ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 408-414

DETERMINATION OF THE LOAD-CARRYING CAPACITY AND STIFFNESS OF FOUR SIDED FURNITURE CASES

Mehmet YUKSEL
Instructor - Mugla Sitki Kocman University in Mugla – Faculty of Technology
Address: Mugla S.K. Universitesi, Teknoloji Fakultesi, 48000 Kötekli/Mugla, Turkey
E-mail: myuksel@mu.edu.tr

Ali KASAL
Associated Professor - Mugla Sitki Kocman University in Mugla – Faculty of Technology
Address: Mugla S.K. Universitesi, Teknoloji Fakultesi, 48000 Kötekli/Mugla, Turkey
E-mail: akasal@mu.edu.tr

Yusuf Ziya ERDIL
Professor - Mugla Sitki Kocman University in Mugla – Faculty of Technology
Address: Mugla S.K. Universitesi, Teknoloji Fakultesi, 48000 Kötekli/Mugla, Turkey
E-mail: erdil@mu.edu.tr

Mehmet ACAR
Research Assistant - Mugla Sitki Kocman University in Mugla – Faculty of Technology
Address: Mugla S.K. Universitesi, Teknoloji Fakultesi, 48000 Kötekli/Mugla, Turkey
E-mail: macar@mu.edu.tr

Abstract:

The objective of this study was to investigate the effect of the panel type, connector type, and anchorage location on load bearing capacity and stiffness of four-sided furniture cases. Real size (1/1 scale) four sided case specimens were constructed of three different wood based panel. Corner joints of four sided cases were connected with two different ready to assemble (RTA) joint techniques including trapez and minifix fasteners. Four sided cases were anchored to the wall from side panels and top panel with L-shape metal connectors. Loading procedures of American National Standards Institute/Kitchen Cabinet Manufacturers Association were followed during the static tests. Loads were applied from top panel's surface with a loading strap. According to results, four-sided cases constructed of 18mm MDF showed higher load carrying capacity and stiffness values than those of 16mm MDF and 18mm PB cases. The cases assembled with trapez connectors yielded higher load carrying capacity and stiffness values than the cases assembled with minifix connectors. Based on the results, it can be concluded that in general, a four-sided case anchored on side panels has a significantly higher load carrying capacity than the one anchored on top panel.

***Key words**: medium density fiberboard; particleboard; load carrying capacity; stiffness; case furniture; furniture connectors.*

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 408-414

INTRODUCTION

Mainly, three construction methods were utilized for furniture systems which was constructed by the frame or case system or by a combination of both that is called as complex method. The frame construction is consisted only by bar members. The case construction means that the members of furniture were panels instead of bars. The complex method is included bar also panel members were used together. Generally, case type furniture is used in homes and offices furniture for storage.

Medium density fiberboard (MDF) and particleboard (PB) are widely used in manufacturing of case type furniture because of their mechanical, physical and surface qualities compared to solid wood.

Nowadays, joints without adhesives are common in furniture construction because their use allows furniture to be shipped in the knock down condition and assembled on site which greatly reduces shipping costs. This is an important consideration both in the case of domestic and export furniture. Ready to assemble (RTA) fasteners are widely utilized in corner joints of furniture constructions.

The most critical point of cases is the specification of fastener types that used for connecting the side panels to bottom panel and top panel of the cases. The rational design of case furniture constructed with RTA fasteners requires information on load carrying capacity and rigidity of these fasteners in MDF and PB for real size case specimens. In spite of their widespread use, limited information is available regarding load carrying capacity and rigidity of real size cases with RTA corner joints.

Published information is mostly related to direct withdrawal resistances of screw-type joints and moment resistances of L-type corner joints (Eckelman 1974, 1975, 1978, Zaini and Eckelman 1993).

Lin and Eckelman carried out a study to determine the effect of joint rigidity on case stiffness. Results indicate that stiffness of a case may be significantly affected by the joint type used, so joints have a significant effect on stiffness of a case (Lin and Eckelman 1987).

