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EVALUATION OF THE MECHANICAL PERFORMANCE OF CHAIRS WITHOUT FASTENERS CONSTRUCTED OF WOOD-BASED PANELS

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ABSTRACT

According to the literature review, limited studies were performed related to the production of "without fastener and ready to assemble (RTA)" furniture made of wood-based panel materials with Computer Numerical Control (CNC) machines and the evaluation of their strength. The aim of this study was to evaluate the cyclic loading performance of different types of RTA chairs without fastener which produced with CNC machines by using engineering design approach and product engineering methods including performance tests. In the production of chairs, 18 mm thick oriented strand board, medium density fiberboard and Oriental beech plywood were utilized as wood-based panels. Within the scope of the study, 4 different chair types without fasteners were designed and produced, and performance tests were carried out in 3 different loading directions (front to back, back to front and side thrust) with cyclic stepped increasing loading method according to the principles of American Library Association specification. Totally, 108 real size chairs without fastener were prepared and tested. As a result of the study, it was concluded that the chairs produced from Oriental beech plywood gave the best performances, while the chairs produced from medium density fiberboard gave performance values close to Oriental beech plywood, except for the side thrust test. However, the mechanical performance values of the chairs constructed of oriented strand board were very low. In conclusion, it could be said that the chairs constructed of Oriental beech plywood and medium density fiberboard without fastener have been found to have sufficient mechanical performance.

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INTRODUCTION

Engineering design, which is an essential stage of furniture design, is not yet being applied systematically in our country and around the world. As a result, many furniture designs cannot be produced with sufficient strength, the furniture cannot perform its functions during use, and it becomes unusable after a short period of time. Some designs, on the other hand, are manufactured with the strength to carry far more than the loads they may encounter during their lifetime, causing both economic and aesthetic issues. This is a common issue, particularly in products such as chairs and armchairs. The designed and manufactured chairs mostly include excessively large sections and unnecessary supporting/reinforcing elements such that they do not look aesthetic, either are not durable and cannot be cost-effective. For the production of strong, durable and high quality furniture frames; it is possible to assemble the furniture members to each other with fasteners as well as joints without fasteners. Since the strength, durability and cost problems of fasteners do still exist, it is necessary to investigate the strength of furniture frames such as chairs without fasteners.

The reduction of natural resources causes the prices of solid wood materials to rise on a daily basis. Chair frames constructed of solid wood are generally more expensive. The use of wood-based panels, which are less expensive than solid wood, will significantly reduce the costs and ensure the efficient use of natural resources.

Computer Aided Design (CAD) refers to the use of computers in manufacturing processes such as revealing and revising the part design, analysis, and design optimization. Computer Aided Manufacturing (CAM) is the use of computer systems to plan, manage, and control a manufacturing process, either directly or indirectly. CAD/CAM systems enable the production of even the most difficult designs, as well as accurate control and the preparation of the part for production. Because of the increase in human consumption, CNC machines are being used more and more today, saving time and labor. Many products are produced using CNC machines today, as the manufacturing industry's business volume increases the demand for more sensitive and higher quality products.

When studies in the field of furniture engineering are reviewed in the literature, it is clear that many studies have been conducted on issues such as strength analysis, structural analysis, and performance test evaluation of frame or case construction furniture. Many studies on the joint design and performance of glued or ready to assemble (RTA) without glue furniture, in particular, attract attention. The development of computer technologies and their application in the furniture industry has recently increased the use of the finite element analysis and structural analysis methods in furniture engineering design.

In furniture strength design, it is emphasized that determining the effective loads that the furniture will be exposed to during use and analyzing the stresses on the furniture, its elements and joints Eckelman (1968) are very essential. In Eckelman's other studies, performance testing methods for tables, chairs, armchairs, and box furniture were described by analyzing the main factors using performance tests (Eckelman 1988a, Eckelman 1988b). In this study of the author, it has been noted that furniture design is of great importance in furniture production. (Eckelman 2003). In the work by Eckelman and Zhang (1995) the content of GSA (General Services Administration Performance Test Method for Upholstered Furniture) was explained, as well as the factors and concepts required for an acceptable performance testing method in the engineering design of upholstered furniture. The cyclic stepped increasing loading method were introduced and provided some chair performance tests and acceptable load values were developed by using this testing method (Eckelman 1999). Then, the content of the performance test management (FNAE 80-214) developed for upholstered armchairs and sofas, as well as the equipment requirements to be used in the laboratory to use this method were presented. Furthermore, acceptable design load values were given indicating light (domestic), medium, and heavy service use to show the application status of this method (Eckelman and Erdil 2001).

It was stated in a study that student chairs made of laminated wood and plywood are expensive in some developing countries and are not designed in accordance with engineering design criteria. According to the study, these designs are more durable and cost-effective than those used in schools. In the study, it was also demonstrated that laminated wood materials can be used to make strong school furniture (Haviarova *et al.*

2001).

The strength of a birch wood chair was determined against various loads that it would encounter during use, then modelled the same chair and determined the stresses at some points against the same loads using the finite element method (FEM). It was reported that the analysis data and the experimental data are strikingly similar (Gustafsson 1996). According to a study related to the using FEM in the structural analyses of furniture; it is difficult to analyze the stresses that occur in chair frames, but the FEM can be used to solve this problem. In this research, chair frame was created out of ash wood, demonstrated how to analyze and design using FEM, and compared the results to the test results. In conclusion, it has been stated that the chair frames can be analyzed using computer aided structural analysis methods (Gustafsson 1997). Analytical models were created for structural analyses of chairs by FEM. It was demonstrated that analytical models created by FEM gave the information concerning the deformations and internal forces on chair members and joints (Kasal and Pullela 1995). In another study; the principles of furniture design and to maximize the strength of members and joints while minimizing material use was aimed to determine. For this purpose, a chair side frame was analyzed with FEM software and proved that this developed program can analyze the rigidity and strength of wooden furniture accurately and quickly (Smardzewski 1998). The difficulties of using the FEM in wood materials and compared the performance tests with the finite element program was investigated (Koç *et al.* 2011). Experimental tests and FEM analyses were conducted for different types of sofa frames constructed of wood and wood composite materials. According to the results, sofa frames constructed with three different side frame types had different mechanical properties, and the FEM results were given reasonable estimates about the strength of sofa frames. As a result, it was stated that the joints are the critical points in furniture and that more durable joints can be made using materials with high bending resistance (Kasal 2006). Effects of the stretcher position on the mechanical properties (load capacity, stiffness, strain distributions) of chairs were experimentally and numerically investigated. The results of the study showed that the loading capacity of chairs decreased firstly and then increased with the growth of the height of stretchers positions. Furthermore, the results of FEM agree with the results of experiments by 10 % (Hu *et al.* 2018). The aim of the other study was to optimize the volume of a beech stool frame to make it lighter, while still meeting the same load requirements. The FEM and MATLAB were utilized for the optimization. The results demonstrated that the optimized stool to be 58 % lighter than the non-optimized version, while also satisfying the strength requirements (Hu *et al.* 2019). The cantilevered leg joint was numerically and experimentally investigated by Chen *et al.* (2022). In the scope of the study, a novel joint was proposed and compared with the typical joint commonly utilized in the cantilevered leg. According to the experimental result of the study, bending moment capacity of the proposed novel joint was significantly higher than the typical joints. Furthermore, stress concentrations obtained by the FEM was consistent with the failure types of the experimental tests (Chen *et al.* 2022). In the other study, strength of the armrest joints of a cantilever armchair were tested. Accordingly, three novel joint techniques were proposed in order to improve the strength, and FEM was used to compare and analyze for obtaining the optimal joint. Then, experimental tests were conducted to verify the results of FEM. As a result of the study, it was reported that the novel cross-stepped tenon joints had better bending moment capacity and stiffness values than commonly utilized tenon joints, and it could be said that the results of the study will contribute to the structural design of modern solid wood chairs (Li and Hu 2023).

