Analysis of strength of corner joints in cabinet type furniture by using finite element method

Hasan Özgür İMİRZİ, Hasan EFE

Faculty of Technology Woodworking Industry Engineering, Gazi University, Turkey

Abstract: In this study, the strength and stifness properties of case type furniture corner joints, which are produced with different production techniques and wood based materials with different thicknesses, were investigated. In the experiments, wood based material; MDF (Medium Density Fiberboard), chipboard with 14,16 and 18 mm thickness, okume *(Aucoumea klainean*) plywood were used. Corner joints of case type furniture, which is produced as L-type, were joined by using dowels and dowel-screws. In addition, polivinilasetat (PVAc) was used in joints. Bearing in mind the critic loads which may affect its usage, experimental samples were trialled under static loads. Three dimensional structure of the experimental samples were analysed an a computer by using finite element method (FEM). Later, experimental data was compared with the analysis data.

Key Words: Case Type Furniture, strength and stiffness Wood Composite, Finite Element Method, ANSYS®, furniture corner joints

1 Introductıon

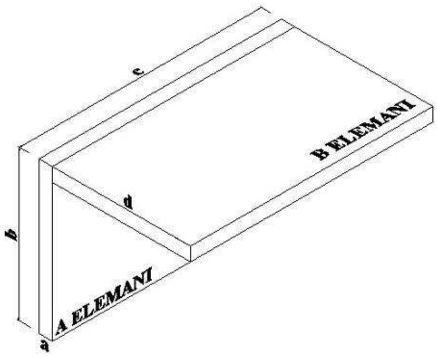
Since furniture units are used for multi-purposes during their usage the sizes and characteristics of the loads by which the furniture will be influenced are very variable. The basic property for most of the constructions is to carry and design loads without causing a defect. In construction design a cabinet, a method ao analysis is required to determine the robustness by installing loads on different joints of the box. There are a lot of researches related to corner joints in case construction of furniture (Eren 1999), (Güntekin 1996),(Denizli 2001), (Norvydas 2004), (Tankut 2005),(Albin et al. 1987). Finite Element Method (FEM) applied in various disiplines, is a numerical method which is used to solve engineering problems that require special analysis. In the Literature, by using different analysing methods in the FEM analysis programs and the topics of model approaches of case type furniture joints were discussed (Eckelman et al. 1985), (Gawroński 2006), (Sydor 2005), (Eckelman et al. 1987), (Mostowski et al. 2006), (Gustafsson 1995), (Gustafsson 1996), (Gustafsson 1997), (Smardzewski 1998),(Smardzewski 2002), (Smardzewski et al. 2011), (Nicholls 2002).

2 Research Objective

The objectives of this research are to investigate the applicability of engineering approach in case construction furniture design, including three dimensional structural analysis and performance tests and to obtain quantitative information on the mechanical performances of the case type furniture corner joints produced with various materials having different thichknesses and configurations by using different joining techniques.

3 Material And Methods

As wood composite material, 14, 16 ve 18mm medium density fiberboard (MDF), particleboard and plywood okume (*Aucoumea klaineana*) were used. In the experiments, PVAc glue and 8mm in diameter 39, 41 and 43mm long, grooved beech wood dowels were used. 4mm in diameter and 50mm long threaded screws were used. Each test sample consist of two elements: A and B perspective and dimensions of the prepared test sample is shown in Figure 3.1. In “L” type experiments two joints type dowel and dowel-screw three wood composite materials (particleboard, MDF, plywood), three different thicknesses panel (14,16 and 18mm) and five samples of each piece (2x3x3x5=90) a total of 90 test samples were prepared for bending experiments. Dimension of test samples, the dowel and the hole centers are shown in Figure 1.



