Research Article
Araştırma Makalesi
DOI: 10.24011/barofd.238179

Journal of
Bartin Faculty of Forestry
2016, 18 (2): 9-19

Bartın Orman Fakültesi Dergisi
ISSN: 1302-0943
EISSN: 1308-5875

STIFFNESS ANALYSIS OF KNOCKDOWN BOOKCASES WITH FINITE ELEMENT METHOD

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ABSTRACT
In this study, in under static load, the stiffness analysis of both wood base materials which are used with for demonte type bookshelves and the stiffness analysis of different fasteners were investigated. Samples of the experiment particleboard (YL) and medium density fiberboard (MDF) were used as wooden composites materials and trapez connector with metal parts, metal minifix connector with metal peg, metal minifix connector with plastic peg, metal T connector, pipe type connector, and corner fitting were used joints. Knockdown bookcases were exposed to static loading for six months by considering the critic loads which could effect while in service use. Bearing in mind the critic loads which may affect its usage, experimental samples were trialled under static loads. Three dimensional structure of the experimentalsamples were analysed an a computer by using finite element method (FEM). Later, experimental data was compared with the analysis data. According to the results of experiments, maximum compliance between ANSYS analysis results and the test results of experiments terms of stiffness coefficient of the application was observed in the bookshelves which are made using particleboard trapeze connector with 96.29%. at least compliance with metal 92.59% with metal minifix connector with metal peg combination made using bookshelves.

Key Words: Knockdown bookcase, Stiffness, Finite Element Analysis

DEMONTE TİPİ KİTAPLIKLARIN SONLU ELEMANLAR YÖNTEMİYLE RİJİTLİK ANALİZİ

ÖZET
Bu çalışmada, demonte tipi kitaplık raflarında kullanılan ahşap kompozit levhalar ile farklı bağlantı elemanların statik yük altında rijitlik analizi araştırılmıştır.. Deneyler örnekleri ahşap esaslı kompozit levhalardan, yonga levha (YL) ve orta yoğunlukta lif levhalardan (MDF) hazırlanmıştır. Bağlantı elemanı olarak trapez, plastik dübelli minifiks, metal dübelli minifiks, metal T bağlantı, pipo bağlantı ve ay bağlantı elemanları kullanılarak kitaplıklar üretilmiştir. Deney örnekleri, kullanımları sırasında etkisinde kalabilecekleri kritik yükler göz önüne alınarak statik yük altında denenmiştir. Deney örneklerinin bilgisayar destekli üç boyutlu yapısal analizi, sonlu elemanlar yazılımı kullanılarak yapılmış ve deneylerden elde edilen veriler, bu analiz verileri ile karşılaştırılmıştır. Deney sonuçlarına göre rijitlik katsayı bakımından deneylerin uygulama sonuçları ile ANSYS analiz sonuçları arasındaki en fazla uygunluk % 96,29 ile yongalevha trapez bağlantı elemanı kullanılarak yapılan kitaplıklarda, en az uygunluk ise % 92,59 ile metal dübelli minifiks bağlantı elemanı kullanılarak yapılan kitaplıklarda olduğu görülmektedir.

Anahtar kelimeler: Demonte Tipi Kitaplık, Rijitlik, Sonlu Elemanlar Analizi

INTRODUCTION

FEM analysis is a good tool to reduce time consuming for theoretical and experimental studies. Use of FEM analysis in furniture design has improved quality and reduced the need for creating and testing a physical prototype in design. However, the FEM analysis results provide good foundations for future studies (Yildirim et al., 2015). The main postulate of FEA is that complex domains can be discretized and represented by an

*Corresponding author (Sorumlu Yazar)
Received (Geliş Tarihi) : 24.05.2016
Accepted (Kabul Tarihi): 08.11.2016

Citiation (Atıf): Karaman, A. Stiffness analysis of knockdown bookcases with finite element method, Journal of Bartın Faculty of Forestry, 2016, 18 (2): 9-19.