According to the literature review, limited studies has been found on the production of “without fastener and ready to assemble (RTA)” furniture made of wood-based panel materials with Computer Numerical Control (CNC) machines and the evaluation of their performance, which is emphasized in this study. The studies under consideration are generally aimed at evaluating the structural properties and performance of furniture connected with glued or mechanical fasteners under a variety of loading conditions. In this context, the concept of furniture without fasteners appears to be a unique concept, and it is critical to design, manufacture, and test furniture in accordance with this approach in order to determine their strength, as well as to introduce, gain, and disseminate this concept in the furniture industry.

The furniture without fastener approach will provide many benefits to the sector’s designers and manufacturers, both technically and economically. As a result, this study is significant in that it is the first of its kind on furniture without fasteners, and its success serves as an incentive and trigger for future research on the subject.

The scope of this study is limited to the design, production, and performance evaluations of chairs without fasteners, and it is a preliminary study in order to carry out more comprehensive and widespread studies in the future, particularly on the adaptation of this approach to the production of upholstered seating furniture. Accordingly, the goal of this study was to evaluate the performance of various types of RTA chairs without fasteners produced in CNC machines from medium density fiberboard (MDF), oriented strand board (OSB), and Oriental beech plywood (BPW) materials using product engineering methods based on American Library Association (ALA) specification.

MATERIALS AND METHODS

Experimental design

In the study, the following steps were performed for achieving the objectives:

Designing the four different chair models (two side frames, two backrest types) without fasteners,

Production of 108 real size chairs without fasteners using the CNC machines,

Testing and evaluating the strength of chairs according to acceptable loads (ALA),

Determining the weak and strong points of the chairs based on the deformation characteristics obtained from the performance tests, and making developer optimization recommendations based on the failures obtained.

Within the scope of the study, four distinct chair types were designed including two side frame types and two backrest type, produced, and tested under cyclic loading in three different directions (front to back, back to front and side thrust). Three different wood-based panels were used in the production of the chairs: 18 mm thick OSB, MDF, and BPW. As a result, 108 chairs were produced and tested, with 4 chair design models, 3 different wood-based panels, 3 different testing directions, and 3 replications for each group.

Full linear models (Model 1, Model 2, and Model 3) for the two-way factorial experiments were considered to determine the effects of chair design model and panel type on the cyclic loading performances of chairs under front to back, side thrust, and back to front loading. The models are as follows Equation 1, Equation 2 and Equation 3:

$$FBPijk = u1 + Ai + Bj + (AB)ij + \varepsilon ijk \quad (1)$$

$$SPijk = u1 + Ai + Bj + (AB)ij + \varepsilon ijk \quad (2)$$

$$BFPijk = u1 + Ai + Bj + (AB)ij + \varepsilon ijk \quad (3)$$

Where FBP_{ijk}, SP_{ijk}, and BFP_{ijk} refer to the cyclic loading performance (N) values of chairs under front to back, side thrust, and back to front loading, respectively; μ_1 refer to the population means for the cyclic loading performance (N) for all chair design model-panel type combinations, respectively; A refers to the discrete variable representing the effect of chair design model; B refers to the discrete variable representing the effect of panel type; (AB) refers to the effect of the two-way interaction among the two variables; ε refers to the random error term; i refers to the index for chair design model, 1,...,4; j refers to the index for panel type, 1,...,3; and k refers to the index for the replication, 1,...,3.

Wood-based panel materials

Designed chairs were produced in 1/1 dimensions without fasteners for performance tests to evaluate their strength. 18 mm thick OSB, MDF, and oriental beech (*Fagus orientalis* L.) plywood (BPW) were used in the production of the chairs. Wood-based panels were obtained from manufacturers in the commercial suppliers as sheet with full dimensions of 2440 mm x 1220 mm. The number of layers of beech plywood is 13. The grain orientation of outer layers of beech plywood and OSB panels was parallel to the long side of the sheet.

Physical properties such as density TS EN 323 (1999) and moisture content TS EN 322 (1999) of the wood-based panel materials used in the experiments, as well as mechanical properties such as bending strength and modulus of elasticity (flatwise and edgewise) TS EN 310 (1999) were determined in this study using the principles specified in the relevant standards. In the BPW and OSB bending test specimens, the grain orientations of the outer layer were cut to be parallel to the longitudinal axis of the specimens both for flatwise and edgewise.

Design and preparation of the test chairs

Four different types of chairs were designed without fasteners, including 2 side frame types and 2 backrest connections. Each of 4 chair designs was constructed of 8 members: 2 side frames, 1 seat panel, 1 backrest panel, and 4 rails. Dimensions and technical drawings of chair models are provided in the Figure 1 and 2, as are the dimensions of the members in Table 1.

