Strength properties of case type furniture produced with different construction techniques and panel thicknesses

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Abstract: In this study, strength properties of 1/1 scaled box typed furniture which are produced with different production techniques and wood based materials with different thicknesses were investiated. In the experiments, among the types of wood based material; MDF (Medium Density Fiberboard), chipboard with 14,16 and 18 mm thickness, okume *(Aucoumea klainean*) plywood are used. In the units of furniture with box construction which is produced as framed and frameless, doweled and doweled screwed joints are used. In joints polivinilasetat (PVAc) is used as an adhesive. Experimental boxes are experienced under static loads by bethinking the critic loads which can effect while usage. Experimental boxes' computer aided three-dimensional structural analysis were carried out by using finite element method (FEM) and experimental data were compared with analysis data.

Key Words: Case Type Furniture, Wood Composite, Finite Element Method, ANSYS®,

1 Introductıon

In today's modern homes, wall cabinets and case type furniture used in kitchens, bathrooms, offices and other rooms for storage are essential furniture. Since furniture units are used for multi-purposes during their usage the sizes and characteristics of the loads which will influence the furniture are very variable. There are two common case construction systems these systems are framed and frameless. All other construction systems combinations of these two systems (Eckelman 1991). The basic property for most of the structures is to carry and design loads without causing a deformation. In construction design of a box, a method of analysis is required to determine the durability by installing loads on the different joints of the box on a framed box construction, structural analysis of the boxes may include front frame sides, top, bottom and back panels. On a frameless box construction includes sides, bottom and back panels. On a frameless box construction, torsional strength of the panels are depend on the rigidity and stiffness of the elements, whereas in a framed box construction bending strength is depend on rigidity and joints of the elements. The behavior of these two systems are different from each other (Eckelman 1991), (Tora 2004), (Calhoun 1993), (Gazo 1995). Stifness of a box was identified by Kotaş (1958). In the Literature, There are a lot of researches related to corner joints in case construction of furniture (Tankut 2005), (Eren 1999), (Güntekin 1996), (Denizli 2001), (Norvydas 2004), (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. The first use of the FEM dates back to 1900s ANSYS program based on the FEM, has been developed since 1971 so that it has had an increasingly large field of application (Anıl et al. 2007). 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), (Nicholls 2002).

2 Research Objectives

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 produced with various materials having different thichknesses and configurations by using different joining techniques.

3 Materials And Methods

Beech (*Fagus orientalis* Lipsky), on the front frame of the test boxes and 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. In the design of the front framed and frameless case type furniture, three different wood composite materials, two joining techniques (dowel and dowel-screw), three different thicknesses panel and three samples of each piece (2x3x2x3x3=108) a total of 108pieces 1/1 scaled test cases were produced. The general dimensions, load application and experimental setup are shown in Figure 1.