The main problem of constructions that jointed with wood based panels is tend to split edges of the panel. This is true when butt type joints are constructed. Bachmann and Hassler were tested split of free edge of a panel was the principle source of failure with demountable fasteners which utilize metal and plastic inserts. The results of their tests provide to point out the importance of taking the natural characteristics of the material into the account when designing with PB. In particular, it is necessary to design the joints in such way that the tendency of the board to delaminate is minimized (Bachmann and Hassler 1975).

Dinc analyzed the diagonal compression and tension performance of samples which were prepared with particle board (PB) and fiberboard (MDF) surfaced with resin sheet. The samples were jointed with plastic and metal minifix joining elements. The strongest result was realized with the combination of plastic minifix and fiberboard. He put forth that the diagonal tension performance was greater than the diagonal compression performance (Dinc 2000).

Yerlikaya and Aktas were studied the failure loads of L-type corner joints in case-type furniture that constructed with five corner joint types which are glass-fiber composite layer (C), dowel (D), dowel + composite layer (DC), dowel + minifix (DM), and dowel + minifix + composite layer (DMC). He analyzed failure load of the joints under tension and compression moments. According to the results, the failure load takes its highest value in the DMC case. On the other hand, it takes its lowest value in the D case (Yerlikaya and Aktas, 2012).

Simek *et al*. determined that two, three, four, or five unglued dowels specimens had significantly higher bending moment resistance than joints that employed only two single cam fasteners without dowels. Thus, they concluded that unglued dowels used to locate the parts for assembly substantially reinforce joints constructed with cam fasteners (Simek *et al*. 2010). Dinc analyzed that the combination of plastic minifix joining elements and processed MDF was observed to give the strongest results (Dinc 2000).

There were determined the effects of the screw sizes and board material type on the load bearing capacity and stiffness of five-sided furniture cases 18*mm* Particleboard (PB) and medium density fiberboard (MDF) were utilized for constructing the cases and nine sizes of screws were used for assembling. Results indicated that in general the five-sided cases constructed of MDF yielded significantly higher load bearing capacities than the PB, but the significance of MDF cases over PB cases in stiffness depends on screw diameters (Kasal *et al*. 2008).

Tankut investigated the effect of material type and thickness on overall case rigidity. Results of his study showed that the stiffness of case furniture could be increased by increasing material thickness from 16 to 18mm, furthermore, by using screw with glue instead of using only screw or applying glue to the dowels and whole edges instead of dowels only (Tankut 2009).

According to study, which was investigated the effects of screw size on ultimate failure load and stiffness of four-sided furniture cases, increasing either screw diameter or length tended to to have a positive effect on the failure load and stiffness (Kasal *et al*. 2011).

OBJECTIVES

The aim of this study was to investigate the load carrying capacity and stiffness of real size (1/1 scale) four-sided furniture cases constructed with PB and MDF by using two different fasteners in corner joints. The factors studied were:

• Effect of panel type (16mm MDF, 18mm MDF, 18mm PB) on load carrying capacity and stiffness of four-sided cases under static load.

• Effect of fastener types (trapez and minifix) used on ultimate load carrying capacity and stiffness of four-sided cases under static load.

• Effect of anchorage point of cases to the wall with L-shape connectors.

• This study provides furniture cabinet manufacturers some information concerning the effects of joint construction factors such as, panel type, connector type, and anchorage point on load carrying capacity and stiffness of real size four-sided furniture cases. The information could give helpful insight to engineers in product engineering of case type furniture.

METHOD, MATERIAL AND EQUIPMENT
Experimental Design

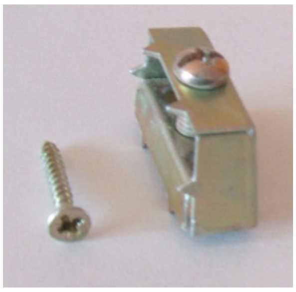
Table 1

The specimen schedule used in the study.