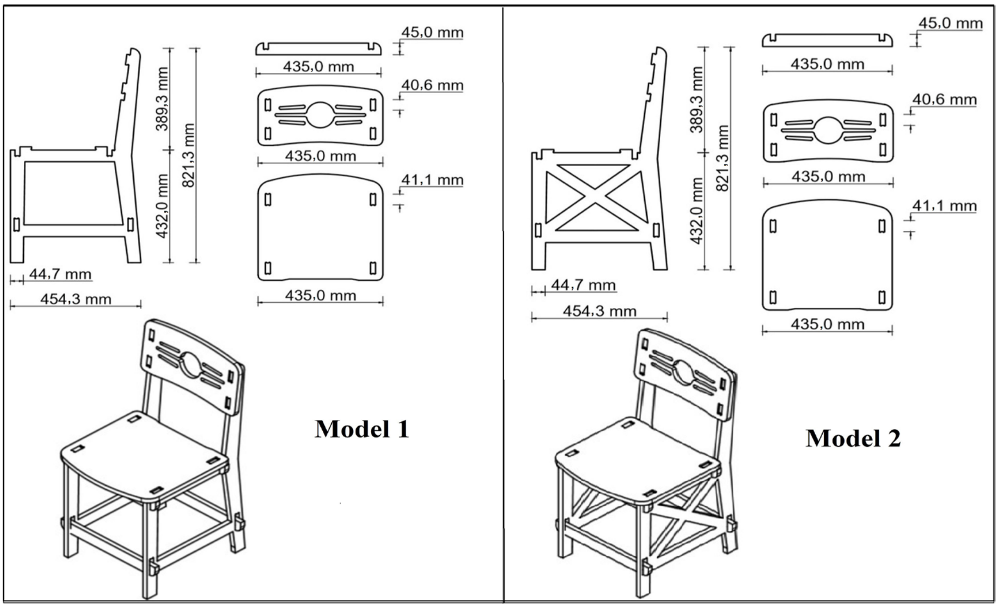

Figure 1: Technical drawings and dimensions of the (a) Chair Model 1 and (b) Model 2.

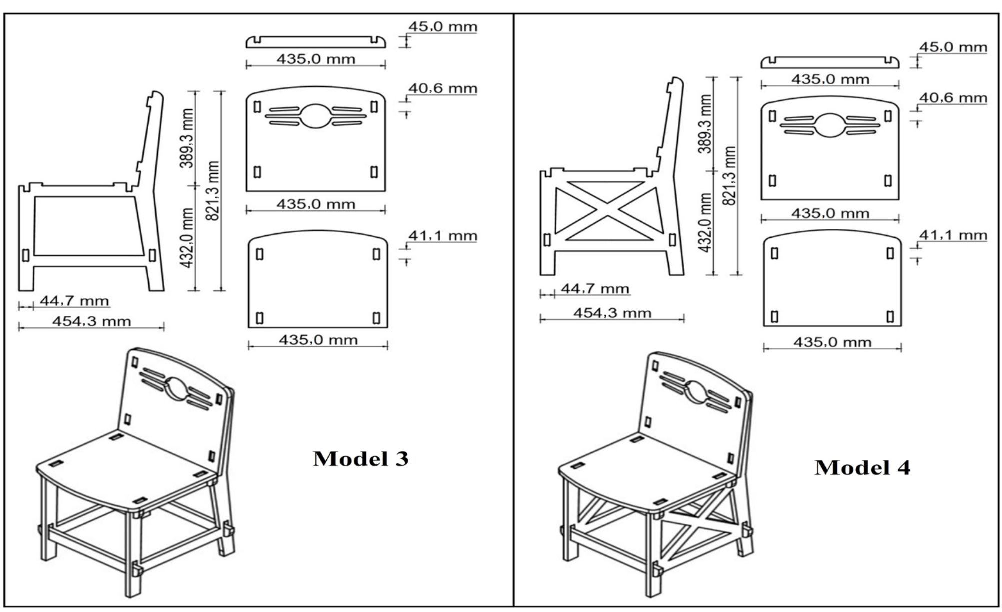

Figure 2: Technical drawings and dimensions of the (a) Chair Model 3 and (b) Model 4.

As seen in Figure 1 and Figure 2, the chair model 1 and 3 have no any stretcher in the side frame, while the chair model 2 and 4 have diagonal fixed (X-shape) stretcher in the side frame. In case of the backrests structure; it is seen that the chair models 1 and 2 have short back panels, while the chair models 3 and 4 have long back panels that extend all the way to the surface of seat panel.

Table 1: Member dimensions of the chair models.

Chair Design Model	Member	Length (mm)	Width (mm)	Thickness (mm)	Quantity Used
Model 1 Model 2	Side Frame	821,3	454,3	18	2
	Rail	435	45	18	4
	Backrest Panel	435	230,1	18	1
	Seat Panel	435	400	18	1
Model 3 Model 4	Side Frame	821,3	454,3	18	2
	Rail	435	45	18	4
	Backrest Panel	435	430	18	1
	Seat Panel	435	400	18	1

Figure 3a depicts the connection used between the interstitial rails of the chairs in four different designs and the side frames connection, while Figure 3b depicts the seat and backrest panel connection details (b).

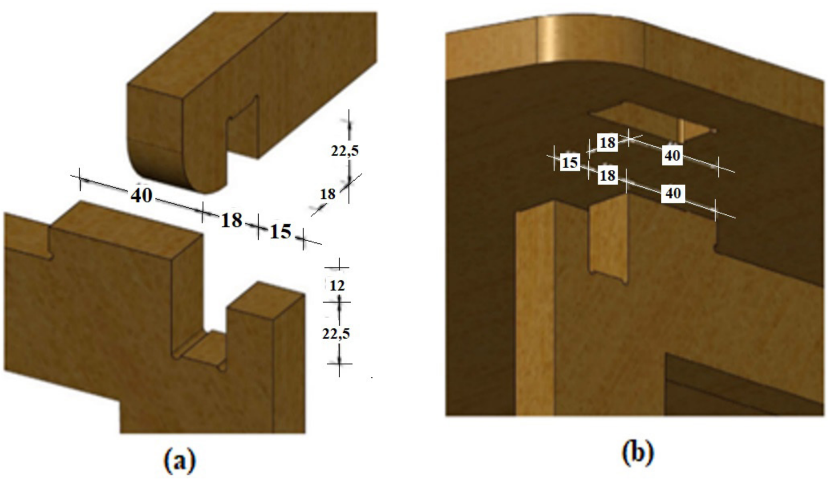

Figure 3: Detail of side frames-rail connections, and (a) Seat and (b) Backrest connections.

During the chair production phase, technical drawings for all members of the chair models were created in CAD first, and then the drawings of the members were placed on the drawing program in a way that minimized sheet material waste. In both the BPW and OSB samples, it was deliberately oriented the grain of the outer layers to be perpendicular to the chair's height, as depicted in Figure 4. This choice was made to enhance the structural integrity in critical areas, such as the corner where the side rail meets the back post, in order to maximize the strength.