A ve B Element Dimensions

Levha Kalınlığı (a)	(b)	(c)	(d)
14mm	200mm	320mm	186mm
16mm	200mm	320mm	184mm
18mm	200mm	320mm	182mm

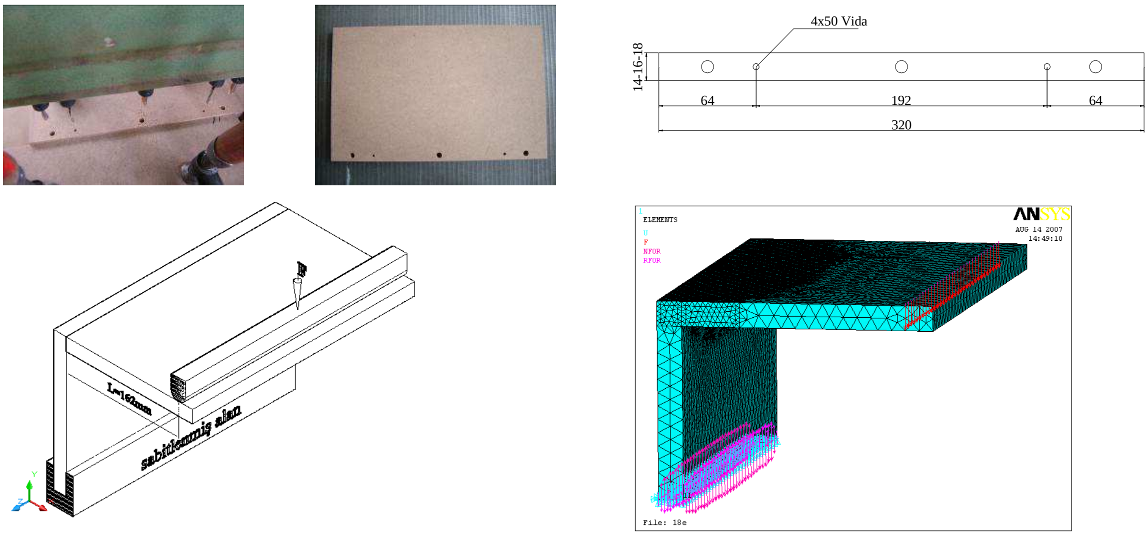


Figure 1. Dimensions of test samples, the dowel and hole centers (dimensions in mm) and Loading shape and experimental setup for bending experiments on “L” type joints.

For bending test element A (vertical element) fixed the platform and load is applied to the end of element B element (horizontal element). Loading continued until a great deal of decrease the resistance shown by the joint. The experimental setup and force application is shown in Figure 1. Moment (M) is evaluated by Equality (1) in bending test.

$$M = F_{max} \times L \ (Nm) \quad (1)$$

Here; M= Moment [Nm], F_{max}= maximum force at the time fracture [N], L= Moment arm [m]

In order to model case type corner joints, Solid 64 element which is included in ANSYS® was used. Solid 64 element having certain characteristics, for example cracking whwn it is tensile crushing under pressure plastic deformation and creep properties, is an eight node solid element. It has three degrees of freedom at each node, showing x, y and z directions (ANSYS® 2007). Technological properties and elastic constant values which are entered Ansys10.0 program for orthotropic and izotropic materials are given Table 1.

Table 1. Elastic constant values of the materials entered into the program

Materials	Modulus of Elasticity [N/mm^2]			Poisson ratio			G modulus of rijidity [N/mm^2]		
	E_X	E_Y	E_Z	v_{XY}	v_{YZ}	v_{XZ}	G_{XY}	G_{YZ}	G_{XZ}
Beech[1]	14010	1160	2280	0,448	0,073	0,708	470	1640	1080
MDF[2]	3200	3400	50	0,45	0,5	0,5	68	68	58
Particleboard[3]	1900	1900	95	0,3	0,3	0,3	794	137	137
Plywood[4]	4800	4800	384	0,3	0,3	0,3	342	322	34
PVAc Glue[5]	460			0,3			177		
Screw[6]	200 000			0,3			-		

[1] (Gawroński 2006), [2] (De Magistris et al. 2004), [3] (Sydor 2005), [4] (Bodig et al. 1982), [5] (Serrano1 et al. 2007), [6] (Smardzewski et al. 2005).