assembly of simpler finite sized elements. This enables description of the global problem via a system of differential equations that account for inter element compatibility and boundary conditions requirements. The concepts, fundamentals and application of FEA are described in detail in many texts (Tanvir and Utku, 1987; Bathe, 1996; Cook, 1981; Zienkiewicz and Taylor, 1988; Zienkiewicz and Taylor, 1989**)**. The tedium of handling the data and the possibility of errors creeping in as the number of elements increase are discouraging factors for the fi nite element analyst (Chandrupatla and Belegundu, 1991). By the much more common use of computers it is nowadays possible to use modern finite element programs in various stages of the design process. In this paper we show how already simple calculations lead to a totally different design of a chair. We also emphasise the need for more research on wood in "furniture size" and not only as part of building structures. There is no need for "triple-security" values when a chair is to be designed but instead it is possible to balance on the edge of the mechanical strength in the wooden members. Further, it is possible to use only wood details where no knots, or other errors are present. This will lead to substantially thinner members in the wooden chair (Gustafsson, 1995). Specimens were structurally analyzed by using finite element method and obtained data were compared to the actual test data. According to results, it has been observed that the three dimensional structural analysis by means of finite element method gives reasonable estimates of the overall strength performances of the sofa frames. As a result of the tests; it was concluded that the wood composite materials could be used instead of solid wood material, and portable connection techniques that provide many advantage for designers, producers, users and seller could be used instead of stable joints in the production of the frame construction furniture, especially in the upholstered furniture frames (Kasal, 2004).

This study was caried out to determine the effect of joint rigidity on case stiffness. Results indicate that joints do have a significant effect, and manufacturers may want to use joints that provide the greatest stiffness in their constructions (Lin and Eckelman, 1987). In this paper, a methot of analyzing the contribution of front frame to overall case stiffness is presented. A ratioanal procedure is then presented for analyzing the effects of joint stiffness on overall case rigidity. The solution of these two problems makes it possible, for the firt time, to rationally analyze and design most commercial case goods furniture (Eckelman and Munz, 1987). An attempt was made to analyse the strength and stiffness of moltinject corner joints of cabinet furniture by comparison with that of pin dowels corner joints. The deflection of cabinet furniture whose corners were joined by the method of moltinject was predicted in this study using FEM calculations. (Cai vd., 1995). The strength of connections and their dimensions do not constitute the function of the position of the connecting member in the chair and the rigidity of the chair side frame depends directly on the position of the connecting member and increases as the position of this element is lowered. The developed computer program allows accurate, rapid and multiple rigidity-strength analysis of furniture frame constructions made of wood. (Smardzewski, 1998).

This paper presents results of evaluating the effect of dewel spacing on bending moment capacity of corner hoints in 32 mm case construction. Laminated praticleboard and laminated medium density fiberboard (MDF) corner joints were tested under compression and tension loads. Experiments have shown taht maximum moment is obtained in joints when spacing between dowels is at least 96 mm. Also, static analysis of the test data indicated that joints loaded in tension and compresion had significant differences at the 5 percent significance level in the moment rersistance since joint strength was strongly related tı the internal bond strength of the board loaded in compression. In both tension and compression tests, MDF corner joints were stronger than particle corner joints (Tankut, 2005). The data in terms of deformation values were analyzed by using finite element analysis (SEM-ANSYS-Multiphysics) and theoretical modeling was carried out. It is determined that the actual data was found out 90-99% compatible with theoretical model. As a result, using finite element method for determining the resistance characteristics of wood corner joints, the theoretical values are found very close to actual values. In future studies, software such as ANSYS finite element programs with the right choice of parameters, can be used for determining resistance characteristics of wood corner joints without doing experimental research (Yörür, 2012). Investigated the fatigue behaviors of mortise and tenon joined armchair frames constructed of Scots pine (Pinus Sylvestris L.) wood material. The finite element method (FEM) was utilized for analyzing by ANSYS Workbench (Static Structure and Fatigue Tool) software. The results show that there are close convergence between experimental study and FEM fatigue analysis results. The consistency level between the fatigue test result and the fatigue FEM analysis obtained was 81.25%. As a result, FEM gives reasonable estimates of the overall strength performances of the armchair construction (Yildirim et al., 2015).