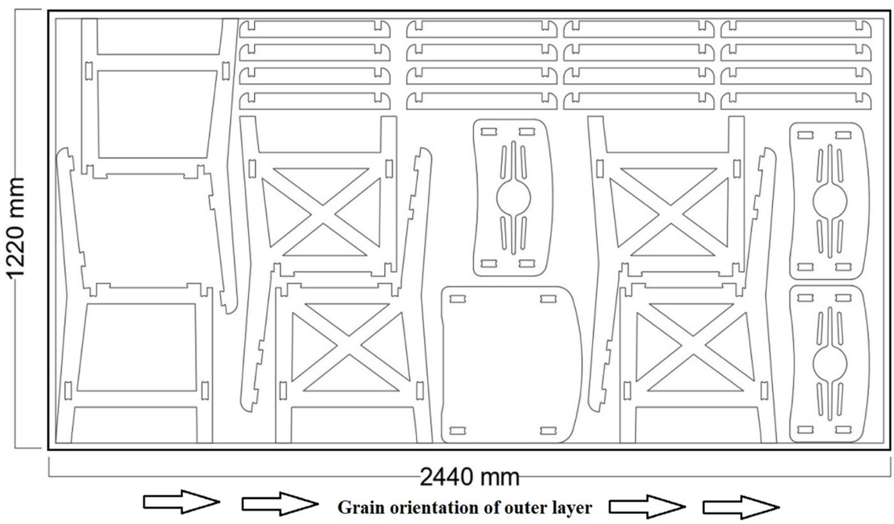

Figure 4: Placing the chair members on whole panel for cutting in CAD with minimum waste.

The drawing placed on the panel sheet was coded with the help of the CAM program and cut on a three-axis CNC (AES Raptor 2142, Turkey) machine (Figure 5).

Figure 5: Three-axis CNC milling cutting operation.

During the assembly phase, two side frames of the same model were kept vertical, and then four rails cut for each chair were aligned with the lock channels on the side frames and hammered into the channel with a plastic surface hammer. The prepared back panel was then taken and aligned to its position on the side frame using a plastic surface hammer. Finally, the seat panel was inserted into the side frame grooves. During these processes, no fasteners or glue derivatives were used to make joints. Figure 6 shows disassembled images of chair models constructed from wood-based panel materials.

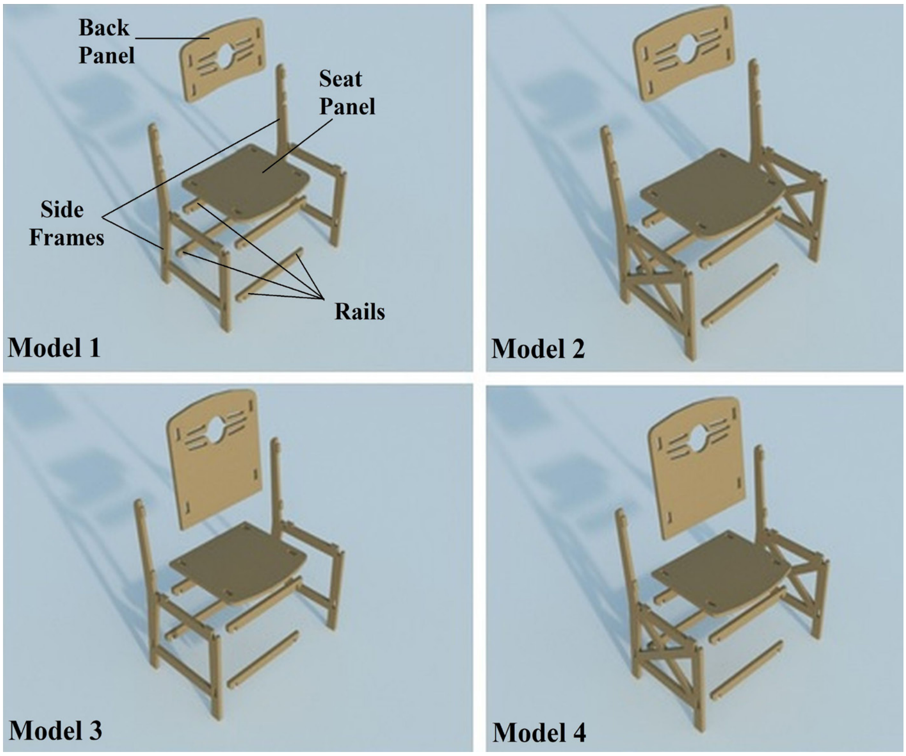

Figure 6: All members and assembling of the chair models.

Testing methods of chairs

Chairs were subjected to performance tests using the cyclic stepped increasing loading method, as specified in ALA by applying the load in front to back, side thrust, and back to front directions. Cyclic loading method is most rationally representing the load application actions of the users, or the actual usage conditions of the chairs. The cyclic stepped increasing loading method applies 25000 cycles of load at each stage for a predetermined load value for each performance test, with a cycle rate of about 20 cycle/min. When this stage is finished, the load value is increased at a predetermined rate, and the first stage processes are repeated. A tested furniture's performance is defined as the highest load value that successfully completes 25000 cycles. These operations are repeated until the acceptable design load values are reached or there is an opening, breakage, or other flaw in the furniture. It will be carried out until such deformations occur (Eckelman 1982, Eckelman 1995, Eckelman 1999).

Tests were carried out on the furniture performance testing equipment at the mechanical testing laboratory in the Wood Science and Industrial Engineering Department of Mugla Sitki Kocman University. The test results were then compared to the acceptable load values (Table 2), which were predetermined in ALA as light, medium, and heavy service (Eckelman 1982, Eckelman 1995, Eckelman 1999). Light uses are used in domestic and private spaces, medium uses are not very busy offices, etc. places, and heavy uses are intensive use in hospitals, schools, libraries, airports, and so on. Chairs were loaded in three directions, front to back (Figure 7), side thrust (Figure 8), and back to front (Figure 9). As a result, 108 chairs in 1/1 dimensions were tested in the study. Table 3 shows the acceptable load values determined for the chair performance tests using the ALA test method, and Table 4 shows the initial loads and load increase values.

Table 2: Acceptable load values in chair tests at various levels of use.

Loading Direction	Light (Home use) (N)	Medium (N)	Heavy (N)
Front to Back	1334	1557	2002
Sidethrust	890	1112	1334
Back to Front	1001	1446	1890

Table 3: Initial loads and load increase values in chair performance tests (N).