Mounting Point	Connector type	18mm PB	16mm MDF	18mm MDF	Total
Sides	Minifix	3	3	3	9
	Trapez	3	3	3	9
Top	Minifix	3	3	3	9
	Trapez	3	3	3	9
Total		12	12	12	36

Overall, 12 sets (3 panel types, 2 connector types, 2 anchorage points) of four-sided cases consisting of 3 replications each, or a total of 36 four-sided cases were prepared for static tests. A full linear model for the three-way factorial experiments (MANOVA) was considered to investigate the effect of panel type (18 *mm* thickness PB, 16 and 18*mm* thickness MDF), connector types (minifix and trapez connectors with dowels which were shown in Fig. 1) and anchorage point (from side panels, from top panel) used on the load carrying capacity and stiffness of four-sided furniture cases. Experimental design schedule is presented in Table 1.

Minifix Connector



Trapez Connector

Fig. 1
Connector types.

Preparation and Construction of Four Sided Cases

Cases were constructed with 18*mm* thickness PB, and 16 and 18*mm* thickness MDF panels. The panels were supplied from the commercial sources. A four - sided case consists of a top panel, a bottom panel, and side panels of the same material. In preparation of cases, 3660x1830*mm* full-size sheets of PB and MDF were cut to obtain the top, bottom, and side panels. These panels were then dimensioned into exact size in width and lengths. The cases dimensioned based on the commonly used wall cabinet size of 750*mm* height by 300*mm* depth by 840*mm* width (Fig. 2).

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 408-414

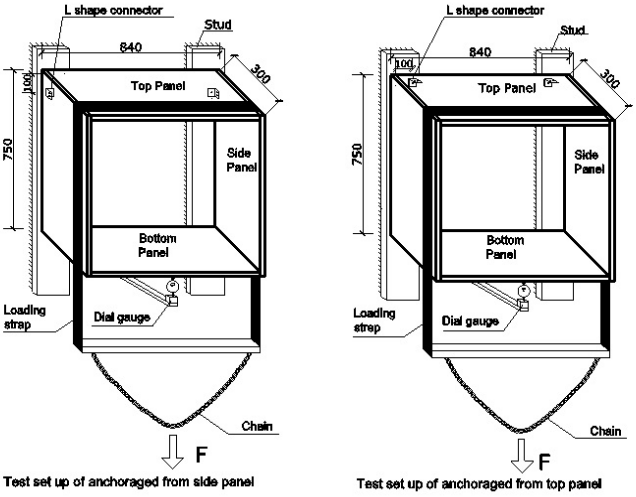


Fig. 2
Test setup for the static test of four-sided cases.

Half of the four sided cases were assembled with minifix and remaining half of the four sided cases were constructed with dowel + trapez fasteners without adhesive. Minifix and trapez type connectors are commonly utilized in the corner joints of the cases in furniture industry of Turkey. In the trapez corner joints, the connectors were fastened with 3.5x25*mm* screw and multi-groove beech dowel which is 8mm in diameter and 34mm in length were used. Metal plug minifixes with a diameter of 15mm were applied to the joint without dowels.

Fig. 3 shows a typical placement of fasteners and dowels in four-sided cases used in this study. In order to avoid moisture content variations, the prepared cases were stored in a conditioning chamber at 20ºC±2 and 65±3% relative humidity prior to test.

Fig. 3
Connector placements in the corner joints of four - sided cases.

Static Tests of Four Sided Cases

Physical and mechanical properties of PB and MDF were evaluated in accordance with the procedures described in ASTM D 4442 (ASTM 2001b) and ASTM D 1037 (ASTM 2001a), respectively. In the static tests, the procedures of testing suggested in the ANSI/KCMA (1995) were followed. Four-sided cases were tested under static loads and force-deflection diagrams were drawn for evaluating the stiffness of cases. Fig. 2 shows loading and supporting conditions of the four-sided cases.