It is aimed that ANSYS analysis results and the experimental results of the static load under rigidity acceptable performance in terms of strength of the demountable type bookcase with wood composite materials with different fasteners estimate or not, whether these can be in the furniture product engineering.

2. MATERIAL AND METHOD

Wood Base Composite Materials

In the preparation of test specimens, particleboard with 18 mm thickness, medium density fiberboard with 18 mm thickness, medium density fiberboard with 4 mm thickness as back panel are used. Physical and mechanical properties of wood-based composite boards are given in Table1 (Bozkurt vd., 1987).

Table 1. Physical and mechanical properties of materials used in this study.

Material	Density (gr/cm^3)	Moisture (%)	Bending Strength (N/mm²)	Modulus of elasticity (N/mm²)
MDF	0.62	7.1	32.12	2780
Particleboard	0.58	6.9	16.58	1822

Physical and mechanical properties of wood-based composite which used in the demonte type bookcase is given Table 1.

Fasteners

The fasteners used for the construction of the demonte type bookcases as shown in Figures 1 through 6. (Hettich International, 2000).

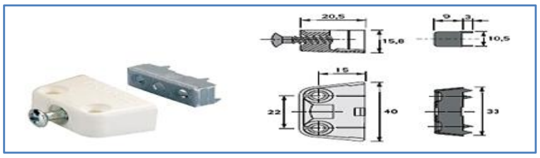


Figure 1. Trapeze (mm)

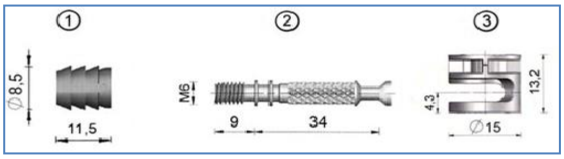


Figure 2. Minifix plastic peg fitting (mm) (1. peg, 2. eccentric shaft and 3. eccentric head)

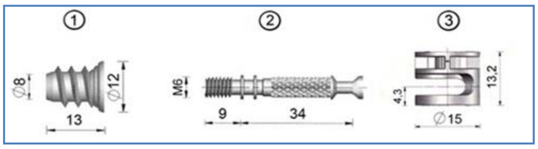


Figure 3. Minifix metal peg fitting (mm) (1. peg, 2. eccentric shaft and 3. eccentric head)

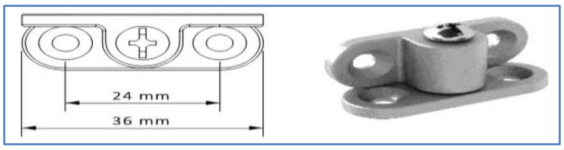


Figure 4. Metal T type connector (mm)

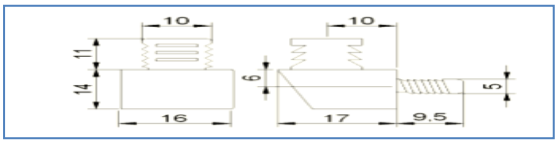


Figure 5. Pipe type connector (mm)

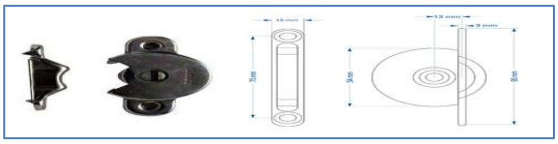


Figure 6. Corner fittings (mm) .

Preparation of Test Samples

Two types of furniture construction material (MDF and PB) were cut in the cutting machine drawing, tilting and circular according to the list in Table 1. Utilizing multi-hole machine, hole mounting processes were realized. Using seven different connection element (trapeze fitting, minifix with metal peg, minifix with plastic peg, metal T type connector, pipe type connector and corner fitting), these parts were installed. Subsequently, back panel mounting process were achieved and using 3.5x16 screws, only the side trays were assembled and so 12 bookcases were prepared in dimensions illustrated in Figure 7.