	1. Step		2. Step	
Loading Direction	Initial Load	Load Increase	Initial Load	Load Increase
Front to Back	445	111	1112	222
Sidethrust	222	111	1112	222
Back to Front	445	111	1001	222

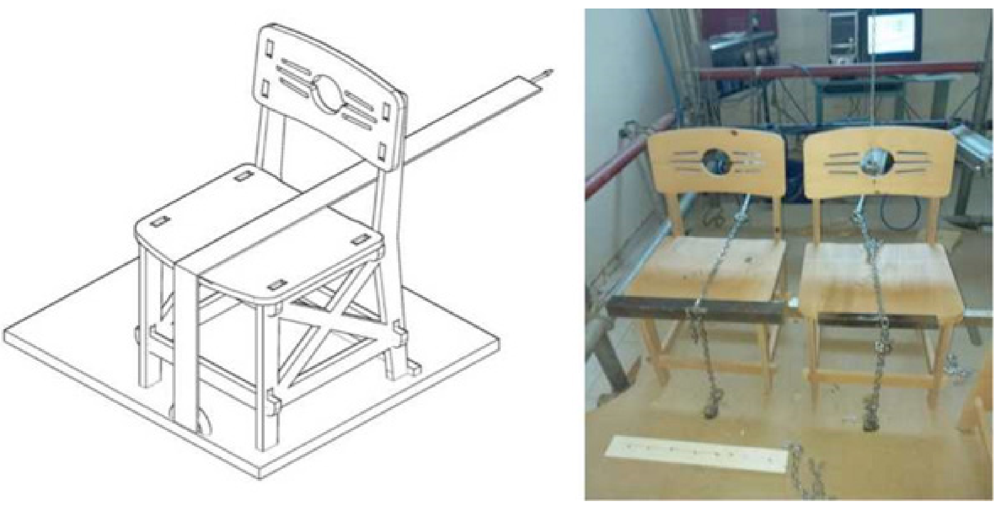

Figure 7: Front to back loading performance testing of chairs.

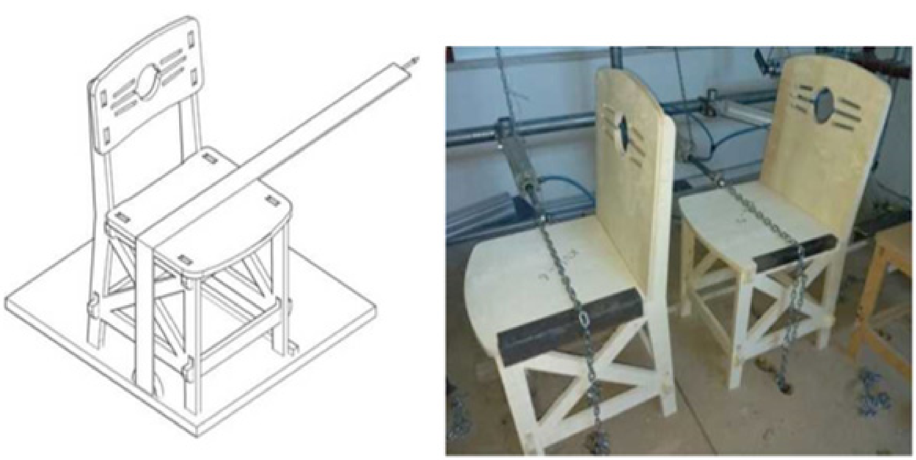

Figure 8: Side thrust loading performance testing of chairs.

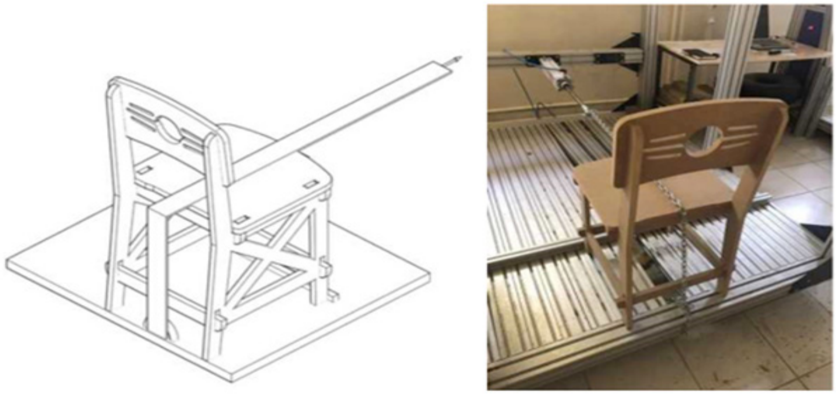

Figure 9: Back to front performance testing of chairs.

RESULTS AND DISCUSSION

Some physical and mechanical properties of wood-based panels

Table 4 shows statistical values for the moisture content and density of the wood-based panels used to construct the chairs, and Table 5 shows their bending strength and modulus of elasticities in both flatwise and edgewise direction.

Table 4: Some physical properties of wood-based panel materials used in the experiments.

	Test Moisture Content		Test Moisture Density		Oven Dry Density	
Panel Type	X (%)	COV (%)	X (kg/m^3)	COV (%)	X (kg/m^3)	COV (%)
OSB	8,3	11,9	560	3,17	530	3,77
MDF	7,2	12,9	700	1,04	690	1,49
BPW	11,2	13,5	540	2,65	470	5,03

X: Mean value, COV: Coefficients of variation

Table 5: Some mechanical properties of wood-based panel materials used in the experiments.

Panel Type	Test Direction	Bending Strength		Modulus of Elasticity	
		X (MPa)	COV (%)	X (MPa)	COV (%)
OSB	Perpendicular to the Surface (Flatwise)	10,40	18,26	1516	12,96
	Parallel to the Surface (Edgewise)	7,65	9,73	1119	12,92
MDF	Perpendicular to the Surface	12,57	4,21	3583	2,10
	Parallel to the surface	28,79	1,21	2604	2,50
BPW	Perpendicular to the Surface	23,40	4,64	6601	8,07
	Parallel to the surface	28,79	1,21	5615	3,90

Failure modes of the test chairs

When the general deformation characteristics of the chairs were examined against to three loading direction, generally it was observed that the whole chair system was displaced (deflected) in the direction of load from the point where the load is applied. Fractures or delaminations occurred at the joints of the chairs in all loading directions. Generally, fractures were observed in the joints of OSB and MDF chairs under the loading, while delamination occurred in the joints of plywood chairs. In the front to back loading; all the joints in the side frames of the chairs were fractured and the chairs were completely broken (Figure 10a). In case of the side thrust loading; fractures or delamination (for BWP chairs) occurred at the points where the back leg of the side frame against the load meets the side rail (Figure 10b, Figure 10c). For the back to front loading; it was observed that the fractures or delamination (for BWP chairs) were at the joint of the front leg and the lower side rail (Figure 10c). Accordingly, it can be said that the wood-based panels are exposed to a significant bending and shear stress at the joints against the applied loads and the material breaks or delaminates at these points where its resistance is exceeded.