All tests were performed with a 50*kN* capacity universal testing machine at a loading rate of 6*mm/min*. Load applied with a loading strap which passes over the top panel and two sides meet under the case where head of the machine is present. Cases were kept and mounted to a metallic main frame which located above the universal machine. The four-sided cases itself was fixed on this main frame by the help of two parallel 100 by 100*mm* studs. These studs were attached to the metallic main frame by nuts and bolts, and then four-sided cases were mounted on these two parallel studs with the help of two L-shape metal fixtures and screws. In the tests, it was designed and thus expected that the failures occurs on corner joints instead of separation of the entire cabinet from the studs. It was assumed that since the loading was balanced to the both side of the cabinet, as it is shown in Fig. 2, there was only one dial gage in the midpoint of the underside of bottom panel which was used to measure the amount of deflection in vertical direction after applying the load on cases. Loading was continued until a failure or full separation occurred in the corner joints of the four-sided cases. During the static tests, failure modes, load carrying capacities, and deflections were recorded. Stiffness values were calculated by taking several measurements of load vs. deflection in the elastic, apparently linear range then fitting them into a regression line by least squares method.

Evaluation of the Data

A three factor analysis of MANOVA general linear model procedure was performed for individual data both load carrying capacity and stiffness to analyze main effects and their interactions on load carrying capacity and stiffness values of four-sided cases. Summary of MANOVA results are provided in Table 2.

Table 2

Summary of the MANOVA results for load carrying capacities and stiffness values

	Source	Degrees of freedom	Sum of squares	Mean squers	F value
Load carrying capacity	A	1	37660723.36	37660723.361	3232.7803
	B	2	1994738.667	997369.333	85.6138
	AB	2	817340.222	408670.111	35.0801
	C	1	1907621.361	1907621.31	163.7494
	AC	1	1454034.028	1454034.08	124.8137
	BC	2	95353.556	47676.778	4.0926
	ABC	2	2029788.222	1014894.111	87.1181
	Error	24	279591.333	11649.639	
Stiffness	A	1	109791.721	109791.721	8.8449
	B	2	23089.503	11544.752	0.9301
	AB	2	13954.216	6977.108	0.5621
	C	1	9434.562	9434.562	0.7601
	AC	1	784.841	784.841	0.0632
	BC	2	62801.600	31400.800	2.5297
	ABC	2	52367.489	26183.744	2.1094
	Error	24	297911.092	12412.962	
	Total	35	570135.023		

A: Anchorage point B: Joint techniques C: Panel type

The least significant difference (LSD) multiple comparisons procedure at 5% significance level was performed to determine the mean differences of load carrying capacity and stiffness values of four-sided cases tested considering the significant three-factor interactions in the MANOVA results mentioned above.

RESULTS

Failure Modes

One type of failure mode was observed in which the failure occurred as the opening of corner joints instead of separation of the entire cases from the studs. All joint failures occurred approximately between 60 to 90 seconds in the tests. Moreover, joints were separated slowly rather than rapidly. Dowels have never broken or deformed.

Failures of the joints for cases that were mounted with L-shape connectors to studs from top panels demonstrated deformations around direction of the dowels as created split approximately 30-40*mm* radius circular influence zones in the PB cases and 50-60*mm* radius influence zones in the MDF cases. However, the cases anchored from side panels to the studs showed deformations as breaking of connector screws in MDF cases and as splits around L-shape connectors of the PB cases. Since L-shape connector screws were broken, the cases which anchored from side panels slipped downward.

During the tests, the fractures occurred on the underside of the top panel. At the end of the tests, the top panels were separated from the side panels for all cases. The separations mostly occurred around the dowels which were in the corners of the back side of the top panel.

Load Carrying Capacity

Some physical and mechanical properties of panels used in the tests are given in Table 3**.** Average load carrying capacity and stiffness values are given in *Table 4*. Results indicated that in general load carrying capacity and stiffness values of four-sided cases were significantly affected by the panel types. The four-sided cases constructed of 18 and 16*mm* MDF showed higher load carrying capacity and stiffness values than those of 18*mm* PB. These differences in load carrying capacity and stiffness values could be explained by differences in density and mechanical properties such as bending strength, IB strength, and modulus of rigidity of panels (*G*). It is a fact that the density and most strength properties of MDF are higher than those of PB.