Table 2. Bill of materials for demonte type bookcase construction (mm)

Member Name	Member Number	MDF (mm)			Particleboard (mm)		
		Length	Width	Thickness	Length	Width	Thickness
Side Panel	2	1350	290	18	1350	290	18
Top Panel	1	564	290	18	564	290	18

Bottom Panel	1	564	290	18	564	290	18
Shelf	2	564	290	18	564	290	18
Back Panel	1	4×600×1350 mm ölçülerinde MDF					

As shown in Figure 7, twelve bookcases were constructed by using six different type fasteners namely; trapeze, minifix with plastic peg fitting, minifix with metal peg fitting, metal T type connector, pipe type connector and corner fittings.

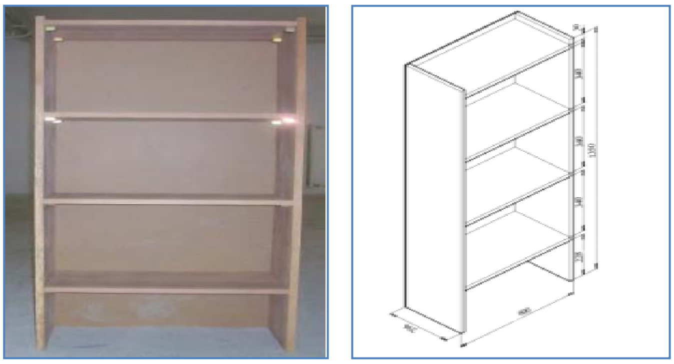


Figure 7. General configuration of bookcases used in the study (mm).

Execution Test

The total of 12 bookcases with 4 shelves were prepared for testing by using 2 types of panel materials and 6 different fittings.

Loading

In order to simulate common loading conditions, the shelves of the bookcases were uniformly loaded 0.238 gr/mm^2 according to British education standard (BS 4875; 1975). The individual weights used in this test were 2600 gr concrete bricks with dimensions of 60×100×200 mm in thickness, width, and length respectively. Total load was 39 kg for each shelf. The bricks were horizontally positioned on a shelf and centered 50 mm from the front and the back sides of the cases Figure 8.

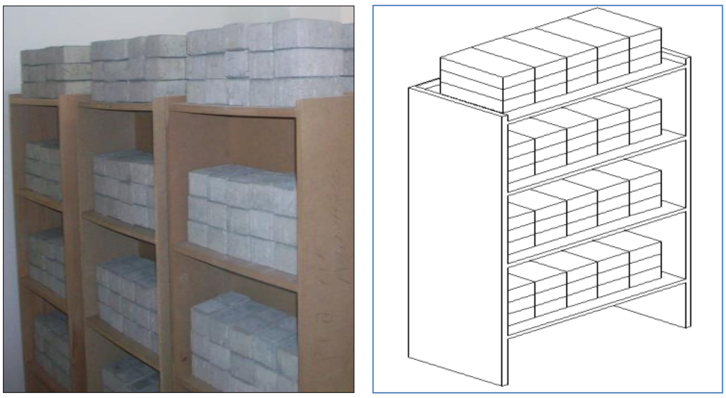


Figure 8. Method of loading

Deflection Measurement

Initial deflection measurements were made on the unloaded shelves at mid-span. After the uniform load was applied as explained above, deflections were measured again. A deflection yoke equipped with a dial gage was used to measure the center deflection of the shelves to the nearest 0.001 mm. As shown in Figure 9, measurements were taken at the midpoint along the length of shelf since maximum deflection occurred at that point. In the case of total deformation of the shelves, the load was maintained on the shelf for six months, and the data were collected regularly during that time. At the end of the specified period of time, cases were unloaded.