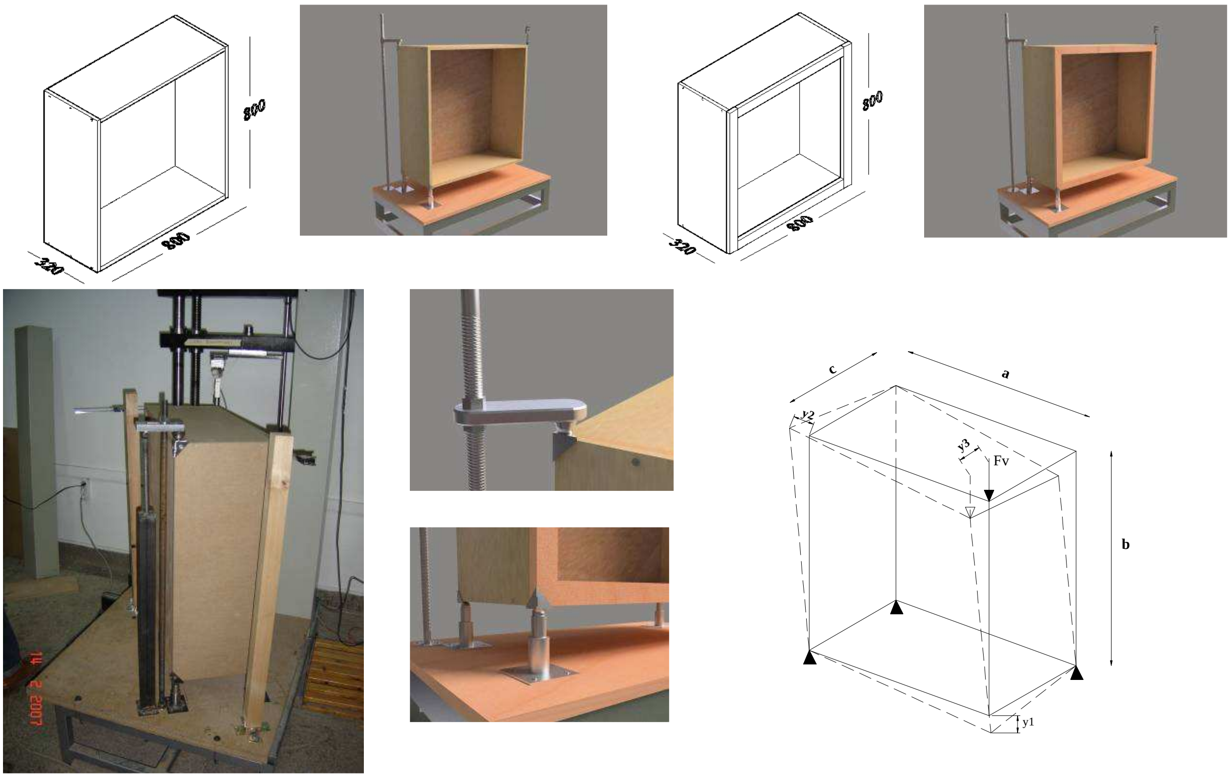

Figure 1. The general dimensions of the framed and frameless boxes (mm), experimental setup and load application point

As a result of the experimentals the maximum forces during fracture were recorded in terms of Newton (N). Besides, during the test in order to evaluate the stiffness of the joints by measuring the displacements in three directions caused by each of the 50 N (5 kgf) more load increase force-displacement relationship was determined. The determination occured (y) under the free corner load (F) can be calculated with Equality 1 (Eckelman et al. 1987).

$$y = F / \left(\frac{f_4}{y_4} top + \frac{f_2}{y_2} bottom + 2\frac{b^2 f_{1,3}}{a^2 y_{1,3}} side + \frac{b^2 f_0}{c^2 y_0} back \right) \quad (1)$$

Here: f_i / y_i = the elasticity of the panels which form the case, (N/mm), y = free corner deformation (mm), a= width of the box (mm), b= height of the box (mm), c= depth of the box (mm), F = force applied in vertical direction (N). After calculating y_1, y_2 Equality is calculated 2, y_3 is calculated Equality 3.

$$y_2 = (c/a).y_3 = (c/a).(b/c).y_1 = (b/a).y_1 \quad (2)$$

$$y_3 = (b/c).y_1 \quad (3)$$

In framed case type furniture, framed case stiffness is determined by Equality 4 and the rigidity of the frame is determined with Equality 5.

$$(1/y_{cf}) = 1/y_c + 4/(y_f) \quad (4)$$

y_c: case rigidity , y_f: frame rigidity

$$y_f = F_4 \times [a^2/48]\,[b/(E_1 I_1) + a/(E_2 I_2) + b/(E_3 I_3) + a/(E_4 I_4)] \quad (5)$$

Here;

E = modulus of elasticity (N/mm^2),
I = moment of inertia of each member (mm^4) moment of inertia is defined by the Equality 6

$$I = w \times d^3 / 12 \quad (6)$$

w = thickness (front to back), (mm), d = depth of each member (mm)

In order to model box type furniture, 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 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	ν_{XY}	ν_{YZ}	ν_{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).

4 Research Results

Observed breaking/cracking types caused by the applied force on framed and frameless case type furniture and deformations obtained as a result of FEM program were shown in Figure 2.