Table 3

Some physical and mechanical properties of the panels used in the study

Panel Type	Moisture content *(%)*	Density*(g/cm³)*	MOR *(Mpa)*	MOE *(Mpa)*	G *(Mpa)*	IB *(Mpa)*
18 *mm* PB	7.01	0.58	11.20	2.031	1.110	0.27
18 *mm* MDF	6.28	0.75	37.32	2.563	2.017	0.75
16 *mm* MDF	5.81	0.73	35.44	3.303	1.858	0.97

MANOVA results indicated that for load carrying capacity, the main factor effects, two-factor interactions, and three-factor interactions were statistically significant at the 5% significance level, while the only anchorage point variable was significant factor on stiffness of the four sided cases. Hence, for load carrying capacity the three-factor interactions were analyzed while the anchorage point factor was analyzed for stiffness values.

Table 4 shows mean comparisons of load carrying capacity of tested four-sided cases with their coefficients of variation regarding the effect of panel type, connector type and anchorage point of L-shape connector to wall. The LSD value of 181.9N was calculated. Results showed that the highest load carrying capacity were obtained from the 18*mm* MDF cases jointed with trapez connector which anchored from the side panels while the lowest load capacity values were obtained from 18*mm* PB cases jointed with minifix connector which anchored from the top panel.

Table 4

Mean comparisons of load carrying capacities and stiffness of four-sided cases

Anchorage point	Panel Type	Connector	Stiffness *(N/mm)*	Load carrying capacity *(N)*	
			X	X	HG
top panel	18 (*mm*) MDF	Trapez	85 (5,0) [a]	1959 (2,8) [a]	F
		Minifix	58 (8,5)	1396 (4,5)	GH
	16 (*mm*) MDF	Trapez	83 (4,1)	1576 (4,3)	G
		Minifix	101 (2,7)	938.7 (3,3)	I
	18 (*mm*) PB	Trapez	108 (9,1)	2740 (6,8)	E
		Minifix	48 (13,4)	1354 (6,9)	H
side panel	18 (*mm*) MDF	Trapez	323 (9,3)	4267 (1,1)	A
		Minifix	62 (3,8)	3735 (3,2)	C
	16 (*mm*) MDF	Trapez	197 (9,2)	3643 (0,6)	C
		Minifix	293 (5,3)	3245 (6,3)	D
	18 (*mm*) PB	Trapez	116 (7,5)	3296 (4,8)	D
		Minifix	156 (9,9)	4051 (1,7)	B

LSD critical value ±181.9N; [a] Values in parenthesis are coefficients of variation; HG: Group Homogeneity

Generally, 18 or 16*mm* MDF cases showed higher load capacities than 18*mm* PB cases. In the cases constructed with 18*mm* MDF, the highest load capacities were obtained with trapez connector and anchored from the side panels to wall while the lowest load capacity values were observed with trapez connector and anchored from the top panel to the wall. In the cases constructed with 16*mm* MDF, the highest load capacities were obtained with minifix connector and anchored from the side panels to wall while the lowest load capacities were observed with minifix connector and anchored from the top panel to the wall. In the cases constructed with 18*mm* PB, the highest load capacities were obtained with trapez connector and anchored from the side panels to the wall while the lowest load capacities were observed with minifix connector and anchored from the top panel to the wall.

Stiffness

Table 5 shows mean comparisons of stiffness values of four-sided cases tested with respect to the anchorage point to the wall. According to test results, the anchorage point which was applied from the side panels yielded considerably higher stiffness values compared to the anchored from the top panels. The LSD value of 76.65 N/mm was calculated. In general, anchorage point of L-shape connectors were found to have a greater effect on stiffness than panel type and corner joint techniques. As it is shown in Table 4, anchorage point applied from side panels shows the highest value of both load carrying capacity and stiffness.