Figure 9. Method of deflection measurement

Rigidity of Joints

The purpose of the measurement of elastic deflection was to determine the rigidity of the joints. In this type of construction, rigidity of joints is important since the applied load on the shelf is carried by them. The elastic deflection of the shelves is directly related to their geometry, material properties, (specifically the MOE and moisture content of the panel material), and rigidity of the joints (Denizli, 2001).
Deflection at mid-span of shelf under the uniform static loading can be calculated using this formula:

$$\Delta max= \frac{WL^4}{384EI} \quad (1)$$

$$I= \frac{bh^3}{12} \quad (2)$$

Where:
Δmax = Deflection at mid-span of shelf (mm)

W = Load (N/mm)
L = Shelf length (mm)
E = MOE (N/mm^2)
I = Moment of Inertia (mm^4)
B = Shelf width (mm)
H = Shelf thickness (mm)

Rigidity constant (*k*) can be calculated by below formula which changes 1 to 5. k = 1 for truly fixed end support and 5 for pin end support.
Where:
K = Rigidity constant
Δmax = Calculated deflection at mid-span of shelf (mm)
de = Actual elastic deflection, (mm)

$$k= \frac{\Delta max}{\Delta elastik} \quad (3)$$

Finite Element Method (FEM) Analysis of the bookshelves using ANSYS™

The performance of structures can be determined either theoretically or by destructive testing. Owing to the availability of computer-based finite element methods (FEM), even complex structures such as furniture constructions can be analyzed without destroying the furniture. This method also helps to accelerate the engineering design of furniture. In this study, the FEM software package ANSYS 12.1™ was used to analyze the bookcase models Figures 10 through 14. Orthotropic and isotropic materials 12.1 ANSYS program for the desired technological properties of elastic constants and entered into the program to the materials used in the experiments was given in Table 3 (Gawroński, 2006).

Table 3. Elastic constants of materials entered into the program.

Material	Modulus of elasticity (N/mm^2)			Poisson			G Stiffness modülü (N/mm^2)		
	E_X	E_Y	E_Z	V_{XY}	V_{YZ}	V_{XZ}	G_{XY}	G_{YZ}	G_{XZ}
MDF	3200	3400	50	0.45	0.5	0.5	68	68	58
Particleboard	1900	1900	95	0.3	0.3	0.3	794	137	137
Plastic	1100			0.42			-		
Metal	200.000			0.3			-		

Material properties are defined separately for each material. Fasteners used in the combining are manufactured of plastic and metal. Elastic constants of plastic and metal materials are entered into the program. Directions of each materials, accoording to the coordinate system x, y and z of the program is defined. The working plane (work plane) was determined. Separating the elements (meshing). In meshing; Frequently meshing operation which are made of small parts. Addition elements in combining place more frequently subjected to separation. This situation increases the reliability of the analysis. Then boundary conditions (support points) and the identification of the installation process has been completed. Boundary conditions in the uniform load test element is given in Figure 10 and loading pattern in box-type furniture is given in Figure 11.

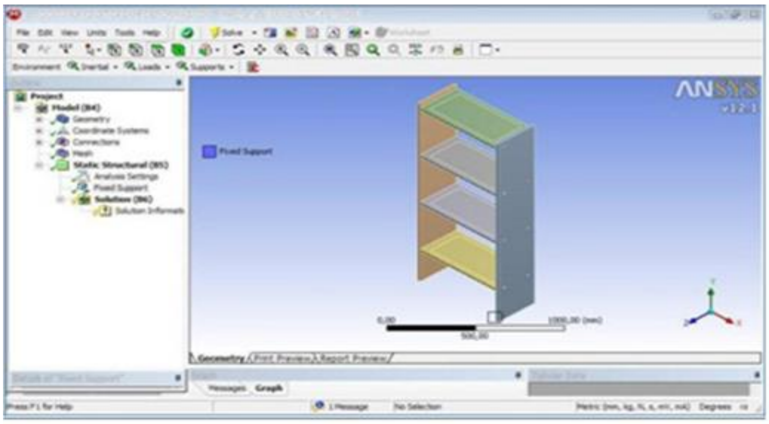


Figure10. Boundary conditions in the uniform load test element.