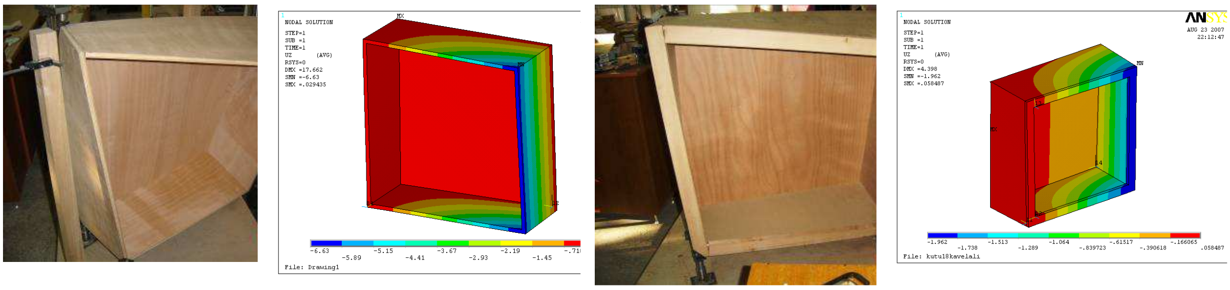

Figure 2. The characteristics of deformations on the experimental boxes and as a result of FEM

The load capacity values, obtained as a result of applied strength to the case type furniture during the test, stiffness coefficients of the experimental boxes (k_s: N/mm) and mean (X: N/mm), coefficients of variation (v: %) and coefficients of determination (R^2) were given Table 2.

Table 2. Strength, stiffness coefficients of the experimental boxes (k_s: N/mm) and mean (X: N/mm), coefficients of variation (v: %) and coefficients of determination (R^2)

Joint technique	Materials	Panel Thickness (mm)	Mean force (N) Frameless	c.v. (%)	Mean force (N) framed	c.v. (%)	Mean Rigidity coefficient Frameless	v (%)	(R^2)	Mean Rigidity coefficient (k_s:N/mm) framed	v (%)	(R^2)
Dowel	P.Boards	14	784,80	6,25	1471,5	5,77	21,02	13,76	0,89	171,82	0,93	0,82
		16	1043,13	3,80	1684,05	4,45	32,46	1,54	0,90	179,33	0,32	0,89
		18	1520,55	3,23	2076,45	7,59	47,87	9,40	0,96	195,00	0,51	0,84
	MDF	14	1111,80	2,55	1847,55	4,06	31,38	2,92	0,87	175,80	0,41	0,85
		16	1520,55	6,45	2076,45	7,59	52,57	10,90	0,85	181,65	1,93	0,89
		18	1765,80	2,78	2305,35	6,38	59,27	0,39	0,95	192,00	0,52	0,93
	Plywood	14	866,55	6,54	1635	8,66	22,69	5,63	0,87	171,00	0,58	0,88
		16	1389,75	5,39	1945,65	12,94	35,79	3,94	0,92	183,33	0,83	0,83
		18	1478,85	5,04	2207,25	2,22	40,45	6,73	0,99	195,33	1,18	0,87
Dowel-screw	P.Boards	14	850,20	6,66	1749,45	9,85	22,43	3,45	0,84	176,67	0,86	0,84
		16	1111,80	6,74	1782,15	4,2	29,87	5,45	0,87	182,33	0,32	0,88
		18	1733,10	3,27	2092,8	2,71	40,17	0,36	0,99	193,00	1,04	0,82
	MDF	14	1383,21	1,23	1782,15	4,2	34,22	1,11	0,96	181,00	0,55	0,89
		16	1962,00	4,33	2174,55	8,54	54,30	2,33	0,96	187,40	1,13	0,95
		18	2109,15	2,33	2305,35	5,63	57,73	1,84	0,99	192,00	0,52	0,93
	Plywood	14	1046,40	7,16	1716,75	12,45	23,33	1,23	0,97	173,63	0,68	0,83
		16	1602,30	3,53	1880,25	1,51	36,67	6,38	0,92	179,00	0,56	0,71
		18	1831,20	6,19	2158,2	6,82	47,28	13,12	0,91	186,00	0,93	0,75

Comparisons of stiffness values obtained a result of theoretical, experimental and FEM program are given in Table 3.