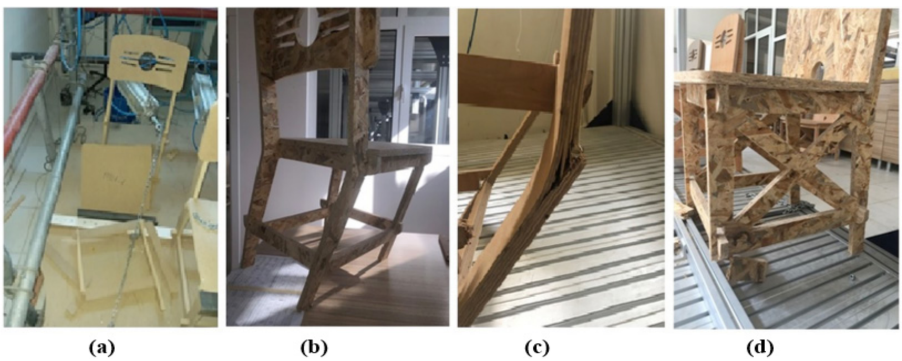

Figure 10: Failures of chairs in front to back (a), side thrust (b), (c), back to front (d) loading.

Mean comparison of the cyclic loading performance of test chairs

Two factor analysis of variances (MANOVA) general linear model procedure were performed for individual data for front to back, side thrust, and back to front loading capacities to analyze main effects (wood-based panel type and chair design model) and their two-way interactions on the cyclic loading performances. Then, the least significant difference (LSD) multiple comparisons procedure at 5 % significance level were performed to determine the mean differences of cyclic loading performances in front to back, side thrust, and back to front loading considering the significant main effects and two-factor interactions in the MANOVA results. Minitab (2023) statistical software was utilized for the statistical analyses in this study.

Table 6 shows the MANOVA results for the effects of wood-based panel type and chair design model on cyclic loading performances of chairs in front to back, side thrust, and back to front directions.

Table 6: Results of the multiple variance analysis.

Loading Direction	Variance Sources	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value	Probability (p<0,05)
Front to back	Panel Type	2	13156828	6578414	336,00	0,000
	Chair Design Model	3	2794589	931530	47,58	0,000
	PT x CDM	6	989235	164873	8,42	0,000
	Error	24	469887	19579		
	Total	35	17410540			
Side thrust	Panel Type	2	6789314	3394657	282,37	0,000
	Chair Design Model	3	127433	42478	3,53	0,030
	PT x CDM	6	275475	45912	3,82	0,008
	Error	24	288527	12022		
	Total	35	7480748			
Back to front	Panel Type	2	15259640	7629820	2468,11	0,000
	Chair Design Model	3	847376	282459	91,37	0,000
	PT x CDM	6	169681	28280	9,15	0,000
	Error	24	74193	3091		
	Total	35	16350890			

PT: Wood-Based Panel Type, DM: Chair Design Model

The effects of wood-based panel type and design model main factors, as well as their two-way interactions, on the cyclic loading performance in front to back, side thrust, and back to front directions were found to be statistically significant at 0,05 significance level, according to the results of multiple analysis of variance. When the calculated F-values in Table 6 are examined, it is possible to conclude that the effect of wood-based panel on cyclic loading performance of chairs is greater, while the design model is less effective.

In mean comparisons based on wood-based panel type; BPW chairs demonstrated the highest cyclic loading performance in front to back (2335 N), side thrust (1464 N), and back to front (2094 N) tests. While the chairs constructed of OSB performed the worst (890 N, 417 N, and 732 N), the chairs constructed of MDF (1890 N, 778 N, 2131 N) performed similarly to the BPW chairs under front to back, side thrust, and back to front loading, respectively.

When BPW chairs were compared to OSB chairs; they performed 162 % better in front to back tests, 251 % better in side thrust tests, and 186 % better in back to front tests. MDF chairs performed 112 % better in front to back tests, 87 % better in side thrust tests, and 191 % better in back to front tests when they compared to the OSB chairs. BPW chairs were compared to MDF chairs; while it was 24 % stronger in front to back tests and 88 % in side thrust tests, it was found to be 2 % weaker in back to front tests.

Mean comparisons for the chair design model show that the models 4 (1965 N, 951 N, and 1853 N) and 2 (2002 N, 914 N, and 1730 N) performed better than models 1 (1446 N, 791 N, and 1582 N) and 3 (1409 N, 890 N, and 1446 N) under front to back, side thrust, and back to front loading direction, respectively. Model 4 and model 2 performance values in front to back and side thrust loading directions were found to be statistically insignificant. Model 2 performed 45 % worse in front to back loading, 16 % worse in side thrust loading, and 9 % worse in back to front directions according to model 1. Model 3 had 3 % lower performance in front to back loading and 13 % better performance in side thrust tests, according to model number 1. According to model number 1, model number 4 performed 36 % worse in front to back loading, 20 % worse in the side thrust direction, and 17 % worse in the back to front test.

Table 7 compares the effects of "wood-based panel type x design model" two-way interaction on the front to back, side thrust, and back to front cyclic loading performance of the chairs.

Table 7: Mean comparison of cyclic loading performance based on the two-way interaction.

Panel Type	Design	Front to Back		Sidethrust		Back to Front	
		X	HG	X	HG	X	HG
OSB	Model 1	704	D	371	F	667	F
	Model 2	1260	B	445	EF	815	E
	Model 3	593	D	445	EF	556	G
	Model 4	1001	C	408	F	890	E
MDF	Model 1	1409	B	593	DE	1965	CD
	Model 2	2298	A	964	C	2335	A
	Model 3	1409	B	667	D	1890	D
	Model 4	2446	A	890	C	2335	A
BPW	Model 1	2224	A	1409	AB	2113	B
	Model 2	2446	A	1334	B	2039	BC
	Model 3	2224	A	1557	A	1890	D
	Model 4	2446	A	1557	A	2335	A

Table 7 shows that the chairs constructed of BPW performed the best results, while the chairs constructed of MDF performed similarly to the BPW chairs, except for the side thrust test. The low performance values of OSB chairs are thought to be due to the low mechanical resistance of OSB panel material. The low values of bending strength, modulus of elasticity, and tensile strength perpendicular to the surface, in particular, indicated that this type of wood-based panels cannot be used to create a structural system that can reliably fulfill its function.