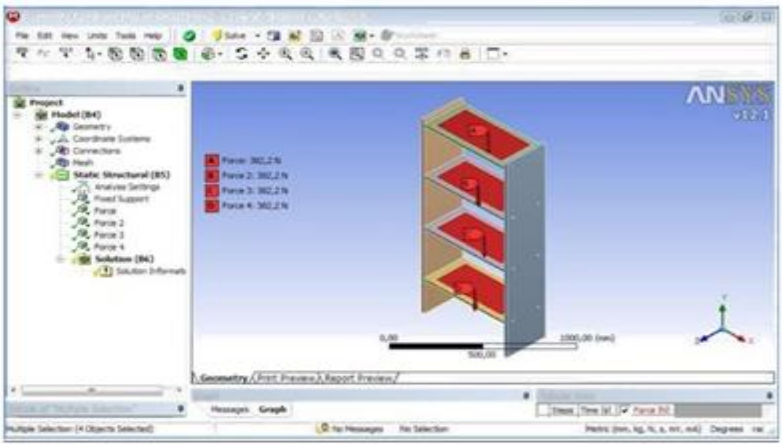


Figure 11. Loading model for the bookshelves.

Statistical Evaluation

For statistical analysis of the results multivariate analysis of variance (MANOVA) was used. When the difference between groups was found to be significant, Duncan Test was used to determine the difference betwen means at prescribed level of α =0.05. Statistical analyses were performed by using the SPSS 15 TM software.

RESULT AND DISCUSSION

The average of the rigidity constant values obtained from experiments, the minimum, maximum and standard deviation values were given in Table 4. It was determined that the rigidity constant value was obtained particleboard and trapeze and minifix with metal peg combination 2.7 the lowest rigidity constant value was obtained medium density fiberboard (MDF) and minifix with metal with plastic peg, metal T type connector and corner fitting combination 2.2.

Table 4. Demonte type bookcase of rigidity constant values under the static load 6 months (mm).

Material Type	Fastener Type	Average	Minimum	Maximum	The Standard Deviation
MDF	TZ	2.3	1.7	2.8	0.22263
	MP	2.2	1.6	2.8	0.19846
	MM	2.4	1.9	2.9	0.1047
	T	2.2	1.6	2.7	0.27318
	P	2.3	1.8	2.9	0.13893
	CF	2.2	1.7	2.7	0.074
Particleboard	TZ	2.7	2.1	3.2	0.22263
	MP	2.4	1.8	2.9	0.19846
	MM	2.7	2.1	3.3	0.1047
	T	2.6	2.1	3.1	0.27318
	P	2.4	2.0	3.0	0.13893
	CF	2.6	1.7	3.2	0.074

(TZ: Trapeze, MP: Minifix with plastic peg, MM: Minifix with metal peg, T: Metal T type connector, P: Pipe type connector, CF: Corner fittings).

Flavor of the different connection types and materials, manufactured using the box design furniture, total deformation values of MANOVA results of analysis of variance were given in Table 5.

Table 5. The results of rigidity constant values analysis of variance.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F Value	Probably ($p < 0.05$)
Material Type (A)	2	0.992	9.099	0.496	1.623
Fastener Type (B)	6	1.436	0.010	0.239	0.784
Interaction A*B	12	2.24	0.008	0.187	0.611
Error	63	19.245	0.003	0.305	
Total	84	1141.404	9.099		

According to the results MANOVA analysis of variance, the material type, the connection type and the amount of the rigidity constant values effects of mutual interactions of these factors 0.05 was statistically insignificant with the margin of error has been detected. Duncan test results, Table 6, Table 7 and Table 8 was given.

Table 6. Duncan test results of the factor of rigidity constant values.

Interactions	Average	Homogenous Groups	Interactions	Average	Homogenous Groups
MDF-MP	2.2	A	YL-MP	2.4	A
MDF-T	2.2	A	YL-P	2.4	A
MDF-CF	2.2	A	YL-T	2.6	A
MDF-TZ	2.3	A	YL-CF	2.6	A
MDF-P	2.3	A	YL-TZ	2.7	A
MDF-MM	2.4	A	YL-MM	2.7	A

(TZ: Trapeze, MP: Minifix with plastic peg, MM: Minifix with metal peg, T: Metal T type connector, P: Pipe type connector, CF: Corner fittings).