During the experiments, the force-displacement relationship was determined by recording displacements in milimetre (mm) occured whwn each of 5kgf (50N) force applied. In defining these relationships according to the method of least squares, "regression analysis" was done. In addition the levels of reliability of regression models were determined by calculating the coefficients of determination.

4 Research Results

Forms of deformations obtained as a result of bending test on “L” type dowel and screw joints and the deformations obtained as a result of FEM program were shown in Figure 2.

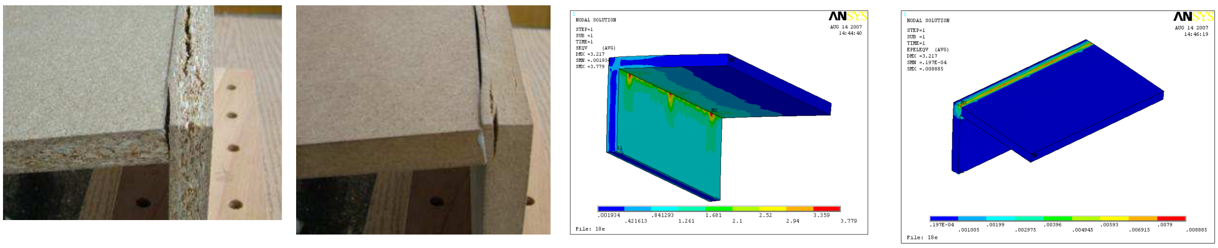


Figure 2. Deformation characteristics as a result of both the experimental test and the FEM program.

Carrying capacity and rigidity values obtained from "L" type corner joints bending test were given Table 2.

Table 2. Moment carrying and stiffness values obtained from bending tests

Joint technique	Materials	Panel Thickness [mm]	Mean force [N]	c.v. [%]	Mean Rigidity coefficient [k_s:N/mm]	c.v. [%]	[R^2]
Dowel	P.Boards	14	28,05	11,90	21,91	20,99	0,97
		16	37,30	8,79	35,88	9,87	0,99
		18	57,45	3,44	51,35	5,35	0,99
	MDF	14	38,20	6,95	33,50	3,21	0,99
		16	41,72	8,25	45,82	3,60	0,99
		18	58,28	5,00	51,18	1,72	0,98
	Plywood	14	52,96	7,61	40,54	8,74	0,98
		16	45,29	13,25	45,43	5,38	0,99
		18	81,76	7,47	75,26	9,59	0,99
Dowel-screw	P.Boards	14	36,33	12,59	24,20	12,20	0,99
		16	55,35	8,40	39,58	10,93	0,99
		18	67,45	5,76	51,38	4,46	0,99
	MDF	14	57,61	5,97	33,27	3,20	0,99
		16	67,54	5,88	47,97	2,75	0,99
		18	92,17	5,31	54,41	4,86	0,99
	Plywood	14	68,27	11,64	40,15	5,04	0,99
		16	65,69	7,21	58,55	7,88	0,99
		18	87,94	3,71	73,80	25,07	0,98

The results of multivariate analysis of variance related to the effect of moment carrying capacity of "L" type corner joints were given in Table 3, the results of multivariate analysis of variance related to the effect on rigidity of joints in making "L" type corners were given Table 4. The average capacities of moment carrying and rigidity were given Table 5.