Table 5

The results of comparison values of stiffness in the anchorage points

Anchorage Point	Stiffness *(N/mm)*	HG
Side panel	191.1 (1.6) [a]	A
Top panel	80.66 (2.2)	B

LSD critical value ±76.65*N/mm*; [a]Values in parenthesis are coefficients of variation; HG: Group Homogeneity

CONCLUSION

In this study, the effect of panel type, connector type, and anchorage point to the wall on load carrying capacity and stiffness values of four-sided cases were investigated. Results indicated that cases constructed of 18*mm* MDF yield higher load carrying capacity values than those of 16*mm* MDF and 18*mm* PB. At the same time, 16mm MDF cases showed higher performance than 18mm PB cases. In this manner, for the cabinet manufacturers, 16*mm* MDF could be recommended as a panel type instead of the 18*mm* PB.

Results of the tests also indicated that the trapez connector shows higher performance than the minifix connector. In addition, the cases which were anchored from the side panel gave stronger performance on the load carrying and stiffness values. Therefore, anchorage point of the case could be recommended to apply to side panel of case instead of top panel.

Consequently, the best choice having the strongest and the most rigid four-sided cases can be achieved by using trapez connector if the construction panel material is 18*mm* thickness MDF; minifix connector if the construction panel material is 16*mm* thickness MDF; trapez connector if the construction panel material is 18*mm* thickness PB.

It can be deduced that corner joint construction of four-sided cases are more sensitive in where they are anchored to the wall in terms of load carrying and stiffness values. This study provides cabinet manufacturers some information concerning the effects of joint construction factors such as, connector type, anchorage point to the wall, and panel type on load carrying capacities and stiffness values of four-sided cases. The information could give supportive insight to engineers in product engineering of cabinet furniture.

REFERENCES

American Society for Testing and Materials (2001) Standard test methods for evaluating properties of wood-base fiber and particle panel materials. ASTM D 1037-99. ASTM, West Conshohocken, PA

American Society for Testing and Materials (2001) Standard test methods for direct moisture content measurement of wood and wood-base materials. ASTM D 4442-92. ASTM, West Conshohocken, PA

American National Standards Institute / Kitchen Cabinets Manufacturing Association A161.1.1995. Performance and construction standard for kitchen and vanity cabinets. Reston, Virginia

Bachmann G, Hassler W (1975) The strength of various furniture constructions, their components, and fasteners. Part I. Holztecnologie 16(4):210 – 221

Dinc O (2000) The determination of performances of portable connection components in some wood-based panels. MSc Thesis. University of Gazi, Turkey

Eckelman CA (1974) Which screw holds best? Furniture Design and Manufacturing Magazine

Eckelman CA (1975) Screwholding performance in hardwoods and particleboard. Forest Prod. J. 25(6):30-35

Eckelman CA (1978) Predicting withdrawal strength of sheet-metal-type screws in selected hardwoods. Forest Prod. J. 28(8):25-28

Kasal A, Zhang J, Yuksel M, Erdil YZ (2008) Effects of screw sizes on load bearing capacity and stiffness of five-sided furniture cases constructed of particleboard and medium density fiberboard Objectives. Forest Products Journal, 58(10):25-32

Kasal A, Zhang J, Yuksel M, Fathollahzadeh A, Erdil YZ, Yıldırım N (2011) Ultimate failure load and stiffness of screw jointed furniture cases constructed of particleboard and medium density fiberboard. Forest Product Journal, vol. 61(2):155-160

Lin SC, Eckelman CA (1987) Rigidity of furniture cases with various joints construction. Forest Product Journal 37(1):23-27

Simek M, Haviarova E, Eckelman CA (2010) The effect of end distance and number of ready-to-assemble furniture fasteners on bending moment resistance of corner joints. Wood Fiber Science 42(1):92–98

Tankut N (2009) Effect of various factors on the rigidity of furniture cases. African Jourenal of Biotechnology 8(20):5265-5270

Yerlikaya NC, Aktas A (2012) Enhancement of load-carrying capacity of corner joints in case-type furniture. Material and designs 37(2012)393-401

Zaini R, Eckelman EA (1993) Edge and face withdrawal strength of large screws in particleboard and medium density fiberboard. Forest Prod. J. 43(4):25-30