Connection type, comparison of the average rigidity constant values were given in Table 7.

Table 7. Duncan test results in rigidity constant values of connection types.

Connection Type	X	HG
Minifix with plastic peg	2.3	A
Metal T type connector	2.4	A
Corner fittings	2.4	A
Pipe type connector	2.4	A
Trapeze	2.5	A
Minifix with metal peg	2.5	A

Duncan test the connection types depending on the result of the difference between the values of the 95% is meaningless at the level of the trust has been detected. According to the type of connection rigidity constant in Table 6. The worst rigidity constant value was determined 2.5 with trapeze and minifix with metal peg connection, the best rigidity constant value was determined 2.3 with minifix with plastic peg connection. The trapeze and minifix with metal peg was better than 8% the minifix with plastic peg. As a result, considering the connection type and material type interaction, the demounting joints according to the stiffness scale of 1 to 5 provide a non-rigid, semi-rigid joint.

Material types, comparison of the average value of rigidity constant are given in Table 8.

Table 8. Duncan test results of material types the rigidity constant values .

Material Type	X	HG
MDF	2.3	A
Particleboard	2.6	A

Duncan test the types of material values depending on the result of the difference between the values of the 95% is meaningless at the level of the trust has been detected. According to type of materials rigidity constant values particle boards (2.6) from MDF (2.3) was higher than 13.04% .

The comparison of the average of the type of connection and interaction of different type of materials rigidity constant values were given in Table 9.

Table 9. The mean values of rigidity constant depending on connection type and material interaction.

Fastener Type	Material Type	
	MDF	Particleboard
Trapeze	2.3	2.7
Minifix with plastic peg	2.2	2.4
Minifix with metal peg	2.4	2.7
Metal T type connector	2.2	2.6
Pipe type connector	2.3	2.4
Corner fittings	2.2	2.6

Connection type and variation of materials in terms of interaction, the best rigidity constant value was determined 2.2 with using MDF and minifix with plastic peg, metal T type connector and corner fittings in the bookcases constructed. The worst rigidity constant value was determined 2.7 with using particleboard and trapeze and minifix with metal peg in the bookcases constructed. According to the type of connection the worst rigidity constant with using particleboard and trapeze and minifix with metal peg in the bookcases constructed, the best rigidity constant with using MDF and minifix with plastic peg, metal T type connector and corner fittings in the bookcases constructed was better than 22.72%. As a result, considering the connection type and material type interaction, the demounting joints according to the stiffness scale of 1 to 5 provide a non-rigid, semi-rigid joint. The combination of the trapeze chipboard box furniture combination and the metal dowels minifs chipboard box furniture combination have free stiffness.

The Comparison of Experimental Results with Finite Element Analysis

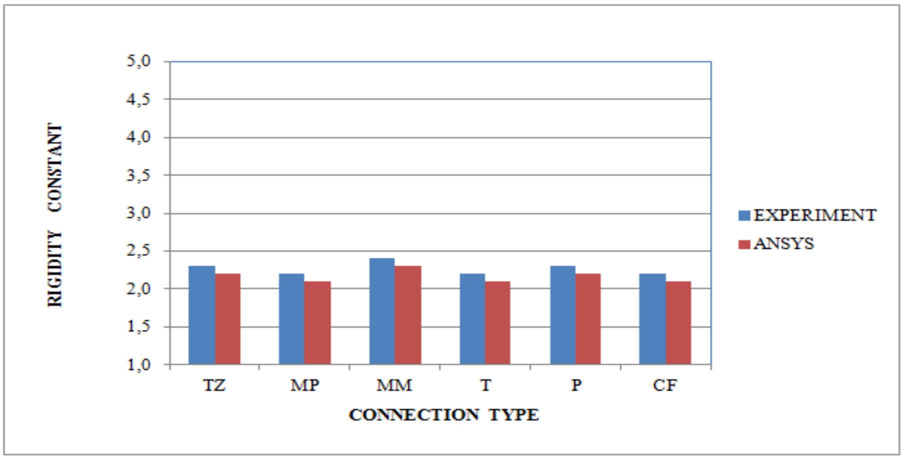
The demonte type bookcases under static load of experimental results with finite element method rigidity constant values comparison were given in Table 10.

