Kavelali birlestirme kurallari [Wood jointing—Rules of the dowel jointing]. TS 4539. TSE, Ankara.
Turkish Standards Institution (TSE). 1999. Lif levhalar—Ozellikler—Bolum 5: Kuru islem levhalarinin (MDF) ozellikleri [Fiber boards—Requirements—Part 5: Requirements of dry process boards (MDF)]. TS 64-5 EN 622-5. TSE, Ankara.
Turkish Standards Institution (TSE). 2005. Kontrplak—Ozellikler [Plywood—Requirements]. TS 4645 EN 636. TSE, Ankara.
Wang, S. Y. 1984. The jointing of particleboard. *Forest Prod. Ind*. 3(2):90–106.
Yerlikaya, N. C. 2013a. Failure load of corner joints, which are reinforced with glass-fiber fabric in case-type furniture. *Sci. Res. Essays* 8(8):325–339.
Yerlikaya, N. C. 2013b. Kabin tipi demonte mobilyalarda birlestirmeler-in egilme momenti uzerine kavela ve minifiksin etkisi [The effect of dowel and minifix on the bending moment in the cabinet-type furniture]. *Artvin Coruh Univ*. *J. Forestry Fac*. 14(1):36–49.
Zhang, J. L. and C. A. Eckelman. 1993a. The bending moment resistance of single-dowel corner joints in case construction. *Forest Prod. J*. 43(6):19–24.
Zhang, J. L. and C. A. Eckelman. 1993b. Rational design of multi-dowel corner joints in case construction. *Forest Prod. J*. 43(11/12):52–58.