As a result, chair design models 2 and 4 constructed of BPW and design model 4 constructed of MDF gave the best front to back cyclic loading performance. In the side thrust loading, design models 3 and 4 constructed of BPW, design models 2 and 4 constructed of MDF in back to front, and design model 4 constructed of BPW performed the best.

Performance evaluation of the test chairs constructed of OSB

Table 8 compares the cyclic loading performances of four different chair design models constructed of OSB chairs in the front to back, back to front, and side thrust directions with the acceptable design loads that were given in ALA, and shows completed total cycles.

Table 8: Evaluation of the cyclic loading performance of OSB chairs according to ALA.

Loading	Model	Mean Cyclic Loading Performance (N)	Mean Completed Total Cycles	Light (N)	Result	Medium (N)	Result	Heavy (N)	Result
Front to back	OSB1	704	117946	1334	Fail	1557	Fail	2002	Fail
	OSB2	1260	231501		Fail		Fail		Fail
	OSB3	593	95754		Fail		Fail		Fail
	OSB4	1001	179790		Fail		Fail		Fail
Side thrust	OSB1	371	63011	890	Fail	1112	Fail	1334	Fail
	OSB2	445	80757		Fail		Fail		Fail
	OSB3	445	82141		Fail		Fail		Fail
	OSB4	408	74010		Fail		Fail		Fail
Back to front	OSB1	667	79951	1001	Fail	1446	Fail	1890	Fail
	OSB2	815	112946		Fail		Fail		Fail
	OSB3	556	60024		Fail		Fail		Fail
	OSB4	890	134746		Fail		Fail		Fail

According to the data in Table 8, none of the four different chair models are suitable for domestic or any kind of usage. This can be due to the low strength properties of the panel materials in the chairs constructed of OSB. In conclusion, it can be clearly said that OSB chairs are unsuitable for use. Figure 11 shows graphs displaying the evaluation of front to back, side thrust, and back to front loading performances of four different model chairs.

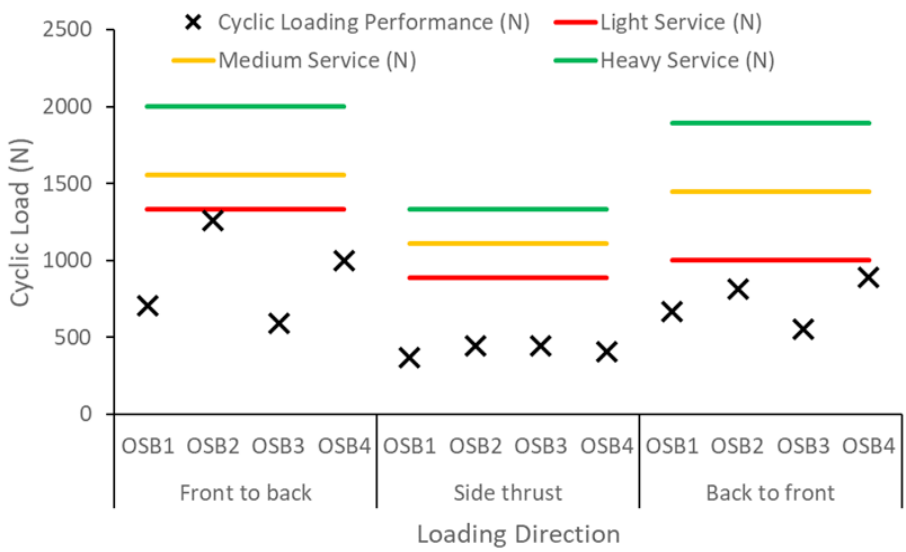

Figure 11: Evaluation of the cyclic loading performance of chairs constructed of OSB.

Performance evaluation of the test chairs constructed of MDF

Table 9 compares the cyclic loading performances of four different chair design models constructed of MDF in the front to back, back to front, and side thrust directions with the acceptable design loads that were given in ALA, and shows completed total cycles.

Table 9: Evaluation of the cyclic loading performance of MDF chairs according to ALA.

Loading	Model	Mean Cyclic Loading Performance (N)	Mean Completed Total Cycles	Light (N)	Result	Medium (N)	Result	Heavy (N)	Result
Front to back	MDF1	1409	215174	1334	Pass	1557	Fail	2002	Fail
	MDF2	2298	314710		Pass		Pass		Pass
	MDF3	1409	213433		Pass		Fail		Fail
	MDF4	2446	325000		Pass		Pass		Pass
Side thrust	MDF1	593	119867	890	Fail	1112	Fail	1334	Fail
	MDF2	964	194264		Pass		Fail		Fail
	MDF3	667	127175		Fail		Fail		Fail
	MDF4	890	182420		Pass		Fail		Fail
Back to front	MDF1	1965	262557	1001	Pass	1446	Pass	1890	Pass
	MDF2	2335	300000		Pass		Pass		Pass
	MDF3	1890	247890		Pass		Pass		Pass
	MDF4	2335	300000		Pass		Pass		Pass

Table 9 shows that, with the exception of side thrust tests, MDF chairs can withstand relatively heavy service loads. Except for the model 1 and 3, they could withstand heavy service loads in front to back tests, according to ALA. Based on these results, it is possible to conclude that diagonal fixed (X-shaped) stretchers in the side frame increases the strength in the front to back and back to front tests. Except for the model 2 and model 4, the cyclic loading performance of MDF chairs in side thrust direction was not successful, according to the test data. As a matter of fact, model 2 and 4 MDF chairs can meet only domestic usage. As a result, significant improvements should be made in the designs of MDF chairs in order to increase performance in side thrust loadings. Figure 12 shows graphics depicting the evaluation of the front to back, back to front, and side thrust loading performances of four different chair models.