Table 3. Average force-displacement relationship accordind to theoretical, experimental and FEM in box type furniture (y_1)

Frame Type	Joint tecniques	Material	Panel thickness	THEORETIC				EXPERIMENT				ANSYS				DIFFERENCE (%)		
				200 N	250 N	300 N	Rijitlik (N/mm)	200 N	250 N	300 N	Rijitlik (N/mm)	200 N	250 N	300 N	Rijitlik (N/mm)	* Δ_1 (%)	** Δ_2 (%)	*** Δ_3 (%)
Frameless	Dowel	PB	14	10,9	13,6	16,3	17,9	8,60	11,6	14,8	20,7	6,55	8,19	9,83	29,9	13,4	30,6	40,0
			16	8,3	10,3	12,4	23,5	5,50	7,65	9,30	32,4	6,07	7,59	9,10	32,3	27,6	0,53	27,2
			18	5,61	7,02	8,42	34,9	3,93	5,07	6,37	47,6	4,58	5,73	6,88	42,7	27,6	11,9	19,0
		MDF	14	8,16	10,2	12,2	24,0	5,73	7,58	9,87	31,3	4,74	5,92	7,11	41,3	22,5	24,3	41,4
			16	5,42	6,78	8,14	36,1	3,43	4,57	5,93	52,1	3,88	4,85	5,82	50,5	30,7	4,00	28,0
			18	4,58	5,73	6,88	42,7	3,10	4,10	5,10	59,4	2,65	3,31	3,97	73,9	28,8	19,1	42,4
		PLY	14	12,1	15,1	18,1	16,1	7,87	10,6	13,6	22,6	6,38	7,97	9,57	30,7	27,2	26,6	46,6
			16	9,74	12,1	14,6	20,1	5,05	6,80	8,53	35,7	6,46	8,07	9,69	30,3	28,5	16,6	16,6
			18	6,54	8,18	9,81	29,9	4,87	6,03	7,33	40,3	4,90	6,12	7,35	40,0	25,8	0,75	25,5
	Dowel-screw	PB	14	10,9	13,6	16,3	17,9	7,73	10,9	13,7	22,4	7,06	8,83	10,5	27,7	18,1	18,5	33,3
			16	8,3	10,3	12,4	23,5	5,93	8,07	10,3	29,8	6,07	7,59	9,10	32,3	20,0	6,25	25,0
			18	5,61	7,02	8,42	34,9	5,00	6,00	7,30	40,2	4,58	5,73	6,87	42,8	12,5	4,76	16,6
		MDF	14	8,16	10,2	12,2	24,0	5,50	6,80	8,80	34,6	4,21	5,26	6,31	46,5	28,5	22,2	44,4
			16	5,42	6,78	8,14	36,1	3,50	4,50	5,50	54,3	3,88	4,85	5,82	50,2	33,0	8,00	28,0
			18	4,58	5,73	6,88	42,7	3,27	4,23	5,17	57,8	2,92	3,65	4,38	67,1	24,5	14,9	35,8
		PLY	14	12,1	15,1	18,1	16,1	8,30	10,0	12,9	23,4	6,37	7,97	9,56	30,7	33,3	20,0	46,6
			16	9,74	12,1	14,6	20,1	5,07	6,77	8,17	36,6	6,40	8,01	9,61	30,6	44,4	20,0	33,3
			18	6,54	8,18	9,81	29,9	3,87	5,20	6,53	46,7	4,83	6,04	7,24	40,6	34,0	14,0	25,0
Framed	Dowel	PB	14	0,85	1,07	1,28	229	1,00	1,40	1,80	172	1,06	1,33	1,60	183	33,1	6,01	25,1
			16	0,82	1,03	1,23	238	1,01	1,32	1,73	179	0,98	1,23	1,48	198	32,9	9,60	20,2
			18	0,78	0,98	1,18	248	0,9	1,2	1,60	195	0,94	1,18	1,41	207	27,1	5,80	19,8
		MDF	14	0,82	1,03	1,23	238	1,00	1,34	1,77	176	1,18	1,47	1,77	166	35,2	6,02	43,3
			16	0,78	0,98	1,17	250	1,00	1,30	1,7	181	0,90	1,13	1,36	216	38,1	16,2	15,7
			18	0,76	0,95	1,14	256	0,95	1,26	1,60	191	0,78	0,98	1,17	250	34,0	23,6	2,40
		PLY	14	0,84	1,06	1,27	231	1,00	1,42	1,80	170	0,94	1,18	1,41	207	35,8	17,8	11,5
			16	0,83	1,04	1,25	234	0,95	1,30	1,70	183	0,88	1,10	1,32	222	27,8	17,5	5,41
			18	0,80	1,00	1,20	245	0,94	1,20	1,60	194	0,84	1,05	1,26	232	26,2	16,3	5,60
	Dowel-screw	PB	14	0,85	1,07	1,28	229	0,99	1,35	1,78	175	1,05	1,32	1,58	185	30,8	5,41	23,7
			16	0,82	1,03	1,23	238	1,00	1,32	1,70	182	0,98	1,23	1,48	198	30,7	8,08	20,2
			18	0,78	0,98	1,18	248	0,90	1,24	1,63	191	0,95	1,19	1,42	206	24,6	7,20	15,5
		MDF	14	0,82	1,03	1,23	238	1,01	1,31	1,72	180	1,17	1,47	1,76	166	32,2	8,43	43,3
			16	0,78	0,98	1,17	250	0,98	1,28	1,62	188	0,91	1,14	1,36	215	32,9	12,5	16,2
			18	0,76	0,95	1,14	256	0,95	1,27	1,59	191	0,78	0,98	1,17	250	33,3	22,8	2,81
		PLY	14	0,84	1,06	1,27	231	1,00	1,40	1,80	172	0,93	1,16	1,39	210	34,3	18,1	10,0
			16	0,83	1,04	1,25	234	0,91	1,38	1,75	178	0,88	1,10	1,32	221	31,4	19,4	5,80
			18	0,80	1,00	1,20	245	0,90	1,34	1,66	185	0,84	1,05	1,26	232	32,4	20,2	5,60