Table 3. Multivariate Analysis of Variance

Source	Degrees of freedom	Sum of squares	Mean squares	F value	P value P < 0,05
Joint technique	1	6876,982	6876,982	355,5867	0,0000
Materials	2	6100,941	3050,470	157,7301	0,0000
JT x M	2	902,498	451,249	23,3326	0,0000
Panel Thickness	2	12565,468	6282,734	324,8601	0,0000
JT x PT	2	195,668	97,834	5,0587	0,0088
M x PT	4	991,666	247,917	12,8190	0,0000
JT x M x PT	4	463,518	115,879	5,9918	0,0003
Error	72	1392,467	19,340		
Total	89	29489,208			

Table 4. Multivariate Analysis of Variance of joints related to rigidity

Source	Degrees of freedom	Sum of squares	Mean squares	F value	P value P < 0,05
Joint technique	1	139,901	139,901	4,7857	0,0319
Materials	2	5080,851	2540,425	86,9025	0,0000
JT x M	2	18,257	9,128	0,3123	Ns*
Panel Thickness	2	11183,775	5591,888	191,2865	0,0000
JT x PT	2	165,126	82,563	2,8243	0,0659
M x PT	4	846,067	211,517	7,2355	0,0001
JT x M x PT	4	198,029	49,507	1,6935	0,1609
Error	72	2104,780	29,233		
Total	89	19736,786			

Ns*: Not Significant JT: Joint technique M: Materials PT: Panel Thickness

Table 5. The average capacities of moment carrying and rigidity

Joint technique	Moment (Nm)	
	(X)	HG
Dowel	49,00	B
Dowel-Screw	66,48	A

LSD ± 1,842 Nm

Materials	Moment (Nm)	
	(X)	HG
P.BOARD	46,99	C
MDF	59,25	B
PLYWOOD	66,99	A
LSD ± 2.256 Nm		

Joint technique	Moment (Nm)					
	Materials					
	P.BOARD		MDF		PLYWOOD	
	(X)	HG	(X)	HG	(X)	HG
Dowel	40,93	E	46,07	D	60,00	B
Dowel-Screw	53,04	C	72,44	A	73,97	A

LSD ± 3,191 Nm

Panel Thickness	Moment (Nm)	
	(X)	HG
14 mm	46,90	C
16 mm	52,15	B
18 mm	74,18	A

LSD± 2.256 Nm

Joint technique	Moment (Nm)					
	Panel Thickness					
	14 mm		16 mm		18 mm	
	(X)	HG	(X)	HG	(X)	HG
Dowel	39,74	D	41,44	D	65,83	B
Dowel-Screw	54,07	C	62,86	B	82,52	A

LSD ± 3,191 Nm

Materials	Moment (Nm)					
	Panel Thickness					
	14 mm		16 mm		18 mm	
	(X)	HG	(X)	HG	(X)	HG
P.BOARD	32,19	F	46,33	E	62,45	C
MDF	47,90	E	54,63	D	75,23	B
PLYWOOD	60,61	C	55,49	D	84,85	A

LSD ± 3,908 Nm

Joint technique	Materials	Moment (N.m)					
		Panel Thickness					
		14 mm		16 mm		18 mm	
		(X)	HG	(X)	HG	(X)	HG
Dowel	P.BOARD	28,05	G	37,30	F	57,45	D
	MDF	38,20	F	41,72	EF	58,28	D
	PLYWOOD	52,96	D	45,29	E	81,76	B
Dowel-Screw	P.BOARD	36,33	F	55,35	D	67,45	C
	MDF	57,61	D	67,54	C	92,17	A
	PLYWOOD	68,27	C	65,69	C	87,94	A

LSD ± 5,527N.