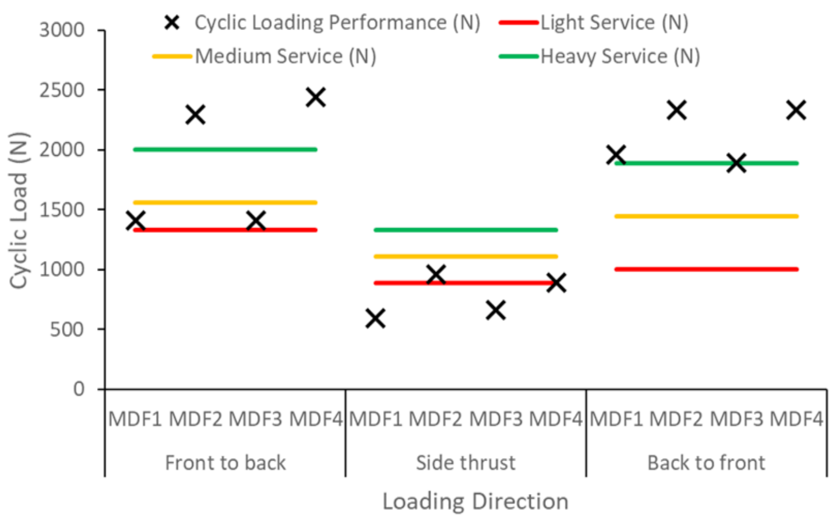

Figure 12: Evaluation of the cyclic loading performance of chairs constructed of MDF.

Performance evaluation of the test chairs constructed of BPW

Table 10 compares the cyclic loading performances of four different chair design models constructed of BPW in the front to back, back to front, and side thrust directions with the acceptable design loads that were given in ALA, and shows completed total cycles.

Table 10: Evaluation of the cyclic loading performance of BPW chairs according to ALA.

Loading	Model	Mean Cyclic Loading Performance (N)	Mean Completed Total Cycles	Light (N)	Result	Medium (N)	Result	Heavy (N)	Result
Front to back	BPW1	2224	300000	1334	Pass	1557	Pass	2002	Pass
	BPW2	2446	316667		Pass		Pass		Pass
	BPW3	2224	300000		Pass		Pass		Pass
	BPW4	2446	325000		Pass		Pass		Pass
Side thrust	BPW1	1409	265005	890	Pass	1112	Pass	1334	Pass
	BPW2	1334	251678		Pass		Pass		Pass
	BPW3	1557	274656		Pass		Pass		Pass
	BPW4	1557	269467		Pass		Pass		Pass
Back to front	BPW1	2113	275000	1001	Pass	1446	Pass	1890	Pass
	BPW2	2039	300000		Pass		Pass		Pass
	BPW3	1890	275000		Pass		Pass		Pass
	BPW4	2335	275000		Pass		Pass		Pass

According to the acceptable design loads that were given in ALA specifications, all the chair models constructed of BPW material can withstand cyclic loading performances greater than heavy service loads. Graphs related to the evaluation of front to back, side thrust, and back to front loading performances of four different design model chairs are presented in Figure 13.

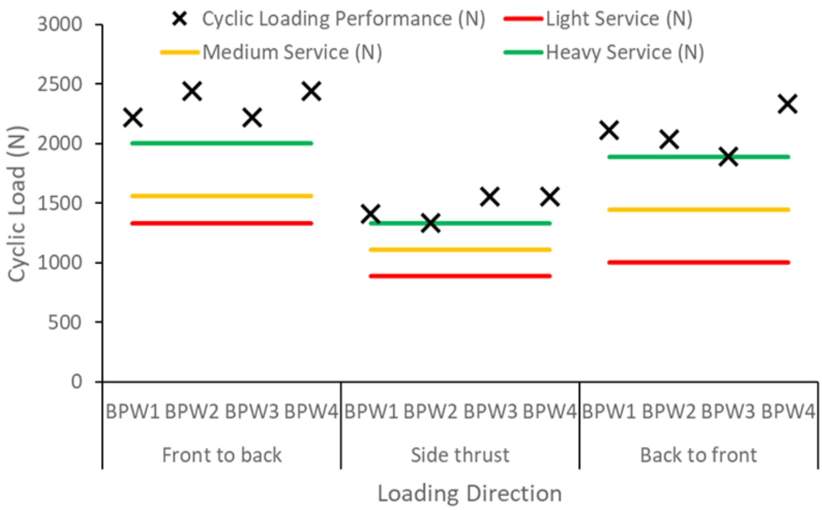

Figure 13: Evaluation of the cyclic loading performance of chairs constructed of BPW.

CONCLUSIONS

The cyclic loading performances of different types of RTA chair models without fasteners, which are mass produced in CNC machines from OSB, MDF, and BPW wood-based panel materials were evaluated in this study by using the engineering design approach and product engineering methods including performance tests, comparing the qualifications according to ALA specifications.

In today's world where computer-aided production technology is developing rapidly and its use is becoming widespread, obtaining preliminary information about the strength of a furniture designed without fasteners before starting the production and ensuring the optimization by making the necessary changes according to this information will facilitate the work of designers and manufacturers. As a result, because aesthetics and durability are the quality indicators in furniture, it can be stated that furniture industry will contribute to economy by producing high quality furniture using developed methods, computer aided productions, and performance tests.

Overall, when the test results are analyzed based on the performance of the chairs in four different models constructed of three different wood-based panel materials, it can be clearly concluded that the strength of the panel materials used in production of the chairs is primary importance. In particular, it has been observed that the strength of the chairs constructed of the panel materials with low bending strength is insufficient. Accordingly, it is recommended to prefer the panel materials with high bending strength to produce durable chairs without fasteners. In all loading types, it has been observed that BPW chairs are more advantageous than MDF chairs, and MDF chairs are superior to OSB chairs in terms of material. Side stretchers (X-shaped) naturally make the chair more rigid in front to back direction such that it is clear that the ultimate failure loads are almost twice for Models 2 and 4 compared with 1 and 3. But these stretchers have not that much of effect in opposite direction loading. An interesting outcome can be concluded as side stretchers give strength to the chair in the case of side thrust loading.

The findings of this study will benefit furniture manufacturers and designers both technically and economically; moreover, life quality of the consumers will be increased. Also, scientific knowledge in furniture engineering field has been improved. Furthermore, outputs that aided the country's economy and the effective and efficient use of natural resources were obtained. According to the results of the study, it is also necessary to conduct scientific studies on the application of the demounted production method without fasteners in upholstered sofa frames in the future.

Authorship contributions

H. D.: Conceptualization, funding acquisition, investigation, methodology, project, administration, resources, supervision, writing – original draft, writing – review & editing.

T. Ç. S.: Conceptualization, data curation, funding acquisition, investigation, methodology, resources, software, validation, visualization, writing – original draft. A. K.: Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, visualization, Writing - original draft, Writing – review & editing. T. K.: Data curation, formal analysis, investigation, resources, software, validation, writing & editing. E. C.: Investigation, resources, software, validation, visualization, writing – original draft ew & editing. E. G.: Formal analysis, methodology, resources, software, supervision, writing – review & editing.

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