Δ_1 (%) *(Theoretic-Experiment)100/Experiment, Δ_2 (%)(Experiment-Fem)100/Fem, Δ_3 (%)***(Theoretic-Fem)100/Fem**

5 Conclusions

According to the results of force carrying capacity of experimental boxes front framed case type furniture has approximately 28% higher value of carrying force than frameless experimental samples. According to the triple interaction of frame type, joining technique and material types the best result was obtained from the front framed samples boxes made from MDF and plywood with dowel-screw. Front framed boxes are 79% are more rigid then frameless boxes according to the results os stiffness coefficients of box type furniture. According to the types of materials significant differences were not observed in the mechanical behavior properties. Deformation characteristics occured in almost the same way but the diffrences were observed among the amounts of deformations. It was observed that experimental samples produced from materials having higher bending strength have less displacement, while the ones produced from materials having bending strength have more lower displacement. It was observed that according to the results of experiments the test samples made from MDF and particleboard panels are closer to the result of structural analysis program but the more significant differences between experiment and ansys in test samples made from plywood. For this reason it is thought that the properties of the element and element type should be entered into the programme considering the layered structure of plywood. When the results were compared computer generated FEM reached the actual behavior whereas the model in FEM program showed a more rigid behavior reaching the breaking point. In this study, for wood material instead of izotropic identification the necessity of orthotropic material identification was emphasized. Stress modelling identification on the corner joints leads to some facilities in the field of numerical analysis. This has been made possible by having more separation elements (mesh) near the corner joints so that the realibility of the analysis increase but it also made analysing solutions take a long time. Implementation of orthotropic-linear-elastic model of panel and connectors simplified the complex geometric form where a screw was modelled like a dowel.

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