Joint technique	Rigidity (N/mm)	
	(X)	HG
Dowel	44,54	B
Dowel-Screw	47,03	A

LSD ± 2,265 N/mm

Materials	Rigidity(N/mm)	
	(X)	HG
P.BOARD	37,38	C
MDF	44,36	B
PLYWOOD	55,62	A

LSD ± 2,774 N/mm

Panel Thickness	Rigidity(N/mm)	
	(X)	HG
14 mm	32,26	C
16 mm	45,54	B
18 mm	59,56	A

LSD± 2,774 N/mm

Materials	Rigidity(N/mm)					
	Panel Thickness					
	14 mm		16 mm		18 mm	
	(X)	HG	(X)	HG	(X)	HG
P.BOARD	23,05	F	37,73	DE	51,36	BC
MDF	33,38	E	46,90	C	52,80	B
PLYWOOD	40,34	D	51,99	B	74,53	A

LSD ± 4,804 N/mm

In case furniture "L" type corner joints bending test, approximately 150N load, which was based on the results of computer aided analysis of the force-displacement measurement, was applied, the deflections were measured. The comparison of stiffness values obtained from test when the load was increased on "L" type corner joining bending tests and the stiffness values obtained from ANSYS program was given in Table 6.

Table 6. The comparison of experimental results and ANSYS result on bending test.

Joint tecniques	Material	Panel thickness	EXPERIMENT				ANSYS				DIFFERENCE [%]
			50N Sehim [mm]	70N Sehim [mm]	90N Sehim [mm]	Rijidity [N/mm]	50N Sehim [mm]	70N Sehim [mm]	90N Sehim [mm]	Rijidity [N/mm])	
Dowel	PB	14	1,91	2,73	3,58	24,96	1,73	2,42	3,11	28,40	12,11
		16	1,40	1,99	2,51	34,09	1,29	1,81	2,31	38,02	10,34
		18	1,13	1,52	1,86	46,05	0,96	1,34	1,73	51,09	9,86
	MDF	14	1,78	2,35	2,89	29,56	1,57	2,20	2,83	31,24	5,38
		16	1,19	1,66	2,06	42,09	1,20	1,68	2,15	40,98	2,71
		18	1,07	1,49	1,87	46,59	0,94	1,31	1,69	52,36	11,02
	PLY	14	1,42	1,89	2,34	36,66	1,18	1,65	2,12	41,68	12,04
		16	0,99	1,43	1,83	48,33	0,89	1,25	1,60	55,11	12,30
		18	0,72	0,97	1,21	71,42	0,69	0,96	1,24	71,43	0,03
Dowel-screw	PB	14	1,99	2,78	3,52	24,87	1,72	2,41	3,10	28,46	12,61
		16	1,19	1,63	2,09	42,00	1,26	1,77	2,27	38,82	8,19
		18	1,00	1,38	1,75	50,11	0,94	1,32	1,70	51,99	3,62
	MDF	14	1,71	2,27	2,84	30,40	1,52	2,13	2,74	32,27	5,79
		16	1,17	1,59	1,97	43,84	1,15	1,61	2,06	42,77	2,50
		18	1,00	1,37	1,72	50,67	0,90	1,26	1,62	54,50	7,03
	PLY	14	1,20	1,70	2,18	40,58	1,14	1,60	2,05	43,02	5,67
		16	1,01	1,33	1,63	52,23	0,86	1,20	1,54	57,25	8,77
		18	0,69	0,98	1,24	71,05	0,66	0,93	1,19	73,94	3,91

PB: Particleboard PLY: Plywood

The obtained values were compared with the results of experimental tests. According to these results in bending tests, it can be said that the result of ANSYS and experimental test between 0,03% and 12,61%. This difference reveals the reliability of the structural analysis.

5 Conclusions

According to case type furniture "L" type corner joining bending test, dowel-screw joints yielded approximately 26% higher moment values than dowel joints. In this study, joints were analyzed with ANSYS finite element method program defining linear and orthotropic material. The results obtained were compared with the results obtained from experimental test.The comparisons reveal that computer generated FEM reached the actual behavior but computer model showed more rigid behavior than the experimental element and reached the fracture.

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Corresponding author:
H.Özgür İMİRZİ
Gazi University Faculty of Technology Woodworking Industry Engineering, 06500 Ankara Turkey
himirzi@gazi.edu.tr