Table 10. The comparison of experimental results with Finite Element Analysis.

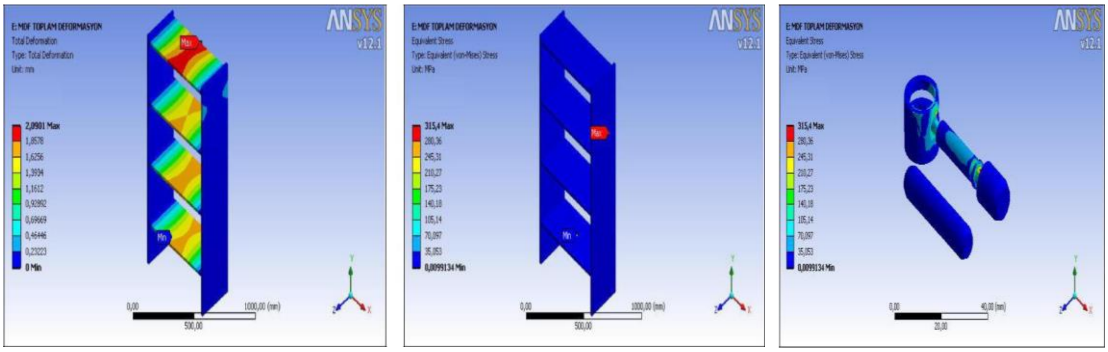
Material Type	Fastener Type	Experiment (mm)	ANSYS (mm)	Relevance (%)
MDF	TZ	2.3	2.2	95.65
	MP	2.2	2.1	95.45
	MM	2.4	2.3	95.83
	T	2.2	2.1	95.45
	P	2.3	2.2	95.65
	CF	2.2	2.1	95.45
Particleboard	TÇ	2.7	2.6	96.29
	MP	2.4	2.2	95.83
	MM	2.7	2.5	92.59
	T	2.6	2.1	95.45
	P	2.4	2.2	95.83
	AY	2.6	2.5	96.15

(TZ: Trapeze, MP: Minifix with plastic peg, MM: Minifix with metal peg, T: Metal T type connector, P: Pipe type connector, CF: Corner fittings).

The most conformity between the experiments results of the application and ANSYS analysis in the terms of rigidity constant is obtained with using MDF panel and metal dowel with minifix the bookcases constructed



Figurel 12 The relationship between the ANSYS results with experimental results obtained under static load the bookcase made from MDF



(a) (b) (c)

Şekil 13 In the bookcases obtained by using MDF panel and metal dowel with minifix ANSYS total deformation results (a) Total deformation, (b) Strain-stress variations, (c) metla dowel with minifix connection stres values.

CONCLUSION

In the bookshelves made using the MDF panel, the most conformity between the application results of the experiments and ANSYS analysis in terms of rigidity constant is 95.83% in the assembling with metal dowel minifix and the least conformity is seen to be 95.45% in the assembling with plastic dowel minifix, metal T type connector and corner fittings. In the bookshelves made using the particleboard panel, the most conformity between the application results of the experiments and ANSYS analysis in terms of rigidity constant is 96.29% in the assembly with trapeze connectors and the least conformity is seen to be 92.59 % in the assembly with metal dowel minifix. In terms of rigidity constant, the most conformity between the application results of the experiments and ANSYS analysis is 96.29% for the panel furniture made by using particleboard trapeze fittings. On the other hand, the least conformity is 92.59% in terms of rigidity constant for the panel furniture made by using minifix fitting with metal dowel. In this study, the combinations of linear finite element analysis were compared with those of the experimental studies. The results of the comparison were determined to be very similar in this study. Prior to the production of a piece of furniture designed, it will make the work of designers easy to obtain preliminary information about the strength of furniture and the necessary changes made for the optimization of furniture in engineering design of furniture.

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